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Rd Research & development

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Sustainable tourism and natural resources management in small islands

The present issue of the magazine *Energia, Ambiente e Innovazione* reports the results obtained through the activities dedicated to the Management of Natural Resources of Eco-innovation Project, focused on sustainable tourism.

Both studies and interventions were carried out between 2012 and 2015 in collaboration with the City Council and the Marine Protected Area of Egadi Islands, within the islets of Egadi Archipelago (few kilometres offshore of the Sicilian west coast). The study area is characterised by many ecological and naturalistic assets, particularly in the underwater environment, where a very high biodiversity is present thanks to the location and its particular hydrologic conditions. Here, the seabed has an irregular morphology with many cliffs, outcrops, sand banks and submarine valleys. It is a natural laboratory where the seasonal anthropic pressure is strongly related to tourism, leisure and professional/illegal fishing, pollution related to urbanisation (more intense in the Island of Favignana); all activities highly impacting the marine ecosystem and main threat for biological resources.

The activities of ENEA were targeted at: monitoring of underground water, analysis and classification of habitats, mitigation of natural risk, valorisation and conservation of natural capital. The actions have been carried out using traditional and innovative techniques, which allowed to better characterise the area, define new procedures for processing and analysing earth observation data, implement new technologies for the management of different natural resources (especially water, sediment and seagrass wrack).

Part of the actions gained the Green Coast Award on 2013, a contest which rewards the project that adopts sustainable solutions in coastal areas, considering the methodological approach, infrastructures, materials and environmental standards, innovation and certification processes. During the project surveys, particular interest was raised for potential reuse of sediments and beached vegetal biomasses. Different scenarios were implemented to foster: reuse of material that must be dredged from the harbour to ensure safety of navigation and encourage sustainable tourism; enlargement of the port layout; realisation of facilities such as beach volley infrastructures; reuse of dredge material in industry; nourishment of beaches and the environmental restoration along the coastline. Some of these solutions have also led to the formulation of legislative proposals, which have been included in a chapter dedicated to the excavated material in the book of the Technical Committee of Contaminated Soil published by the prestigious national editor Sole 24 Ore on July 2015, and presented to the Italian parliament in September 2015.

The seagrass wrack, which consists of residues of *Posidonia oceanica,* has been used for different purposes. First

of all, the transfer of vegetal biomass from the beaches to the foot of cliffs at potential risk of collapse was tested, in order to prevent people from being exposed to rock falls. Secondly, a multipurpose facility built with beached biomass, comprising a casing made of biocompatible fibre and filled with the wrack collected on the shore, has been implemented by ENEA (patent number RM2014A000151). The design implementation of this technology is under development, in collaboration with the University of Rome "Sapienza" (Architecture Science in Product Design), as part of a green building application in coastal areas. Finally, these structures have been used to create a substrate for the re-establishment of seagrass shoots on the seabed, which is essential to maintaining the presence of the meadow and reduce coastal erosion. The first test showed that this technique is potentially applicable whenever the impact of a strategic life-line on the *Posidonia oceanica* meadow must be offset (e.g., by positioning pipelines, powering electric lines, re-gasifying infrastructures, etc...). More in general, we believe that all the achievements performed within the Egadi Archipelago have led to excellent results and high visibility for ENEA, and that the entire project can be immediately replicated in similar environments, where the economic development of these regions can be reached through reuse of natural resources and mitigation of the impacts of human activities or natural hazards.

The present special Issue is dedicated
to the memory of our colleague
Paolo Massanisso

Stefano Donati
Director of the Marine Protected Area (MPA) of Egadi Islands

Biodiversity protection and sustainable management of coastal areas: The Marine Protected Area of Egadi Islands

The Marine Protected Area (MPA) of Egadi Islands, northwest coast of Sicily Island, is the largest area in the Mediterranean Sea, stretching over with its 53,992 hectares. Established in 1991, since 2001 it is managed by the Municipality of Favignana on behalf of the Italian Ministry for the Environment, Land and Sea. The Egadi's archipelago is located in the Strait of Sicily, and includes the islands of Favignana, Levanzo, Marettimo and the islets of Formica and Maraone.
The archipelago lies on the continental shelf of western Sicily, which is an extension of the northern geological nature, characterised by the presence of vast calcarenitic deposits on most of the seabed between the Islands of Favignana and Levanzo. The archipelago emerges from a platform which is characterized by erosive and depositional forms, such as underwater cliffs, terraces, river valleys, paleo-beaches and dunes, which testify different stages of the last cycle of glacio-eustatic sea level changes. The seabed morphology is very irregular: wide flat areas are alternated by very steep slopes related to the presence of the Islands, ridges, paleocliff and valleys. Favignana and Levanzo are closer to Sicily and connected to the mainland by a platform and a slight depression. Marettimo is in the outer platform, constantly separated from the mainland since the Pliocene by a 350 m deep channel. Exchange of water masses within this channel, generates strong currents between the western and the eastern Mediterranean Sea.
Medium-fine sand characterises the seabed. Its organogenic component is derived by shells, whereas the limestone component is derived from erosion of the rocky outcrops. The submerged vegetation of the archipelago varies over different substrates, transparency of the water column and the hydrodynamics. The seabed of Favignana and Levanzo is characterised by bionomic features typical of intertidal and infralittoral plans, frequently dominated by brown algae up to 10-12 meters of depth, followed by a dense *Posidonia oceanica* meadow. In these two islands, the populations of the circalittoral plane are present only in some sites of the southern side of Favignana and offshore shallows. Around Levanzo (between -60 and -100 m), the *Laminaria rodriguezi* facies occupies large areas of the seabed, where hard substrate and intense bottom currents are concentrated.
Marettimo has a similar infralittoral zone, but also a wide circalittoral zone up to the edge of the continental shelf. The upper infralittoral seabed has photophilic biocenosis, characterized by a wide belt *Cystoseira amentacea var. stricta* and *C. brachycarpa*. The *C. amentacea var. stricta* creates a continuous belt around

the archipelago, always with top covers above 60-80%, and sometimes above 100%. In Marettimo, below the belt *C. amentacea var. stricta,* populations of *C. Mediterranean and / or C. elegans* are sometimes present.
The vermetid "trottoir" (or reef), is a biogenic construction, due to sessile gastropod *Dendropoma petraeum*, which is extremely abundant and with a great amount of structure on the coastal strip of the three islands of the archipelago.
It develops close to the mean sea level for an estimated length of more than 10 km along the coast, playing a vital role for protection against coastline erosion. The *Astroides calycularis*, is a thermophilic madrepore colony species –which suffers regression phenomena in many areas along the Mediterranean– stretches over the first infralittoral fringe just below the vermetid reef: extensive colonies are mainly found along the submerged cliff of the integral reserve (Zone A) and in shallow water caves of Marettimo.
Both *Dendropoma petraeum* and *Astroides calycularis* are among the species in jeopardy or at risk of extinction within the Mediterranean.
The carbonate coasts of Egadi Islands are characterised by a superficial and deep karst system, which represents a typical landscape. A large number of caves and coastal tunnels as well as the underwater karst system are part of many submerged and semi submerged caves. The whole carbonate component habitat extension to the sea is estimated to be about 4,000 hectares.
The low brightness of the seabed overhanging, in many cases favours the development of sciafili and corals concretions. The roughness of limestones also increases the settlement of meroplanktonic larvae and formation of shelters occupied by a rich endolitic fauna.
The MPA includes the largest (about 7,700 hectares) and best preserved *Posidonia oceanica* meadow of the Mediterranean Sea. The *Posidonia o.*, is a priority habitat and represents the most important biotic community as it is abundant and well distributed within the Egadi Islands, especially on medium-fine sand, which is scarce in deep water. The upper limit of the meadow ranges between -2/-9 m, at Favignana, and -12/-15 m at Marettimo. In the Egadi archipelago the foliar length *of Posidonia o.* can reach more than 2 m and it grows up to -52 m of depth. At lower depth and in coves, scattered Posidonia patches alternated with biotic photophilic and rocky seabed are frequently observed.
Posidonia is considered the green lung of the Mediterranean Sea, playing different roles crucial to the marine ecosystem.
In addition, the *Posidonia o.* forms an area of vital nursery as it protects the youth of hundreds of species of organisms, produces oxygen, absorbs a very considerable amount of CO_2, and helps to mitigate the coastal erosion through the formation of "*banquette*" on beaches, that are produced by the accumulation of dead leaves in the winter.
Another important species, discontinuously distributed on the seabed of Egadi Islands is *Lithophyllum byssoides*, a calcareous algae that can form large concretions ("trottoirs"), currently steadily distributed in various areas of the Mediterranean Sea, which hosts specific and rich wildlife

communities. Around the Egadi Islands there are also several rocky sites which are spectacular from both an aesthetic and naturalistic point of view as they are dominated by gorgonians, sponges with a highly structured marine population.

A very high biodiversity is generated by the habitat described above, resulting in a marine life that includes many protected and endangered species. After numerous reports and sightings, ISPRA and the MPA of Egadi Islands have recently documented the presence of at least one specimen of monk seal (*Monachus monachus*) during the winter season, a species classified as critically endangered by the IUCN and included in several international conventions and directives.

Numerous sightings have occurred as well as recovery of specimens of sea turtle *Caretta caretta*, which do not nest in the Islands, but is an assiduous frequenter of the MPA's waters. Bottlenose dolphins (*Tursiops truncates)* and spinner dolphins (*Stenella coeruleoalba)* are present among the marine mammals even if they have to be accurately determined. Sightings of sperm whales (*Physeter microcephalus)* are not rare. The porbeagle sharks (*Lamna nasus* and *Prionace glauca)* are widespread. Two charismatic species are more rarely encountered, the white shark (*Carcharodon carcharias)* that goes in the Channel of Sicily during reproduction, and the elephant shark (*Cetorhinus maximus).* Among corals, real "forests" of gorgonian *Paramuricea clavata* and, in other sites, specimens of *Corallium rubrum*, *Gerardia savaglia* and *Centrostephanus longispinus* are found. Among the shellfish it is worth mentioning the widespread presence of a species at increasing risk, the *Patella ferruginea*, and numerous colonies of the famous bivalve *Pinna nobilis*. Among the crustaceans, it is important to mention the presence of *Palinurus elephas*, *Scyllarides latus* and *Scyllarus arctus*. Also the fish fauna is rich and varied. Many species reported an increase in the average size and number of individuals: stone bass *(Epinephelus marginatus and Polyprion americanus);* corvina (*Sciaena umbra);* umbrine (*Umbrina cirrhosa);* sea breams (*Dentex dentex*; *Diplodus cervinus; Seriola dumerili);* swordfish (*Xiphias gladius);* bluefin tuna (*Thunnus thynnus thynnus).* The marine avifauna is another attraction, especially with the presence of a colony of the rare storm petrel, *Hydrobates pelagicus*.

The fauna, flora and habitats described above have an exceptional value for environmental conservation, and represent a major tourist attraction for all sea-sports fans. The MPA has 76 diving sites. They are both superficial (with exceptional values), and deep (cave or underwater archaeological sites as a famous battle at sea between the Romans and Carthaginians took place in the area located north-west of Levanzo). They can be visited only with guides and authorized divers, likewise, snorkelling and sea-watching are practised under supervision.

The institutional mission of the MPA is the protection and enhancement of the marine environment, environmental education, awareness and information of users, research and monitoring, integrated management of the coastal zone, and the promotion of sustainable development, with particular reference to the eco-compatibility of tourism. It is divided into four areas

of different protection levels and with different access possibilities and use limitations.
All tourist (bathing, navigation, anchoring, mooring, diving, recreational fishing) or commercial (fishing and marine services to tourism) activities are regulated by the MPA's Rules and Disciplinary measures, annually drawn up by the managing authority.
The Marine Protected Area is a member of Federparchi, of MedPan network, it is twinned with the Monterey Bay Marine Sanctuary (California, USA) and constantly works in synergy with the major Italian environmental associations and local associations.
In recent years, the Park Authority has started up a process of management, monitoring and control of the territory based on participation and sharing of local stakeholders. Beside the projects with ENEA, other research developments, studies and monitoring activities are carried out in collaboration with numerous national research institutions (ISPRA, CNR, University of Palermo, CoNISMa). Every summer, the MPA uses a fleet of four ships, operating every day to support surveillance activities, crime prevention and control at sea. These activities are carried out by the competent authorities (Coast Guard, Municipal Police, Carabinieri, Prison Police, Financial Police and State Police). The MPA has obtained, among all the 27 Italian protected marine areas, the best management assessment by the Ministry of the Environment, for the allocation of government funds on 2013. The MPA is self-financed thanks to the procedures of permits, ticket entrance and sanctions; it started up various forms of sponsorship and fundraising at the local, regional, and national levels.
Among the major projects carried out by the MPA in recent years (2010-2015), the project MASTER was aimed to the positioning of bollards on the seabed of the Archipelago in order to reduce the impact of illegal trawling, that affects the seabed by rooting out the *Posidonia oceanica* meadows and depletes fish resources. It has produced outstanding results in just two years (-50% abuses, based on the blue-box data). Phase 2 of the project is currently underway in Levanzo and Marettimo. Also MPA installed 14 mooring fields, in many sensitive areas within the 3 islands, where a total of 150 buoys are placed during the summer in order to prevent recreational boats from damaging the seabed with their anchors. Accessibility to the most beautiful and popular coves represents one of the most significant income to the economy of the Islands.
In collaboration with ENEA, the environmental certification of tourism services (accommodation, catering, rental boats, cars, motorcycles and bicycles, guided tours at sea, passenger transport on land and sea, fishing, diving, bathing facilities, mooring services) has been appositely implemented and adopted by more than 60 operators.
In addition, within the GERIN Project, new management strategies for the reuse of seagrass wrack have been tested in order to avoid disposal of this natural bio-resource into landfill. The results of this studies and best practices have led to a change, after many years. The regulation of the MPA has been modified in 2015, by inserting an article

entirely devoted to the management of the beached vegetal biomass in order to allow local authorities to turn this problem into an opportunity for economic development.
With the project "Sea Guardians" we have been involved for two years in the monitoring of protected species within the Archipelago through the collaboration of 40 professional fishing boats. The Castle of Punta Troia, in Marettimo, is a property of the Favignana city council, dedicated to the Museum of prisons that is now hosting the "Observatory of the Monk Seal" and used as an information centre for visitors and as a residence for researchers involved in monitoring species. At the prestigious Palazzo Florio in Favignana, the first recovery centre for sea turtles has been set up. The centre is managed in cooperation with WWF Italy and Legambiente, and thanks to the project Life+2012 "TartaLife" it will be strengthened in order to become a reference rescue centre in the Mediterranean Sea.
The MPA is also partner to the "ENPI CBC Med-Jellyrisk", for environmental monitoring and mitigation of the proliferation of jellyfish along the coastal areas of the Mediterranean Sea, with the role of deploying three experimental anti-jellyfish nets. Within the project "Fishermen and dolphins", the MPA operates in order to mitigate potential conflicts between the fishing industry and whales by direct reimbursement to fishermen of the fishing nets damaged by bottlenose dolphins. The MPA constantly promotes responsible tourism and sustainable sports, such as sailing, windsurfing, kayaking, swim-trekking, triathlon, cycling, hiking and climbing.
In recent years, the MPA of Egadi Islands has consolidated its role as a laboratory for advanced sustainable management of coastal areas, applying and implementing best practices that have been appreciated at national and regional levels and also proposed in other areas upon recommendation of the Italian Ministry of the Environment. The Egadi's MPA has also become a reference for the eco-sustainability of the local market.

Acknowledgments

Special thanks go to the Municipality of Favignana-Aegadian, the Mayor pro-tempore and President of the MPA Giuseppe Pagoto, and his predecessor Lucio Antinoro in particular, for the results described. Special thanks go to the staff of the MPA, composed of competent professionals and enthusiast personnel, who contributed, with dedication and sacrifice, to all the projects described above: Daniela Sammartano, Salvatore Guastella, Pietro La Porta, Ilaria Rinaudo, Monica Russo, Giuseppe Sieli, and all the other staff members and volunteers who, at various levels, supported us in recent years.

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Anthropic pressures on Egadi Islands

The Egadi Islands are three main islands off the western coast of Sicily, close to Trapani and Marsala: Favignana, Levanzo and Marettimo. There are also two minor islands, Formica and Maraone, lying between Levanzo and Sicily. Favignana and Levanzo are closest to the coast (16 and 13 km), whereas Marettimo is located 24 kilometers far from it.
The largest island in the archipelago is Favignana, with a land area of 19.8 square kilometres.
The Egadi Islands, like most Mediterranean islets, have radically changed the traditional lifestyle and the economic development model, based for centuries on the almost self-sufficient resources and production activities, mostly related to the sea (fishing and fish processing) and to the land.
During the second half of the 1900s, the development of transport radically transformed this model to make smaller islands, at least those closest to the coast, more tightly interconnected and dependent on the mainland. This change is both in terms of material resources, now mostly coming from the outside, and of human resources. In fact, this situation has given rise to daily and seasonal commuting to and from the islands that is likely to contribute to the depopulation in wintertime, with a serious impact on the care of the land.
From the economic point of view, however, instead of the traditional activities tourism has been increasingly developing an so have all the activities associated to it (e.g., the construction and maintenance of holiday accomodations). Nevertheless, particularly in the case of Favignana, which is the most populous island and very close to the coast, such activities have led to a strong anthropic pressure concentrated in a few months of the year (summer) on the one hand, and a reduction of the resident population during the winter months on the other.
These two negative phenomena are strictly interconnected and should therefore be contrasted with appropriate policies aimed at the seasonal adjustment of tourist flows.

Use and occupation of the territory - The depopulation

Land use in the three major islands of the Egadi archipelago is different. Favignana is the most populated island, hosting the largest number of resident people (about 75%) and tourists, where most of the productive activities in the area take place.
For this reason, unlike Levanzo and Marettimo – where settlements have largely developed within the historic center – Favignana has recently developed tourist resorts (e.g., holiday homes, accommodation, villages/camping areas), being its historical settlements located outside the historic center and mainly linked to mining and farming activities.
The depopulation of marginal areas, and of small islands in particular, is one of the most important issues also from the environmental point of view. Actually, the population drain leads to the degradation of territories and the loss of their cultural

identity, often characterized by unique traditions.
Therefore it is important finding a balance between tourism and resident population, which encourages local job thus avoiding depopulation and the invasive use of natural resources that may seriously affect their integrity.
Unfortunately, the number of residents have suffered a significant decrease over the last few decades: data available from 1971 to now show a steady reduction until 2001 and an arrest of this trend from 2001 onwards (Figure 1).

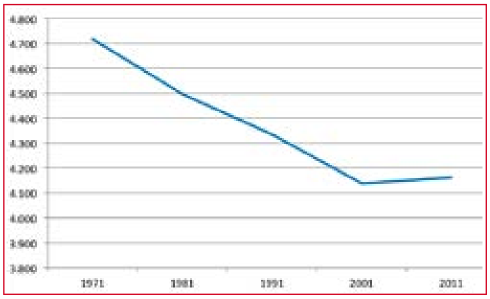

FIGURE 1 Demographic trends 1971-2011
Source: Urbistat, 2011

Since 2001, albeit with some fluctuations, this trend has essentially stopped.
Another worrying phenomenon is the aging of population. The old age index -i.e., (Population> 65 years/Population 0-14 years) * 100– in 2011 in Favignana was 295.07, a figure much higher than both the average value of 144.5 scored in Italy in 2011 (source: Tuttitalia.it ISTAT data) and, on average, the values reported for southern Italy, that are lower than those of the center-north.
These data lead us to reflect on the aging of population, which could cause a gradual depopulation of the islands despite the considerable presence of production activities related to tourism. However, the seasonal nature of most of these activities produces phenomena of temporary residence. Indeed, except for the summer months, during the rest of the year the opportunity to work in the islands is very limited.
This has gradually produced a process of emigration, which contributed to the aging of population along with the fact that a large amount of Favignana residents spends most of the year elsewhere, also because of the reckless general rise of prices associated to tourism, heavily impacting on the budgets of the islanders' families.
Depopulation and aging have mostly been affected by the phenomenon of disappearance of traditional activities, such as tuna killings ("*mattanze*") and the extraction of material from clay pits, in addition to farming and agriculture. Moreover, in the past, the identity and economy of Favignana were tied to Florio's family through the Florio factory (the second industrial structure born in Italy after Fiat), which employed thousands of people in the island and was dedicated to the entire production chain for tuna products. These activities could completely cover the islanders' job demand also attracting labourers from outside to reach the 10,000 permanent residents only in Favignana.

Tourist-driven pressures

The three major Egadi islands are faced with all the typical problems of restricted and isolated areas. To these are added those resulting from pressure on the environment by services arising from the summer tourist flow when, in August, the only island of Favignana is home to about 60,000 people daily, compared to a resident population of about 4,500 people. These numbers are especially

related to the proximity of the islands to the coast with a tourist flow, often only daily, from the centers of Trapani, Marsala and Palermo.

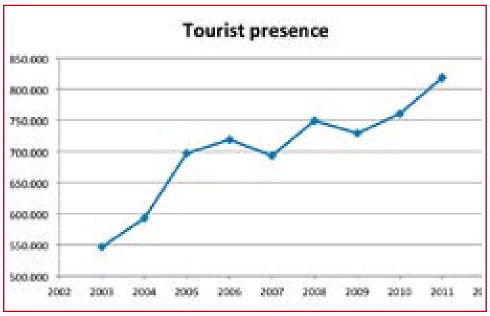

FIGURE 2 Tourist presence 2003-2011

The city of Favignana has had a strong growth in tourism over the past decades (Figure 2). Consider that it has gone from 23 years in the sector "hotel-restaurants" (with 33 employees) in 1971 to 81 stores and 364 employees in 2012 for the same sector. The tourist flow in the Municipality of Favignana is concentrated in a few months of the year, causing great pressure on the environment. The main form of hospitality that has been developed on the three islands, especially in recent years, is in private homes given for rent in the whole season summer (only in Favignana there are about 1,600 dwellings used especially for seasonal stays, bot by the owners of the houses and by seasonal tourists).
This kind of hospitality is particularly developed in Levanzo and Marettimo, which have a limited number of residences or hotels. The recent "Report on Tourism in the Province of Trapani period 2012-2013" of the Province of Trapani also reports the data of 2011 and estimates for 2012, highlighting the growth of tourism that seems enhanced in the following years (2013 and early 2014). This growth is particularly significant in terms of arrivals (+7% in 2009-2012) and much less in terms of attendance (only 0.8% increase over the same period) because of a reduction of the average stay (which decreased by 5.8% in the period 2009-2012). The presence of foreigners has increased by 48.9% in terms of arrivals and 45.7% in terms of attendance, and has compensated for the decrease of Italian tourists in terms of attendance (-2% between 2009 and 2012). As already stated elsewhere above, the primary concern of local tourism is related to the high concentration of flows, as shown in the graph (Figure 3).

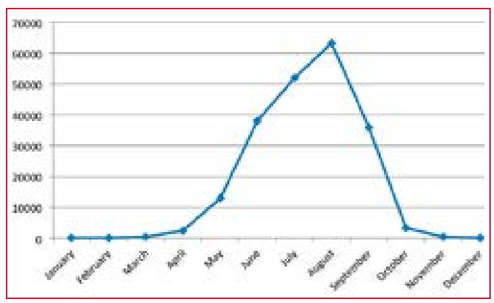

FIGURE 3 Data tourist arrivals in 2013 (ENEA processing data APT Trapani)

This concentration exerts the strongest tourist-related pressures on the environment (waste, water consumption, waste water, traffic, etc.) and promotes depopulation.
Exacerbated by territorial discontinuity which involves a huge increase in marine traffic, especially in the case of Favignana and Levanzo (closer to the coast), the tourist impact is worsened by the presence of numerous boats that come daily from cities and seaside resorts nearby with heavy consequences affecting a sea of extraordinary merit but also highly vulnerable, that is rightly protected by the presence of the largest marine protected area in Europe ever.

New technologies for the detection of natural and anthropic features in coastal areas

Some results of the sub project GE.RI.N (Natural Resources Management) conducted in the Marine Protected Area of Egadi Islands (Western Sicily) are presented. Coastal and seafloor morphology has been investigated integrating different data sources and using remote sensing data acquired by the Ministry of Environment during the MAMPIRA Project. This approach allowed us to recognize the real extent and distribution of several rocky outcrops emerging from the sandy bottom, south of Favignana Island (known as “I Pali”), and the anthropogenic features generated by the effects of traps, trawling and anchor on the *Posidonia oceanica* meadow that, within the Egadi Archipelago, is the largest in the Mediterranean Sea [1] (www.ampisoleegadi.it). Unpublished and detailed characterization of the seafloor and assessment of human impacts are the main results of the present study, which demonstrate how remote sensing technologies have a great potential and relevant management implication for Marine Protected Areas and the preservation of emerged and submerged environment

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S. Cappucci, M. Del Monte, M Paci, E. Valentini

Introduction

The management of natural resources is particularly important in coastal environments, especially in Marine Protected Areas (MPA), where human activities and conservation of natural habitats have to be balanced according to a sustainable development.

To achieve this objective, direct and indirect environmental investigations were carried out in order to characterize and monitoring the emerged and submerged environment with innovative technologies. Among the many activities of the GE.RI.N project, the morphology of the coastal environment (both emerged and submerged) was investigated with GIS and remote sensing tools. The seafloor of the Egadi archipelago (~54,000 hectares) hosts several itineraries for Diving (http://favignana.santateresa.enea.it/) and it has been colonized by the most extensive *Posidonia oceanica* meadow of the Mediterranean Sea (~7,700 hectares) [2].

From the geological point of view, the island of Favignana has a N-S oriented synformal ridge (known as Montagna Grande), formed by a continuous succession of Mesozoic limestone and dolostone. Its slopes are quite steep and affected by landslides (especially in the eastern sector). Part of the ridge is lowered by extensional tectonic elements and covered by two more recent (Pliocene and Pleistocene) flat arenaceous deposits that, in the eastern part of the island, are improperly called “*tufi*” [3].

Many gravelly and sandy pocket beaches are spread along the coast belt, often bordered by steep calcareous/arenaceous cliffs [4]. Sedimentological characteristics and organogenic content of these deposits suggest an infra-littoral origin [5]. Some of these cliffs, (e.g. Cala Rossa, Bue Marino and Cala Azzurra) are affected by significant slope instability [6].

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From an oceanographic point of view, this area presents a complex water circulation because located between the western and eastern basin of the Mediterranean Sea. It undergoes, therefore, to water mass mixing effects. The range of transition produces significant changes in the thermohaline structure, with vortices and spots of biodiversity and high productivity. The Egadi archipelago is characterized by deep and surface currents, which can reach high speeds (especially inside the submarine canyon separating the island of Marettimo from Favignana and Levanzo), whereas deployments of current meter SD6000® conducted between September 2000 and January 2001 on the shoreface of Cala Azzurra at 9 to12 m depth, revealed clockwise currents with speed values ranging between 4,4 and 8,2 cm/s.

In stratigraphic and sedimentological terms, we are now living in the Holocene, the geological epoch that began 12,000 years ago after the Pleistocene. Nevertheless, P. Crutzen, Nobel Prize for Chemistry in 1995 for his studies on the ozone hole in Antarctica, coined the term Antropocene in order to define this last part of Holocene and identify it as the first geological era, in which human activities have been able to influence the natural balance of the Planet.

The Anthropocene [7], is a term widely used to denote the present time interval, in which many geologically significant conditions and processes are profoundly altered by human activities. These include changes in:

- erosion and sediment transport associated with a variety of anthropogenic processes, including colonisation, agriculture, urbanisation and global warming;
- the chemical composition of the atmosphere, oceans and soils, with significant anthropogenic perturbations of the cycles of elements such as carbon, nitrogen, phosphorus and various metals;
- environmental conditions generated by these perturbations; these include global warming, ocean acidification and spreading oceanic 'dead zones';
- the biosphere both on land and in the sea, as a result of habitat loss, predation, species invasions and the physical and chemical changes noted above.

In the present study, manmade features have been mapped in the emerged and submerged environment within the Egadi archipelago, which seems an "open laboratory" for Antropocene studies.

Data and materials

Several sources of information were consulted and raster and vector available dataset collected, organised, geo-referenced and re-interpreted. Layers inherent to cartography, topography, bathymetry, marine biotic communities, geology, hydrogeology, use of soil, vulnerability and the geological risk (landslides along stretches of coastline subject to coastal erosion in particular), were implemented. The data, provided by the Town Hall and the Egadi Islands' MPA, integrated within the Geological mapping, the PAI and the Regional Technical Cartography (Figure 1), were georeferenced and transformed into a single reference system (WGS84) to obtain a geographically coherent database.

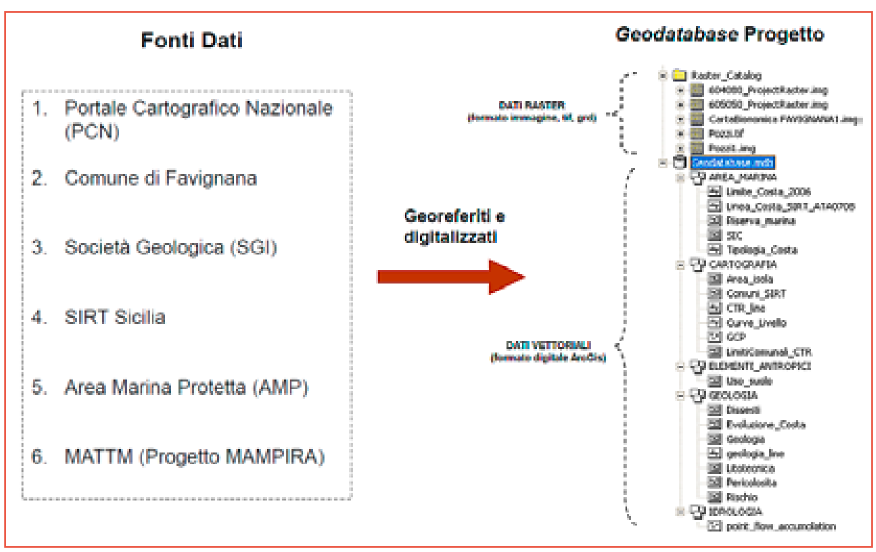

FIGURE 1 Structure of the Geodatabase

To characterize and map the seafloor, an important contribution has been provided by remote sensing data collected by the Ministry of Environment during the MAMPIRA project (Monitoring of Marine Protected Areas Affected by Environmental Offences). A description of the dataset acquired through aerial surveys on May-August 2012 is reported below; technical specifications of the main sensors are reported in Table 1.

1. Topographic dataset of the coastal strip – products derived from high resolution topographic LiDAR survey (DSM first, last DSM, DTM, points xyz, intensity).
2. Bathymetric dataset of Marine Protected Area– merging of bathymetric LiDAR up to 40 m of depth and and Multibeam survey at greater depths.
3. Multispectral Dataset of Egadi Islands - 102 bands in the spectrum of visible, near infrared, and thermal acquired with MIVIS sensor (Multispectral Infrared and Visible Imaging Spectrometer) radiometrically, geometrically and atmospherically corrected [8; 9].

Method

All available information and environmental data were organized to make a geo-database easily upgradable and integrated over time. A Digital Elevation Model (DEM) using topo-bathymetric data was realised linking the two Multi-Beam (40-70 m of depths) and LIDAR (up to -40 m) datasets. The DEM was obtained by creating a mosaic of 65 plates (0.04°, each corresponding to a side of about 4 km), with a total area of about 665 km^2. Then, a shading and lighting relief were applied to better highlight the morphology of the DEM area. Finally, for spots of particular interest, specific maps of slope and exposure were created for the interpretation of seafloor morphology and sedimentary structures.

The remote sensing data were also integrated into the GE.RI.N geo-database to be processed and compared with other information layers, in order to support the interpretation of the geological and geomorphologic elements derived from the DEM. During the MIVIS survey, a spectral radiometric *in situ* survey was made at ground for calibration and validation of the data collected by plane. The *in situ* spectral measurements were carried out (in collaboration with ENEA) in several stations on sandy and mixed (rocky and sandy) seafloor, at a depth of over 20m [8]. At that point, the *P. oceanica* meadow was still visible from the boat. In each station, samples of surface sediment were collected with a Van Veen grab. Grain size distribution was then determined by gravimetric dry sieving methods. A watchdog control unit was installed at about 10 m of height to monitor the intensity and direction of wind, precipitation, temperature between July 2012 and July 2013.

Results and discussion

Geomorphological and sedimentological structures on seafloor were examined through the analysis of

Parameter	Dataset Topography	Dataset bathymetry	Dataset multispectral
Sensor Used	ALTM Gemini – ALTM Pegasus	scan FugroMK3/MULTIBEAM SeaBat 8160	MIVIS
Resolution Medium	0,8 pt/m^2	0,25 pt/m^2	3X3m
Scanning Frequency	100-70 kHz	1,5 kHz	
Side Lap	30 %	30 %	
Planning Resolution	~2 m	~4 m	
Planimetric Altimetry	± 0,30 m	± 0,50 m	
Altimetric Accuracy	± 0,15 m	± 0,50 m	
Spectral Bands	-	-	102
Visible (20 bands)	-	-	0,43 – 0,83 µm
Near Infrared (8 bands)	-	-	1,15 – 1,55 µm
Middle Infrared (64 bands)	-	-	2,0 – 2,5 µm
Thermal infrared (10 bands)	-	-	8,2 – 12,7 µm

TABLE 1 Technical characteristics of remote sensing data

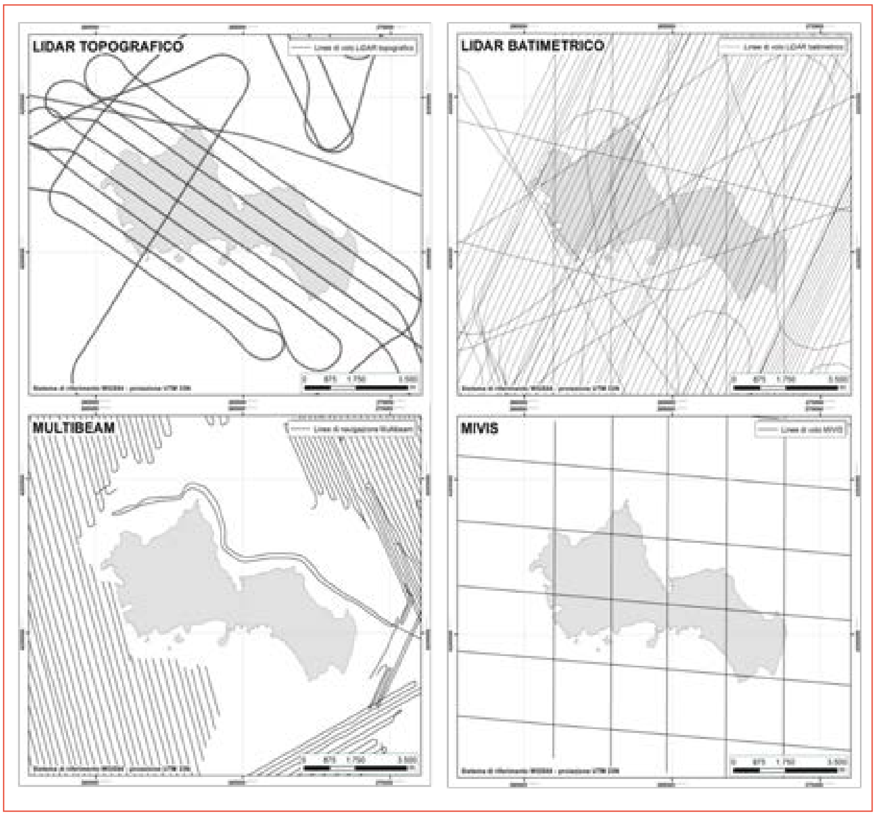

FIGURE 2 Trajectories acquisition of topographic, bathymetric and multispectral data

the existing maps, the Digital Elevation Model and hyperspectral data acquired under the project MAMPIRA, the accuracy of which has been improved thanks to direct and indirect in-situ investigations. The seafloor morphology is highly different with rocky and sandy shoreface, submarine canyons, vermetidi's *trottoir* and shoals of high rocky outcrops. A number of morphological elements influenced by tectonics, by changes in sea level and erosion due hydrodynamics can be observed. There are also many submerged forms ever detected so far. Some of them are described as follows.

Shoals

The study area is characterized by a variety of seafloor geological and geomorphological features. South of Favignana Island, at a depth of 19 to 50m, many rocky shoals sharply rising from the bottom were found (Figure 3).

FIGURE 3 Results of the topo-bathymetric surveys of Favignana Island. The angle of shading is 315°. Up left a rose diagram of wind speed and direction

FIGURE 4 Draw of Punta Longa Palo, signalled by [5].
Source: http://favignana.santateresa.enea.it

FIGURE 5 Depressions on sandy bottom along the east coast of the island of Favignana

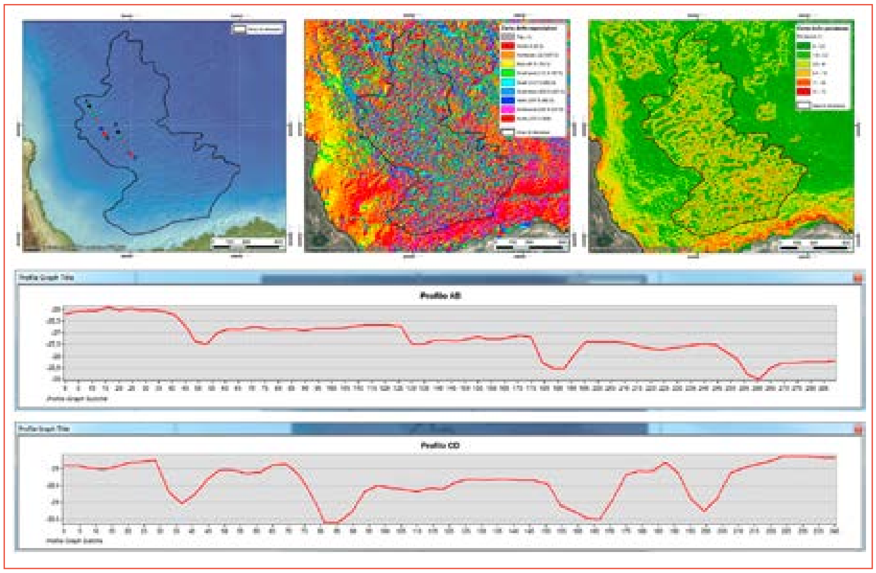

FIGURE 6 At the top bathymetric, slope and lighting maps are reported. Below, anthropogenic furrows and asymmetry of superimposed sedimentary structures are observed along two NW-SE oriented transects

These morphostructures, also known as "Pali", are shoals with subvertical walls partially reshaped by the erosive action exerted during the last Holocenic sea level rise. They have a subplanar top and, direct observations [10] detected steep and terraced slopes (Figure 4). This is the first time that these morphostructures, already identified by other authors [11], have been mapped in a sub-linear and sub circular trend. Such geomorphological elements are significant, from an ecological point of view, for structuring animal populations, as reported on the submerged itineraries map [12].
The 1:12,500 geological map of the Favignana and Levanzo Islands [4], shows part of the shoal's top, composed of dolomitic limestones and dolomites stromatoliti of Mesozoic, emerging above the mean sea level. These landforms ("i Pali") have a morphological convergence with Montagna Grande (the N-S oriented ridge above mentioned). They are made of the same lithology of Montagna Grande, and the slopes morphology look-like that of larger slopes of the ridge. Therefore, they probably represent a small remodelled part of this ridge in the underwater environment.

Depressions on sandy bottoms

The eastern coast of Favignana, from Cala Rossa to Cala Azzurra, is characterised by sandstone cliffs of about 10-15 meters height and a sandy sea floor up to ~20 m of depth (Figure 5). A detailed analysis of bedforms revealed a series of NNE-SSW elongated depressions sub-parallel to the coastline. The genesis of these morphotypes is not influenced by bottom currents or relict bedforms (i.e. natural origin), but by trawls towed during fishing activities that destroy the seagrass meadow, leaving depressions of different width and depth on the bottom. Therefore, such bedforms were attributed to Anthropocene [13; 14].
Another stretch where seafloor is covered by anthropogenic features is located just north of Favignana Village (north centre of the Island), at a depth of about 25m. The area was used for the "Tonnare", a network of several traps fixed to the bottom through large anchors and stand through the entire water column (from bottom to surface) with the aim of intercepting tunas and capturing them during the "*mattanze*" (tunas killing), activity which made this place famous all over the world. Their anthropogenic origin is demonstrated

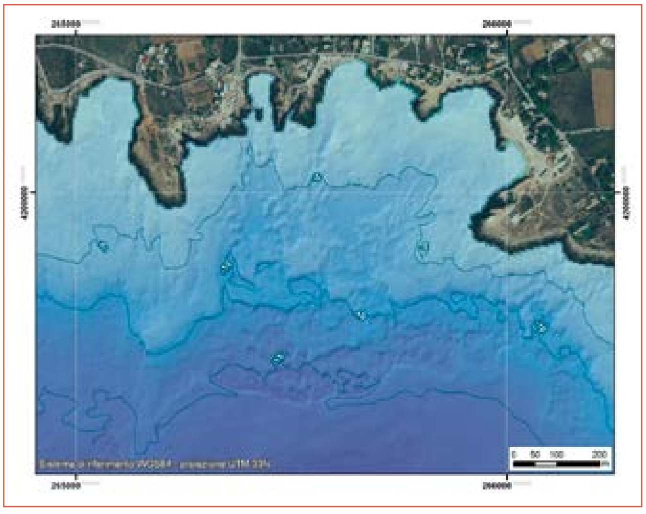

FIGURE 7 Example of Posidonia meadow damaged by anchors on the seafloor in front of Lido Ravine (southern sector of Favignana)

by visualisation of asymmetric and irregular profiles along orthogonal transects, which are highlighted by slope and lighting (Figure 6).

Intramatte

P. oceanica meadow characterizes the seafloor of the Egadi Islands. It is a priority habitat of the 43/92/EU Directive, abundant, well distributed and it is the most important biotic community. Despite the good preservation of the meadow, and its remarkable extension between the Egadi and the coast of Trapani, DEM observation revealed several compromised areas and *intramatte*, especially between 5 and 20 m depth (Figure 7). Differences of submerged vegetation cover have been interpreted as morphological evidences of damage created by boats anchorages berthing inshore and grubbing up clods of meadows during the recovery. Further information can be obtained both analyzing spectral response from in-situ measurements (Figure 8) and using this data to improve the hyperspectral MIVIS image classification.

Conclusions

The "shoals" observed in the south-central part of the island between 20 (top) and 50 m (base) depth are remains of the emerging part of the Mesozoic limestone-dolomite morphostructure forming the ridge of *Montagna Grande*. Some authors [15; 16; 17] have referred to basins and structural features formed during the Plio-Pleistocene extensional tectonic phase, which are emphasized by the submarine morphology. But what are the "shoals" (*I Pali*")? When did they form? What were they like during the Last Glacial Maxium (LGM)? Is their formation associated to faults, or are they morphological features related to selective erosion? Probably "*I Pali"* have been shaped by waves which have carved the slopes of these submerged rocks during the last Holocene sea level rise (and/or LGM sea level fall), as suggested by a series of erosion cliffs and

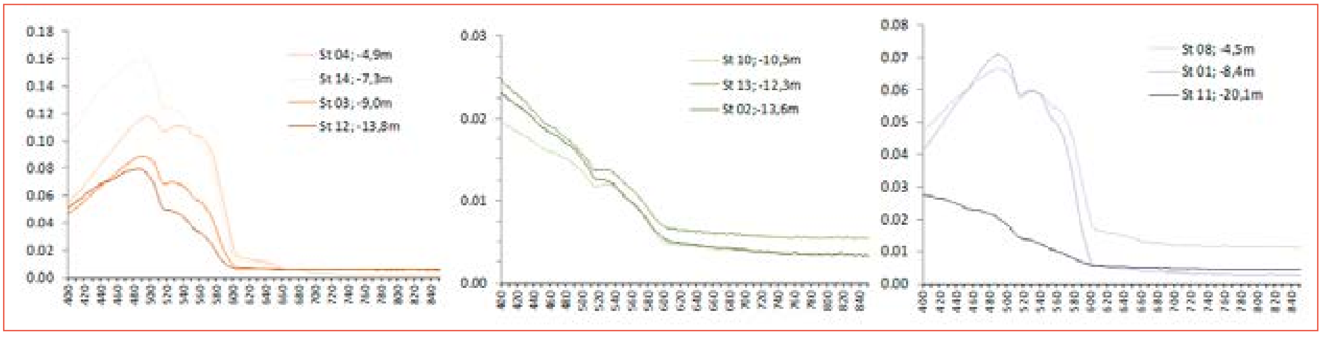

FIGURE 8 From left to right, examples of the in-situ spectral radiometry of the sandy seafloor, *P. oceanica* meadow and sandy seafloor with *P. oceanica*. The depth for each curve is recorded in the legend

wave-cut platforms. A second hypothesis explaining the morphological characteristics observed along the slopes of the paleo-stacks is a selective, polygenic erosion of low-angle carbonates and dolomites layers having different degree of erodibility. These processes occurred in the subaerial environment, before the last sea level rise and flooding, when these features were probably Island-detached from the shoreline (Cappucci *et al.*, in progress). Further study on detailed stratigraphic reconstruction, description of shapes and sizes (including the slope of the tested layer) may help to correlate this information with the tectonic movements and the rate of the sea level changes (Antonioli *et al.*, *pers. comm.*), but this study goes beyond the objectives of the present work.

Other bedforms, in particular *intramatte* and the depressions left by the action of trawling or anchors of tonnare have been dated as Anthropogenic features. An institutional timing for Antropocene should be established, during which humanity has become a major force of the Planet's geological transformation [18]. Man has changed the climate, leading to sea level rise, and has extensively contributed to mining activities. Actually, the presence of several quarries in Favignana is the evidence that the exploitation of natural resources started during the Roman Empire. Humans have shifted more sediment than all rivers combined together, and the present paper demonstrates how intensively the sea bed has been exploited, with a consequent heavy impact on the local ecosystem. Preliminary data processing and interpretation have allowed unpublished and detailed characterization of the seafloor along with the assessment of human impacts through a geomorphological and ecological analysis.

Detailed maps based on remote sensing data have been successfully created and, despite the lower resolution of DSM compared to other generated by using different data sources [19], they allowed to make many discoveries and conclusions. These maps could be used in the private sector for fishing, mining, and coastal management, as well as maritime uses planning (positioning of emerging technologies such as wind-wave power generation in particular). Legislators and stakeholders will also depend on these maps to support well-informed decision making on the use of natural resources. In particular, these data will allow the MPA management to implement and refine the ongoing protection actions and procedures for the preservation of the marine environment. The placement of anti-trawling bollards, the installation of moorings for buoys, and experimental measures for environmental requalification are aimed at encouraging greater tourist accommodation, in the framework of promoting sustainability and green economy [20].

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A hydrological and geochemical survey of the groundwater resource of Favignana Island

Small islands suffer water shortage, and tourist pressure makes it even worse: Favignana island is the site that best represents such conditions, due to the contrast between the intense anthropization and the harsh nature of the terrains. The ENEA study hypothesized a solution in identifying the best areas where groundwater is abundant and presents the best conditions to take water samples for anthropic use. With hydrological measurements and chemical analyses, an area theoretically interesting has been identified in the eastern sector, where groundwater is better in quality and just a few meters deep below the ground. Westwards, instead, it is at a lower depth and saltier, due to its more intense contamination with seawater. Yet the amount of available groundwater is everywhere so poor that more intense water sampling is not recommended: people have always been living in good balance with nature, and they know how to manage the island's groundwater resource, fed by rare precipitations, as a supplement to the drinking water supply coming from Trapani

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Introduction

The small islands scattered over the Italian seas have always had to cope with a shortage of water resources, because of the harsh nature of insular grounds and the scanty areal extent of the islands themselves [1]: moreover, their aquifers are usually very thin, and the water in the wells is scarce and often brackish; in fact, often low quality is added to the natural scarcity of water resources, due to the seepage of salty water from the surrounding sea [2].
Islanders have therefore learned, over the centuries, to manage their water resources in extremely thrifty ways, developing peculiar techniques to collect and preserve the rainwater, such as conveying it from the basin-shaped roofs of their houses downward into underground cisterns [3]. Actually, agriculture has been affected too, compelling farmers to breed drought-resistant and brackish-water-tolerating cultivars [4, 5].
Nowadays, the growing tourist pressure [6, 7] is worsening the problem, particularly during the summer: if, on the one hand, it is an income source for islanders, on the other it demands larger amounts of freshwater, indispensable for restaurants and hotels [8-12].
With high summer temperatures, and scarce seasonal rains, the islands of the Egadi archipelago, off the western end of Sicily, in sight of the town of Trapani, are among the most sensitive ones to this serious inconvenience: that is why they represent the ideal subject of a study aimed at dealing with the problem [13-16].
Actually, the present ENEA study fits in the activities targeted at a more sustainable touristic offer [17,18]: in detail, the starting purpose was to detect possible areas where groundwater is of the best quality, and where it

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would be suitable to rationally concentrate pumping from the wells, to supplement the freshwater supply currently coming from an aqueduct from Trapani [19-22].

Geology and hydrogeology of Favignana

With a length of 9 km (west to east) and a maximum width of 4.3 km (north to south), the island of Favignana extends over an area of 19.4 km^2, along a 33 km long coastline [23, 24]. It hosts a ridge of dolomite and limestone oriented North to South -on top it stands Mt. Santa Caterina (312 m a.s.l.)- and two plain areas west and east of it, respectively (Figures 1 and 2). The ridge is bounded on both sides by a system of faults which have lowered the carbonate sequences, causing them to be covered by more recent deposits, mainly calcarenite [25-33].
Therefore, three hydrogeological basins should be considered in Favignana (Figure 3), corresponding to the two plains and the central ridge. The structural discontinuity surfaces, bordering on both sides the ridge itself, act as groundwater divide: only after heavy rain periods some limited groundwater is allowed to flow from the ridge toward the coastal plains.
In the western sector extensive outcrops of limestone can be found, side-by-side with less widespread calcarenite, as the evidence of a less deep lowering

FIGURE 1 Mt. Santa Caterina and the western plain

FIGURE 2 The town of Favignana and the eastern plain

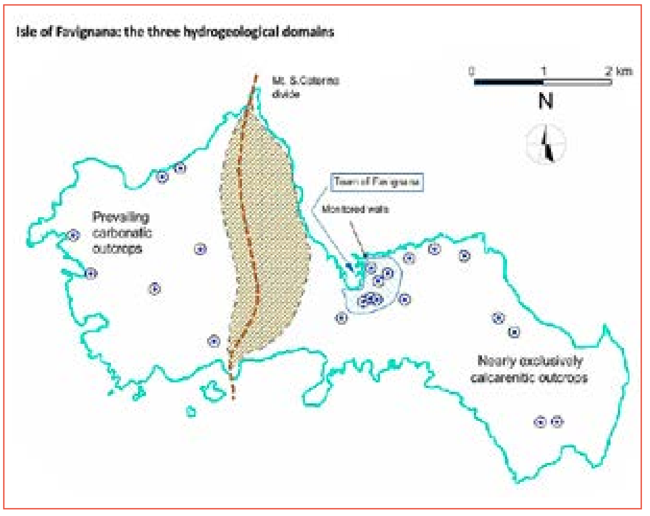

FIGURE 3 Schematic hydrogeology of Favignana

of those rocks in this area [34-39]. As a consequence, as it will be discussed later on, the groundwater in this sector is somewhat different from the water in the eastern sector: it is on average deeper and saltier.
In the eastern sector, instead, calcarenite covers the whole area, with a thickness varying from two to thirty meters. This rock has been extensively exploited over the centuries as building material (called "Tufo" all over Southern Italy) [40-44], to the extent that

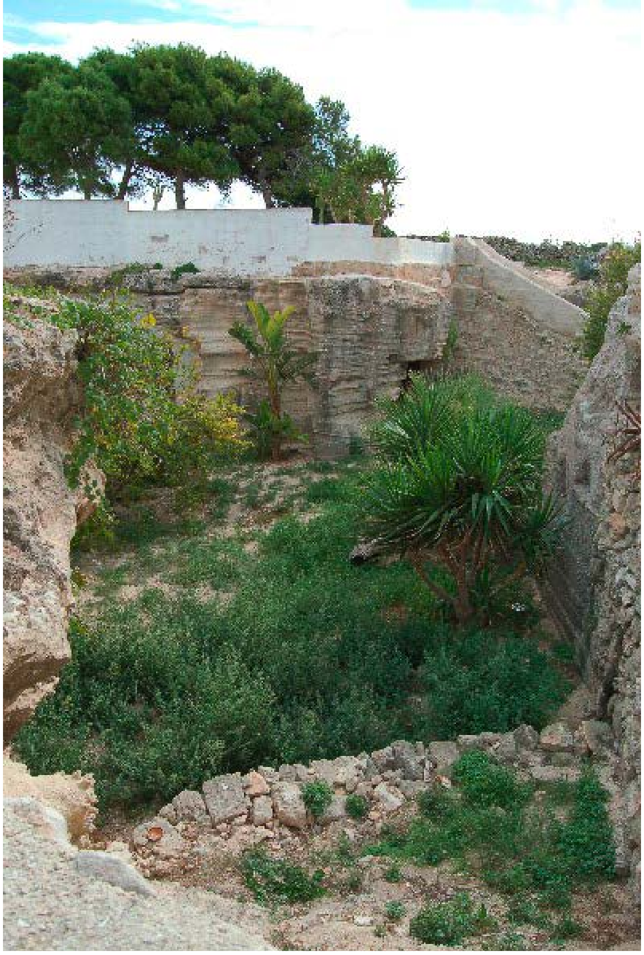

FIGURE 4 A typical quarry of “tufo”

several quarries and caves pierce everywhere the terrain, giving the landscape its characteristic rough appearance (Figure 4).
These calcarenite outcrops are not uniform, showing cross and parallel bedding. They are also commonly alternated with lenses and thin beds of sands and conglomerates. From this it ensues that the groundwater in this sector is actually not hosted in a single, large aquifer, but in a group of small aquifers, some in hydraulic continuity some isolated.
The scarcity of rainfall, the calcareous nature of the relief, and the limited extension of the island itself do not allow watercourses to form: only during some violent storm, accompanied by heavy downpours, small brooks form in some valley of the ridge, that dry up in a few hours.

The survey

In the field

In order to characterize and monitor the groundwater of Favignana, two surveys were carried out in 2012, measuring the water table from selected wells with a phreatimeter, main physical and chemical parameters (pH, temperature, electrical conductivity, dissolved oxygen, redox potential) with a multi-parametric probe, and collecting water samples for further determination of major cations, anions, and trace elements at the environmental biogeochemical laboratory of the ENEA Casaccia Research Centre.
The monitoring was not targeted at the effective potability of groundwater in a strict (and legal) sense: a rather different approach should have been necessary, planning biological analyses too, and a different and more complex handling of the samples, from their sampling to storing and analyzing. The chemical results of this survey, instead, were intended primarily to characterize the groundwater in terms of their salt content: the first step was to differentiate the waters of the various island zones, and locate the best tapping spots (if possible and suitable).
With a preliminary investigation on the island, together with Favignana municipal officials, 22 wells were selected for their practical accessibility, among the 520 registered on the whole island: 7 in the western sector, 4 in the eastern sector, and 11 in the urban area, in the center of Favignana. While almost each of them was open, and directly accessible with the measuring instruments, in some cases it was only possible to get from a tap the samples for the analyses.
Through a topographic survey performed with a DGPS equipment (Figure 5), reference ground elevations have been fixed for each site, in order to measure the elevation above sea level of the groundwater table all over the island, and its variation from one season of the year to another.
The two seasonal campaigns were performed

FIGURE 5 Measuring the DGPS position and elevation

FIGURE 6 Monitoring procedures on a site

respectively at the end of the colder and wetter season (end of April), and at the end of summer (end of September), to collect the data representative of the richer and the poorer conditions of groundwater.
The measurements and analyses described below have been followed as a routine procedure for all the 17 wells directly accessible; in the other 4, due to the reduced diameter of the wells, it was not possible to insert the probe; in one case, due to the sealed well, the sample was collected from a hose. For all those wells not directly accessible for the probe, the measurement of chemical and physical parameters was carried out on the surface through portable meters equipped with sensors and electrodes (Figure 6).

Operating procedures

- Measuring the water table depth (static level) by inserting a phreatimeter in the well down to the water.
- Purging the well and cleaning the water: a preliminary, brief discharge of the water from the well is necessary, in order to remove the upper stagnant water layer and clean up the remaining to be analyzed.
- Measuring the physico-chemical water parameters by inserting the probe into the well. The data are taken in three steps, during a second purging. On the wells of Favignana a low-flow pumping was used, for no longer than 10 minutes, due to the scarcity of the water in the wells. As the values of pH and electrical conductivity became stable, water samples were finally collected.
- Collecting the samples of water: for the analyses of hydrogencarbonate, a water sample was taken in a 250 mL polyethylene bottle, previously rinsed with the same water. Water samples for analysis of cations and anions: each water sample was filtered with a 0.45 μm mixed esters of cellulose filter and divided into two parts. The first part was acidified to pH < 2 with HNO_3 (BDH-Aristar grade) and saved for the

determination of major cations and trace elements, while the second was kept for anion determination. Once collected, the samples were immediately stored at 4 °C waiting for the laboratory analyses.
- For each well, the whole operation of sampling has taken about one hour and half.

For each well, the data registered by the multiparametric probe were compared to those obtained from the samples collected in parallel and analysed with the portable field analyses equipment (Figure 7): the results (for temperature, electrical conductivity and pH) were satisfactory, the average deviation between probe and field instruments never exceeding 10%, with very good R^2 values for the correlation lines. Only for the Eh data no correlation has resulted but, according to the field experience, this was to be expected in the presence of brackish waters.

Results

The water table

The comparison between the GPS elevations of the ground in the sites and the depth of the water level in the wells has allowed to outline an overall view of the groundwater table levels all over the island. The analysis of the results shows up two points:

1. All the groundwater levels lie in the 0-50 cm a.s.l. range, with a mean value of 28 cm. The western sector of the island has a ground elevation (averaged on the sites of the wells) of 15.35 m, and a water table level of 0.26 m a.s.l. In the eastern sector, with an average ground altitude of 9.21 m, the water table level is 0.29 m a.s.l. Here a further distinction can be made, most of the wells being concentrated in the centre of Favignana, with a mean ground elevation of 6.13 m and a water level of 0.31 m a.s.l.: other wells, in the rural east, lie at a ground elevation of 21.53 m showing a water level of 0.21 m a.s.l.
2. Between the wet and the dry season the groundwater levels show, on average, a difference of 2-3 cm, that is less than 10%. In detail, in the western sector the difference is 3.8%, and in the eastern sector is equal to 8.8%.

FIGURE 7 Checking the data from the probe

Chemical analyses

The concentration data of the water samples collected from the wells monitored in Favignana have been projected onto a Chebotarev quadrangular diagram (Figure 8), which allows to represent the chemical composition of water with a single point.

From the diagram a wide differentiation among the waters coming from the sampled wells can be inferred: in particular the sample from the well FA16 (Figure 8) can be considered end-member of the waters flowing through the calcarenitic terrains so widely diffused all over the island of Favignana, mainly in the eastern sector: in fact, it shows a relatively abundant content of calcium, magnesium and hydrogencarbonate ions; therefore it falls in the quadrant of the waters classified as bicarbonate-alkaline-earth waters.

The opposite end-member of the group is represented by the brackish waters (wells FA26 and FA15, Figure 8), with a high concentration of sodium (≈ 1500 mg/L) and chloride (> 2400 mg/L) ions, and with an electrical conductivity in the order of 9000 μS/cm. These waters are classified as sulfate-chloride-alkaline waters.

The rest of the waters show characteristics that are intermediate between bicarbonate-alkaline-earth and the sulfate-chloride-alkaline waters, with a prevalence of the bicarbonate-alkaline-earth kind.

In the Schoeller diagram (Figure 9), the slope of each segment joining the points of two different ions represents the characteristic ratio between those two ions: parallel segments denote waters with the same ionic composition, while segments with different gradient denote different

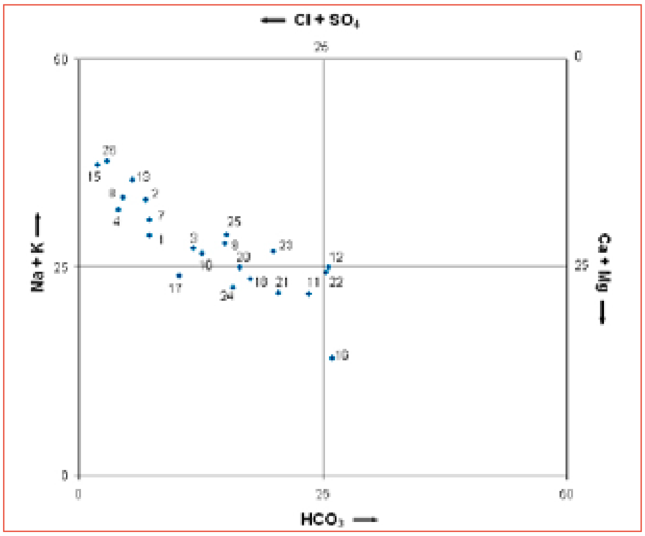

FIGURE 8 The Chebotarev diagram: water classification and evolution of the groundwater chemical composition

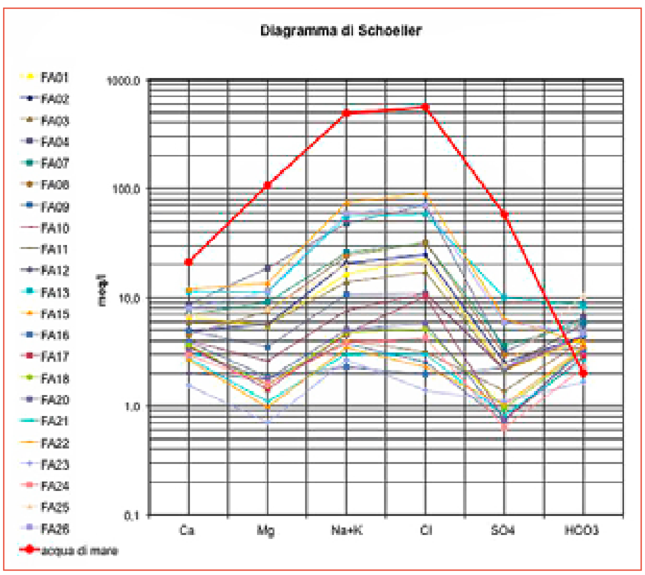

FIGURE 9 The Schoeller diagram: comparison between the ionic concentrations from the groundwater samples collected in Favignana

hydrochemical characters. A detailed analysis of the Schoeller diagram created for these water samples confirms a similar composition for most of the examined waters.

Particularly, most of the segments forming the distinctive lines of the water samples taken from wells FA04, FA13, FA15, and FA26 show a quasi-parallel trend, not only reciprocally, but also compared with the standard seawater line used as a comparison (sea water with a salinity of 35‰) [45]. These samples, showing electrical conductivity values exceeding 7000 μS/cm, represent the end-members of a geochemical facies evolved into chloride-alkaline through the mixing of originally fresh water with other saltier water due to a probable marine intrusion.

Discussion

Both in the western and in the eastern sectors, the water table is always few tens of centimeters above sea level, in wells where the mouth is as high as 32 meters as well as in wells where it is just a couple of meters above sea level (Figure 10). This result is evidence of the poor groundwater resource all over the island, independently from the nature or characteristics of the terrain, where the well has been drilled or excavated.

Between the wet and dry season the water table shows no significant differences, since they are limited to a few centimeters. Oh the other hand, the Favignana's people is accustomed since the first prehistoric colonization to cope with drought and poor water resource: they have

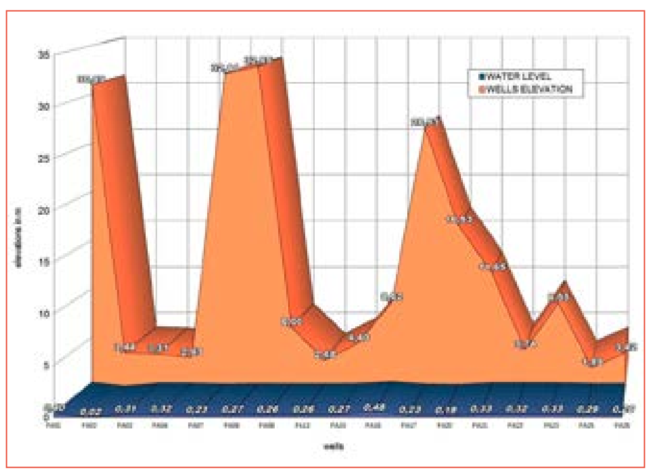

FIGURE 10 Water levels *vs.* ground elevations

FIGURE 11 Ruins of an ancient roof-and-tank set

soon learned to spare it, to manage it without wasting it, to secure at least a minimal reserve of water all over the year. Hence, in order to achieve this goal a house building technique has been developed over the centuries, that allows to collect rain water on the roof of the houses, from where it is pipe-conveyed down into cisterns often carved out right below the houses themselves (Figure 11).

According to the geographical distribution of the electrical conductivity values all over the island, two trends are distinguishable. The electrical conductivity data in the wells of the western sector range (annual average) from 2435 to 4830 μS/cm, with a maximum of

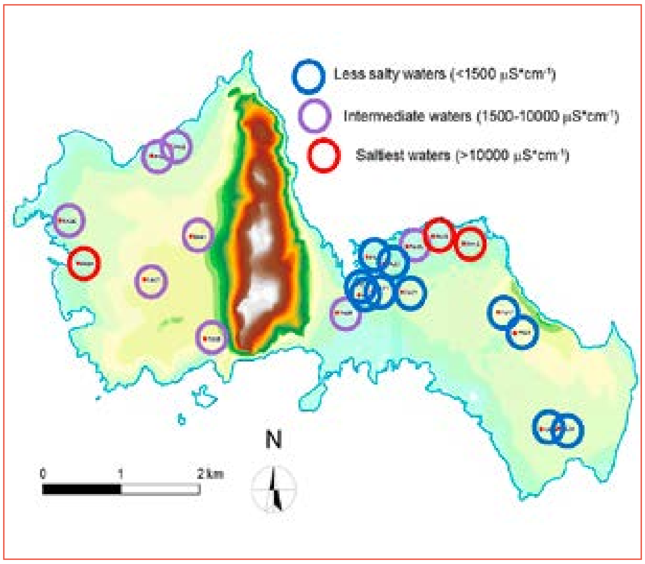

FIGURE 12 The distribution of conductivity in the two sectors of Favignana

9125 μS/cm in the well FA04. In the wells of the eastern sector, values as low as 676 μS/cm and as high as 11110 μS/cm (Figure 12) have been measured instead.

Although the mean electrical conductivity values of the two sectors are not so much different (4359 μS/cm vs 3563 μS/cm, both high values, anyway, for a groundwater), in the western area a more homogenous distribution can be observed, while eastwards the values are very different, even at a distance of a few hundred meters (Figure 12). This is coherent with the literature, where it is reported that in Favignana two wells can often be found in the very same lot, providing a different kind of water, one fresh and the other salty.

This difference mainly depends on the different geology of the two sectors, as already anticipated above (Figure 3): in the eastern one, the calcarenite outcrops are not uniform but commonly alternating with lenses and thin beds of sands and conglomerates. Therefore the groundwater in eastern Favignana should be considered as a set of little aquifers -contiguous and/or overlapping, isolated or linked together- each with different water qualities. In the western sector, instead, outcrops of carbonatic rocks are more abundant with respect to more scattered calcarenite banks.

Another cause of the difference between western and eastern sector is that the former is almost uninhabited, with few rural buildings dispersed over the country areas and no urban centers; conversely, the latter sector is the real vital center of the Island, from the town of Favignana in the center of the island to the tourist facilities on the more eastern coast.

As for the wet and the dry seasons, there are some differences indeed, nevertheless they are the most various and apparently accidental variations: somewhere they are positive, somewhere negative. No correlation has been found with the seasonal variation of the water table either.

Comparing the average electrical conductivity values with the ground elevations above sea level at the sites of the wells (Figure 13), instead, it is easy to see that higher electrical conductivity values are more common in shallower wells (even with conspicuous exceptions): it could be easy to conclude that this occurs since these wells are nearer to the seashore than the deeper ones. In fact electrical conductivity is function of the salt content, and this latter is, in turn, function of the mixing with the sea water surrounding the island. The cited exceptions, however, demonstrate that the underground conditions of Favignana are not so easy to describe: well FA22, for instance, in the middle of the town, one hundred meters from the quays, hosts water with the lowest electrical conductivity (i.e. the lowest content in salts): 676 μS/cm as annual average. In the western sector, wells FA02 and FA03, excavated in a calcareous outcrop, although situated some 100-200 meters from the rocky northern seashore, give water that is quite salty indeed (3200 μS/cm and 2435 μS/cm, respectively), but not so salty as the other wells situated slightly above sea level (where electrical conductivity rises as high as 6000, 7000, even almost 12000 μS/cm).

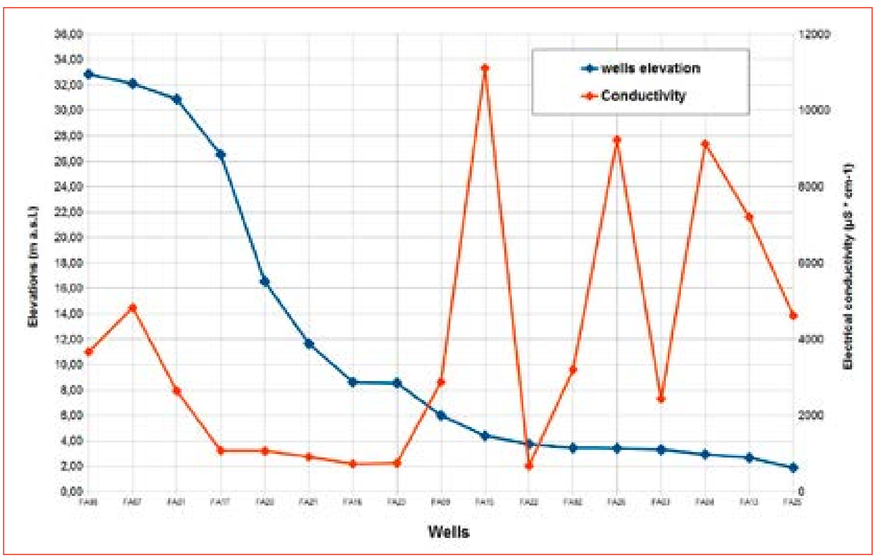

FIGURE 13 Conductivity *vs.* ground elevation

Conclusions

On the sole Favignana Island (with its area of less than 20 km^2) 520 wells are officially registered at present: even if many of them are out of service, and others belong to houses inhabited only for limited holiday periods during the year, it is still a huge number of points from which the groundwater can be tapped.

In addition to this anthropogenic potential consumption of groundwater, another way water is wasted due to the cited characteristic quarries and caves located everywhere in the eastern sector of Favignana: most if not all of them reach the water table, so their floor, and even their walls, act as evaporation surfaces contributing to the loss of the available groundwater.

All this could pose a serious threat to the survival of the natural groundwater resource, if people do not manage it with responsibility: according to the results of this survey, it can be said that there is no real danger, because water tapped from the island wells is not used extensively but only for limited domestic uses, such as irrigation of small orchards and hygienic purposes. The islanders know very well how much water they can yield from the ground, and where it is brackish and where fresher: they know very well that they cannot draw more water, nowhere, otherwise groundwater will be polluted irremediably by the ingression of sea water, which would advance to replace the overexploited fresh water. Therefore, groundwater should not be considered as a resource that could be exploited more intensively, neither all over the island nor in some chosen wells: the demand for fresh, drinking water could only be satisfied by the water supply coming from Sicily through the existing pipeline.

Acknowledgements

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Distribution of antifouling biocides in coastal seawater of Egadi Islands

The pollution level due to antifouling biocides in the Marine Protected Area of Egadi Islands (MPA) has been evaluated by both grab and passive sampling. Analyses of tributyltin (TBT), diuron, irgarol, chlorothalonil and dichlofluanid have been carried out on seawater and sediments. The results indicate a good condition of the coastline, but further studies with passive sampling for TBT are required to help the MPA administrators to control the status of the seawater with a methodology suitable to reach the Environmental Quality Standard values established by the Water Framework Directive

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Introduction

Colonization by fouling organisms is a problem for any structure placed in the aquatic environment and can be controlled through both chemical biocides and non-biocidal technologies. In spite of the progress made on diverse non-biocidal technologies and an increase in the commercial use of fouling-release coatings, the majority of vessels are still protected by antifouling (AF) paints containing biocides.
Formulations containing tributyltin (TBT) were the most successful against biofouling but they were banned in 2008, due to the detrimental impact on sealife. Currently, most antifouling paints contain copper or zinc as an active ingredient and a "booster" biocide to strengthen the effectiveness of the formulation [1].
In particular, the herbicides irgarol 1051 (2-methylthio-4-tert-butylamino-6-cyclopropilamino-s-triazine) and diuron (3-(3,4-dichlorophenyl)1,1-dimethylurea) and the fungicides chlorothalonil (2,4,5,6-tetrachloro iso-phthalo nitrile) and dichlofluanid (N-dichlorofluoromethylthio-N′, N′-dimethyl-N-phenylsulfamide) are extensively used worldwide in AF paints [1].
The widespread use of biocides in AF paints has resulted in high levels of contamination in the environment and has raised concerns about their effects on marine communities (shell malformation in oysters, mortality of mussel larvae and imposex in gasteropods), leading to policy actions to regulate their utilization and to set environmental quality standards (EQSs).
The Water Framework Directive (WFD) of the European Commission (EC 2000/60/EC) describes the monitoring of priority substances and other pollutants in surface waters, including coastal waters. The daughter directive 2008/105/EF of the European Parliament and the Council of the European Union has defined EQSs for priority substances in water and sediment, with the aim to protect the aquatic environment from adverse effects of these substances. Amongst the priority substances, specific compounds have been classified as priority hazardous substances, with the aim to cease or phase out their discharges, emissions and losses.
The list of priority substances include the biocides TBT (priority hazardous substances) and diuron and, after a recent revision (Directive 2013/39/EU), irgarol.

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Passive sampling (PS) has proven to be a reliable alternative to grab water sampling as it allows high volume sampling systems to ensure significant results while maintaining low detection limits [2]. Semi-permeable membrane devices (SPMDs) have been used extensively for the screening and the source identification of a variety of non-polar organic contaminants. SPMDs consist of a thin layer of a neutral lipid (usually trioleine) enclosed within a thin-walled, flat-lying, low-density polyethylene (LDPE) tubing. In the aquatic environment, SPMDs allow to measure not only the presence but also the bioavailability and potential bioconcentration of organic lipophilic compounds with octanol/water partition coefficients $\log K_{OW} > 3$.

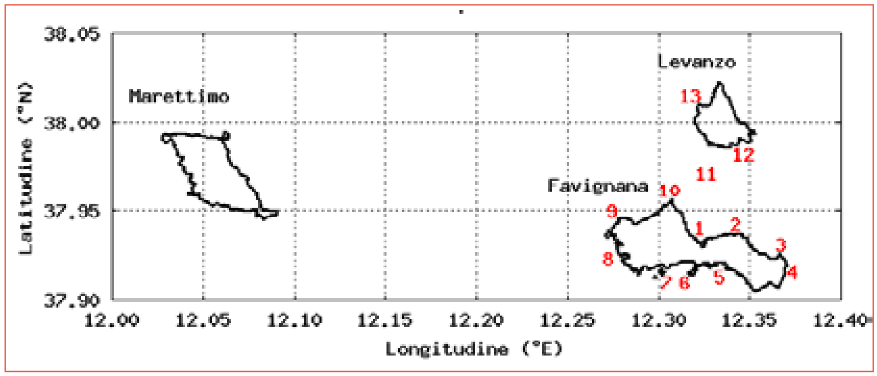

FIGURE 1 Location of sampling points for 2012 monitoring campaign

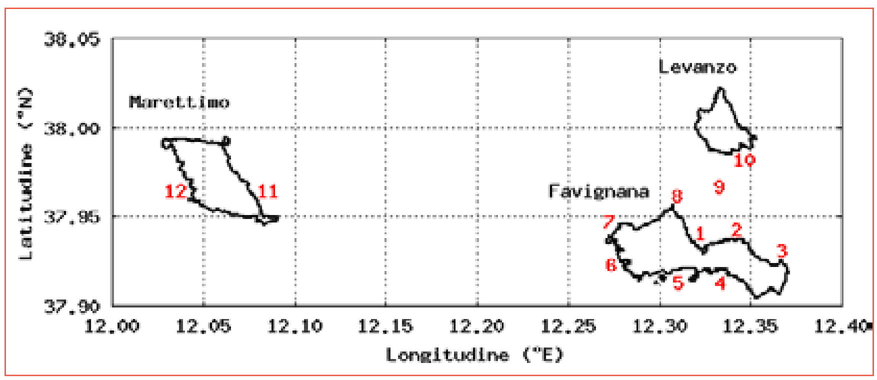

FIGURE 2 Location of sampling points for 2013 monitoring campaign

In the last few years, the assessment of anthropogenic pressure on marine environment has led to stronger protection efforts of marine ecosystems. Marine protected areas (MPAs), in particular, have become an extensively advocated form of marine conservation and their number is constantly increasing worldwide. It is generally recognized that MPAs are essential for conservation as they can provide unique protection for critical areas and spatial escape for overexploited species. MPAs safeguard populations or assemblages within their boundaries, but they are less effective for protection from some major threats to marine environments [3]. These threats include coastal modifications and subsequent changes in local hydrodynamic and sedimentary regimes, the spreading of exotic species, disease epidemics and, above all, contamination by chemicals that is not possible to control directly.

Limited data and information are available on the environmental occurrence, fate, toxicity, and persistence of antifouling biocides. In particular, to our knowledge, no direct evaluation of these compounds is available for the Marine Protected Area of Egadi Islands.

The goal of this research is therefore to estimate the pollution level by TBT and other antifouling biocides in the 4 zones of the MPA through spot sampling for seawater. Organotin-compound sediments analysis and TBT seawater passive sampling have been carried out, due to TBT particular persistence in sediment and possible presence at very low concentration (<1 ng/l as Sn).

Materials and methods

Study areas

The Egadi Islands' Marine Protected Area includes the islands of Favignana, Levanzo, Marettimo and the islets of Formica and Maraone. Figures 1 and 2 show sites selected foryears 2012 and 2013 monitoring, respectively. All the points were in zone C, with the exclusion of points 10 and 13 in the first campaign (Faraglioni and Levanzo, B zone) and 8 and 12 in the second campaign (Faraglioni, B zone, and Marettimo, A zone, respectively).

Sampling

Water and sediment samples were collected in September 2012 and September 2013, before the end of summer, when boating activity is still intense and the contamination from AF paints is expected to be significant. Seawater was collected in all 25 sites; in 7 sites it was not possible to collect any sediments due to the rocky bottom (4 in 2012 and 3 in 2013).
A Glass-Sampler Probe (International PBI, Milan, Italy) was submerged to a depth of 0.5 m below the sea surface and seawater samples were collected in pre-cleaned 1 l glass bottles. All the containers were additionally rinsed with seawater before sample collection. The aqueous samples for analysis of Monobutyltin (MBT), Dibutyltin (DBT) and Tributyltin (TBT) were acidified *in situ* with 0.8 ml 37% HCl per liter. The aqueous samples for analysis of biocides compounds were added *in situ* with 2 ml of dichloromethane per liter. All water samples were stored in a fridge at 4 °C until the analysis.
Surface sediment samples were collected in 18 sites (9 in 2012 and 9 in 2013) by a stainless steel Van Veen grab sampler. After collection, sediments were stored at -20 °C and then transported to ENEA laboratories, where the sediments were sieved at 2 mm: the fraction <2 mm was considered for analysis. After sieving, sediments were freeze-dried.
Standard SPMDs (length 91.4 cm; width 2.5 cm; LDPE wall thickness: 70–95 μm) with 1 ml of 99% purity triolein) were purchased from ExposMeter AB, Tavelsjö, Sweden. Before use, all the support devices were washed with tap and distilled water before being rinsed with acetone and hexane. The SPMDs were transported in sealed clean metal cans and refrigerated at 4 °C. The SPMDs were assembled with proper supports and inserted into stainless steel cages (canisters, ExposMeter AB, Tavelsjö, Sweden) on the boat just before the positioning. The canisters were deployed between 1 to 6 meters below the water surface and properly fixed to a buoy or to a quay by a scuba diver (Figure 3). After retrieval, the SPMD strips were immediately roughly cleaned with acidic (HCl) water and stored at 4 °C in the metal can.

FIGURE 3 Passive sampler placement by scuba diver in Preveto site

Analysis

Biocides

500 ml of water were placed into a 1 l separatory funnel, 50 ml of dichloromethane were added, and the mixture was shaken for 2 min. The layers were allowed to separate and the organic layer was filtered through anhydrous sodium sulphate and collected in a round bottom flask. Another 20 ml of dichloromethane were added and the sample was extracted as above. The extracts were reduced to approximately 0.5 ml on a rotary evaporator and then transferred to a vial for GC-MS analysis. [4].
To evaluate the recovery, samples of synthetic seawater were spiked with biocides at two different levels: 10 and 100 ng/l. The samples were analyzed according to the procedure described above. Four replicates of each level were analyzed. The recovery values were greater than 86% for both levels with a standard deviation of 9% in the most unfavorable case. LODs for this method were 1 ng/l for all the biocides.

OT compounds

Spot samples

1 L water samples (pH adjusted to 2 at the moment of sampling) were added with an appropriate amount of a solution of ^{119}Sn -enriched butyltin compounds (an isotopically enriched solution of MBT, DBT and TBT) as procedure/quantification standard, and allowed to equilibrate for 15 min with occasional agitation.

The extraction was performed in a separatory funnel with at least 2 aliquots (30 ml) of a 0.03% tropolone solution in dichloromethane (to improve the extraction efficiency of the monosubstituted species), and the organic phase was collected through anhydrous sodium sulphate. The organic phase was evaporated on a rotary evaporator down to a final volume of 1 ml at the temperature of 30 °C. The organic extract was transferred into a vial, added with 2 ml of hexane and 1 ml of isooctane (as keeper solvent) and then evaporated almost to dryness under a gentle stream of nitrogen. The organotin compounds were pentylated by Grignard reagent and then were extracted twice with 1 ml of hexane. The extract was concentrated and purified on a silica gel column. After concentration down to 0.5 ml, 1 µl of the final solution was injected for GC-MS-SIM analysis and organotin quantitative determination was based on isotope dilution method [5].

For sediments, approximately 1.0 g of freeze-dried material was taken as sample and extracted with 15 ml of 0.03% (w/v) tropolone in methanolic solution and 1 ml of concentrated hydrochloric acid. The supernatant was transferred to a separatory funnel and the extraction procedure was repeated. After the addition of the 0.03% tropolone solution in dichloromethane, the subsequent steps were the same as in the seawater extraction.

Method limits of detection for seawater (as cations) were 2.5 ng/l for TBT and 2.0 ng/l for DBT and 1.5 ng/l MBT. All the analyses were carried out by the same operator. Method limits of detection for sediment (as cations) were 1.2 µg/kg for TBT and 1.0 µg/kg for DBT and 0.8 µg/kg for MBT.

A certified reference material, a coastal sediment (IRMM BCR 462) and fortified blank seawater samples (TBT, DBT and MBT spiked at 10 ng/l and 100 ng/l as cation) were used for validation of the procedures. The analysis of the reference material (n = 3) showed a good performance, results overlapped the certified values ± their uncertainty and recoveries from fortified blank seawater samples (n = 5) were: TBT 92 ± 21%, DBT 87 ± 23%, MBT 82 ± 24% (10 ng/l) and TBT 96 ± 10% DBT 92 ± 13% MBT 86 ± 20% (100 ng/l). The GC-MS determination was done in a single run for all the samples including blanks and BCR 462.

Passive samples

After an exposure time of 21 days the collected SPMD samples strips were washed with acidic (HCl 1%) water and then stored at -20 C°.

The samples were dialyzed with 150 ml of hexane (two cycles of 24 hours). The organic phase was evaporated on a rotary evaporator down to a final volume of 1 ml at the temperature of 30 °C. The organic extract was transferred into a vial, added with 1 ml of isooctane (as keeper solvent) and then evaporated almost to dryness under a gentle stream of nitrogen. After that, the samples were treated as described above for organotin determination, whereas quantitative determination was based on the isotope dilution method.

As quality control, SPMD blanks (for the procedure and for the campaign) were analysed in parallel with the samples. No TBT was found in the blanks analysed.

The concentration in the seawater has been calculated with the method and constants described by Harman et al [6] , where the sampling rate of TBT for the SMPD was 2.67 l/d.

Results and discussion

The major input of TBT, diuron, irgarol, chlorothalonil and dichlofluanid into marine systems derives from anti-fouling paints, but occurrences have been related also with their use in other human activities (farming and conservation)[7]. For TBT, diuron and recently irgarol, EQS values for annual averages (AA-EQS) and maximum allowable concentrations (MAC-EQS) have been established in the WFD. Table 1 reports the EQS values. For chlorothalonil and dichlofluanid EQS standards are not present but values around 5 -10 ng/l are in discussion for proposed EQS [8-10].

	AA EQS µg/l seawater	MAC EQS µg/l seawater	AA EQS µg/kg sediment
TBT as cation	0.0002	0.0015	5
Diuron	0.2	1.8	N.A.
Irgarol	0.0025	0.016	N.A.

TABLE 1 Environmental Quality Standards (EQS), Annual Average value (AA-EQS) and Maximum Allowable Concentration (MAC-EQS) defined by the Directive on Environmental Quality Standards (2008/105/EC) for TBT, Diuron and Irgarol in seawater coastline and sediment. N.A Not Available

	TBT ng/l
Favignana Port	2.8±0.5
Preveto	1.0±0.3
Faraglioni (B zone)	0.3±0.1

TABLE 2 Concentration of TBT in SPMD samples from 2012 monitoring campaign. All results are expressed as ng/l cations

In all the seawater samples collected by spot sampling, the concentration of TBT and biocides were below the limit of detection, i.e. 2.5 ng/l for TBT, 2.0 ng/l for DBT, 1.5 ng/l for MBT and 1 ng/l for all the other biocides.
For diuron, irgarol, chlorothalonil and dichlofluanid the absence of detectable traces in seawater samples and the LOD of the analytical method are such to state that the presence of these biocides are well below the EQS defined by WFD or internationally recognized (Table 1).
Other studies have shown the absence of diuron, irgarol, chlorothalonil and dichlofluanid in areas of the Mediterranean sea [7] including other MPAs.
Since the marine environment is not affected by these biocides, at the moment, their utilization as antifoulants and in farming activities as herbicides and/or fungicides seems to have a limited or not relevant impact on the seawater.
Despite the total ban of TBT-based paints [11], TBT was still a commonly encountered contaminant in the seawater, and the presence of organotin compounds is yet recorded in the coastline sites. Many studies have involved surveys on TBT distribution in the water column, sediments, and biota [12-14]. Measurements taken prior to restrictions on TBT have shown levels higher than 500 ng l^{-1} in North American and European marinas. In recent investigations, it has been reported that TBT concentrations have generally declined, rarely exceeding 100 ng l^{-1}, even if hot spots have been reported especially in those countries where IMO restrictions have not been applied. When concentration in the seawater is at least 3-5 ng/l, the conventional methods of spot sampling, coupled with classical methods of analysis, are sufficient to detect the presence of TBT and its degradation products. In this study, TBT concentration in seawater samples collected by spot sampling was always lower than the method detection limit (2.5 ng/l); consequently it was impossible to verify water contamination and quality standards, considering that EQS values for TBT are 0.2 and 1.5 ng/l, for AA and MAC, respectively (Table 1), that is well below the LOD.
Passive sampling devices are therefore necessary for levels below 2 ng/l. Passive samplers have been validated and provide high sampling rates (liters/day) for various contaminants, thus allowing to quantify extremely low pollution levels in water, using similar methods of analysis as for grab sampling. In particular, SPMD can be used for the analysis of TBT [15, 16] thanks to its octanol/water partition coefficient $\log K_{OW}$ >3. The TBT data of passive samples are in agreement with the results obtained with samples collected with classical procedures (Table 2). Indeed, all the samples collected by passive devices have showed a concentration around or lower than 2.5 ng/l, which is the LOD of TBT with grab sampling. The lowest concentration of 0.3 ng/l was found in the B zone of the protected area (Faraglioni), 1.0 ng/l in the Preveto samples and, finally,

	TBT µg/kg	DBT µg/kg	MBT µg/kg
1) Favignana Port	4.0±0.5	3.0±0.4	3±0.5
2) Punta San Nicola	n.a	n.a	n.a
3) Cala Rossa	n.d.	n.d.	n.d.
4) Punta Marsala	n.d.	n.d.	n.d.
5) Cala Monaci	n.a	n.a	n.a
6) Punta Longa	n.d.	n.d.	n.d.
7) Preveto	n.d.	n.d.	n.d.
8) Cala Rotonda	n.d.	n.d.	n.d.
9) Punta ferro	n.a	n.a	n.a
10) Faraglioni (B zone)	n.d.	n.d.	n.d.
11) Canal Favignana Levanzo	n.d.	n.d.	n.d.
12) Levanzo Port	2±0.3	8 ±0.6	2±0.3
13) Levanzo (B zone)	n.a	n.a	n.a

TABLE 3 Concentration of butyltin compounds in sediment from 2012 monitoring campaign. All results are expressed as cations µg/kg d.w. (n.d. not detectable: LOD TBT 1.2 µg/kg d.w., DBT 1.0 µg/kg d.w., MBT 0.8 µg/kg d.w; n.a, not available)

	TBT µg/kg	DBT µg/kg	MBT µg/kg
1) Favignana Port	3±0.3	2±0.2	2±0.2
2) Punta San Nicola	n.a	n.a	n.a
3) Punta Calarossa	n.d.	n.d.	n.d.
4) Cala monaci	n.a	n.a.	n.a.
5) Preveto	n.d.	n.d.	n.d.
6) Cala Rotonda	n.d.	n.d.	n.d.
7) Punta ferro	n.a	n.a	n.a
8) Faraglioni (B zone)	n.d.	n.d.	n.d.
9) Canal Favignana Levanzo	4±0.5	2±0.2	4±0.4
10) Levanzo Port	2±0.2	5±0.5	3±0.3
11) Marettimo Port	2±0.2	1±0.1	1±0.1
12) Marettimo (A Zone)	n.d.	n.d.	n.d.

TABLE 4 Concentration of butyltin compounds in sediment from 2013 monitoring campaign. All results are expressed as cations µg/kg d.w. (n.d. not detectable: LOD TBT 1.2 µg/kg d.w., DBT 1.0 µg/kg d.w., MBT 0.8 µg/kg d.w; n.a, not available)

the highest concentration, 2.4 ng/l, was found in the Port of Favignana.
Clearly, only a passive sampling strategy can deal with these concentrations, which are below the range of routine methods of analysis.
Marine sediments still represent a problem in the long term because they are a source of biocides for the water column and biota even after the source of contamination has been removed. The ability of marine sediments to accumulate these compounds varies geographically and geologically, according to the physicochemical characteristics of the sediment (e.g., particle size and organic carbon content). In particular, the restriction on the use of TBT [11] has not yet led to TBT disappearance in port areas, owing to its hydrophobicity and long persistence (years) in sediments [12-14]. The TBT contaminated sediment may continue to act as input sources of TBT to overlying water by desorption or resuspension of sediment-bound TBT in areas where maritime traffic is intense.
The sediment samples collected in the MPA of Egadi Islands clearly showed that butyltin compounds are consistently detected only in port areas, even if at low concentrations, in agreement with published work for sediment collected in others Sicilian MPAs [17]. Favignana, Levanzo and Marettimo ports showed TBT concentrations ranging from 2 µg/kg to 4 µg/kg (Tables 3 and 4) in both monitoring campaigns. Such concentrations can be classified as the lowest among the Italian port areas [18], always below the EQS of WFD (5 µg/kg).

Conclusions

The analysis of seawater samples from different location of Egadi Islands' coastline indicates the absence of diuron, irgarol, dichlofluanid and chlorothalonil in all the MPA locations studied.
The LOD of the analytical method is sufficient to state that the presence of these biocides in the seawater is well below the EQS defined by the WFD for diuron and irgarol and the accepted international quality standards for dichlofluanid and chlorothalonil.
TBT presence was not detected by grab sampling but only using passive sampling, at concentration levels higher than the extremely low EQS defined by the WFD (<1 ng/l).
The results confirm that only passive sampling by SPMD allows to measure TBT levels in the investigated areas reaching quantification limits similar to the requested EQS for this contaminant. TBT in sediments is only detected in portual samples, with concentrations below

the EQS of 5 μg/kg. This presence could explain the detection in passive sampling due to the remobilization of sediment with consequent resuspension of TBT.

TBT will probably cause problems long after it has been banned, remaining a matter of concern and requiring monitoring for the years to come.

These findings confirm that pollution threats to marine systems (like the dispersion of pollutants, in our case) should be addressed by MPAs also through the development and implementation of smarter monitoring systems [19]. Passive sampling devices proved to be useful to cope with this kind of pollution, particularly if extremely low levels have to be detected [20], in compliance with the EQS (annual average in particular) defined by the WFD for priority substances.

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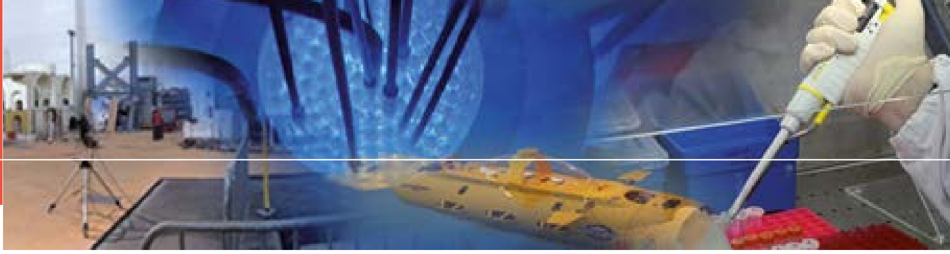

Characteristics and possible reuse of Favignana Harbor's sediments

Italy is a country with a high coastal development where multiple activities are located in sites near the coast, which makes the handling of marine sediments a topic of particular interest and socio-economic importance. At present, the excavation of the seabed and the subsequent discharge of resulting materials into the sea represents a risk due to the possible spread of contaminants in the ecosystem. National and international legislation has recognized the immersion of contaminated material into the sea as an event of perturbation to the environment while promoting alternative management options and introducing the concept of sediment as a "resource" and not as a "waste". There is a wide range of treatment technologies available and they significantly influence the reuse of dredged material. In the present work, a site-specific conceptual model of the small harbour of Favignana is presented and, on the basis of some preliminary analytical tests on superficial samples, the assumptions of management options are predicted. One of them is particularly interesting as it could be applied to other cases where, for reasons of safety of navigation, small volumes of slightly contaminated sand (less than 25,000 m^3) must be dredged and, after removing chlorides, they may be used on land to create sporting centres and increase tourist capacity

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Introduction

Sediments are suspended or deposited solids, acting as a main component of a matrix, which has been, or is susceptible to being transported by water [1]. With the raise of tourist flows, sediment is becoming an important natural resource for the economic development of many countries, and its correct management is playing a crucial role in the environmental, social and economic sectors (Figure 1).
From the social point of view, sediments form beaches and are distributed along coasts. So, their abundance strongly influences the capability to contrast flooding, in order to facilitate recreational and cultural events. From the economic point of view, especially in small islands, the accommodation capacity of tourists is affected by the number of berths, the safe navigation within harbor that should not be affected by siltation [3, 4]. From an environmental perspective, the sediments also play a vital role in the health of aquatic ecosystems as a result of interactions with pore water and the water column

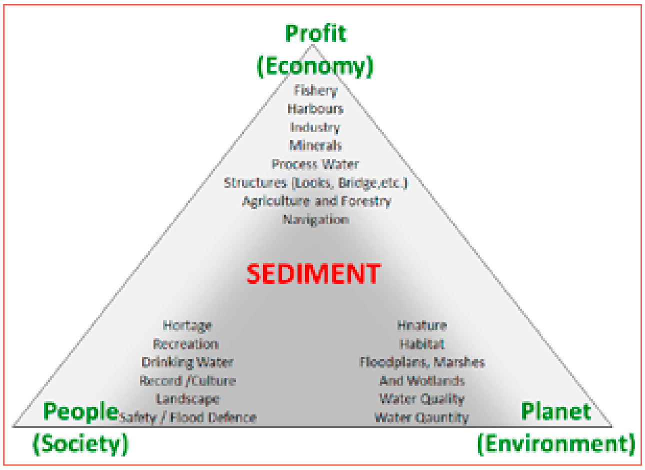

FIGURE 1 The three fields of sustainable development and their interaction in relation to sediment. Modified from [2]

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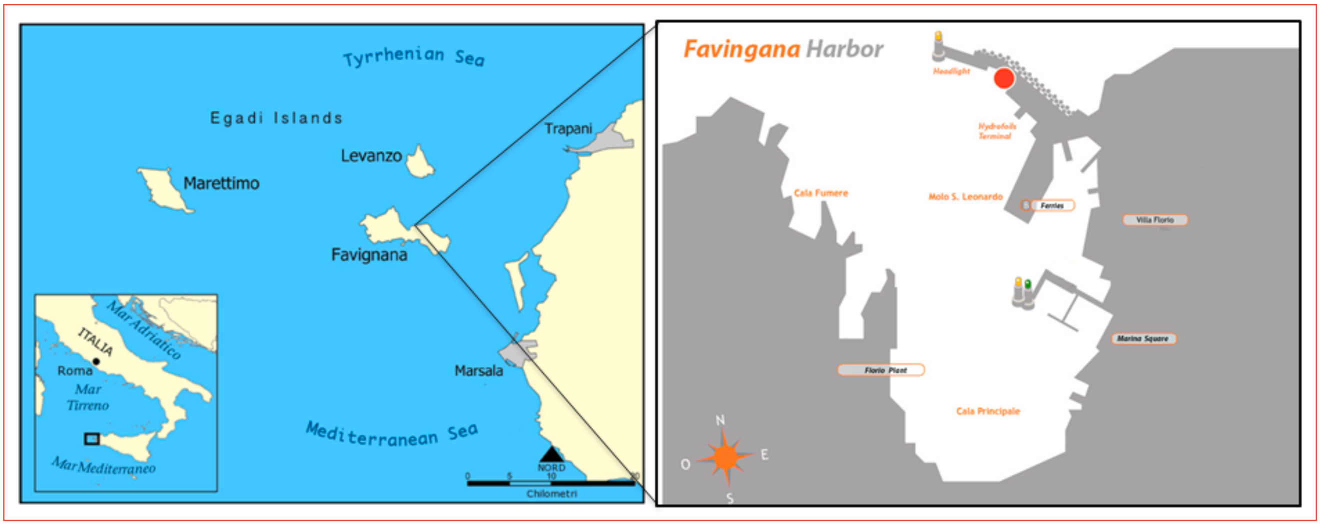

FIGURE 2 Egadi archipelago and Favignana Harbour

above them due to the direct contact of many aquatic organisms and following food web.

However, once present in water bodies, pollutants tend to be absorbed by particulate matter and to settle onto the bottom. Such process generates the formation of contaminated sediments, defined as "*soil, sand, minerals and organic matter accumulated on the bottom of a water body and containing toxic or hazardous substances at levels that may cause adverse effects on human health or the environment*" [5]. Accumulation of contaminants within sediments can derive from natural or anthropogenic sources. The natural mechanisms are identified with volcanic eruptions, forest fires, the biosynthesis performed by plants or bacteria and all phenomena that exclude human impacts. However, natural processes can lead to concentration exceeding the threshold of contamination defined by national legislation. In some sites, such abundance establishes a reference value of natural background. Anthropogenic sources, however, are represented by all the activities that produce and/or use toxic or harmful substances and that can affect the ecosystem in which they are issued [6]. Anthropogenic contaminants may enter the aquatic environment through punctual sources, such as industrial or civil discharges, or from diffuse sources, such as runoff, erosion of farmland treated with pesticides and atmospheric deposition. For this reason, the conceptual model of contamination is the preliminary part of the process of investigation and remediation of the seabed.

The Italian current legislation is based on the Legislative Decree no. 1 of 24th January 2012 (converted into Law no. 27 of 24th March 2012), in which Article 48 is referred to "Dredging Rules" and re-writes the previous detailed regulations regarding dredging, regulated by art. 5 of Law no. 84 of 1994 [7, 8, 9]. While the legislation tends to mitigate the environmental impact derived from the movement of sediments in the coastal marine environment, there are still strong references to the prevention of the disposal of dredged material that should be applied to harbour areas without the need to remove sediments at the points where they are most polluted, which often coincide with navigation channels, or internal parts of the harbour, where hot spot are more abundant. Security issues and maintenance dredging should be authorised with simplified procedures, while we still suffer to adopt best practices for sediments management in relation to low levels of contamination.

The goal of ENEA was to implement a management model of harbour sediments, which, after characterization and possible treatment, may find reuse avoiding landfilling. This strategy combines the need to avoid the silting of coastal infrastructures, ensure the maintenance and permit the transit and mooring of vessels, in order to provide the tourist industry with a valuable natural resource through periodic excavations of the bottom in compliance with the classification regulation concerning water, waste and soil [10], as well as the legislation relevant to dredging, like art. 48 of the Italian legislative decree of 24th January 2012 [7].

Favignana Harbour

The Favignana Harbour (Figure 2) is developed in the sheltered inlet of Cala Principale (north central area of Favignana Island). It is equipped with a pier about 110 m long, which extends to north-west. The smaller Molo S. Bernardo stretches for about 85 meters in a southerly direction. About 100 berths are available, 30 of which dedicated to boats of travellers/ navigators. On the seabed the *Posidonia oceanica* meadow is present. The harbour of Favignana Island is located in the Marine Protected Area, defined as "*the buffer zone between the valuable natural areas and external unprotected areas, where the activities of enjoyment and sustainable use of the sea of low environmental impact are permitted*".

Methods

Based on the complexity of sediments management and the need to guarantee periodical dredging, as well as to sustain tourism in the area (harbour, sports activities and versus municipalities and tourist operators), a simple and straightforward method was implemented in four steps:

- implementation of conceptual model;
- sediments characterisation;
- technical and economic analysis of remediation technologies;
- classification of sediments and management scenarios.

Due to the low level of contamination of the Marine Protected Area and the limited extension of the harbour layout (i.e., volume to be dredged), the following assumptions have been made:

- variation of contamination level with depth is modest. It means that characterisation of superficial sediment has been carried out to reduce the cost of sampling and laboratory analysis in the first exploratory phase of the work;
- on-shore management options have been taken into account. So, the bioavailability and effects of contamination on marine organisms have been ignored as dredged material will not be in contact with coastal marine water bodies, if reused.

Implementation of conceptual model

Since marine sediments are potential targets of intentional or accidental contamination, a detailed conceptual model has been implemented. Four main contamination sources were identified around the harbour basin and, for each of them, a specific schedule of production activities was compiled: (1) Florio's factory; (2) Gas station; (3) Waste Water discharge; (4) Boat repair (*Camperia*); see Figure 3. For each of the potential source of contamination, the transfer model and the final target have been identified. The conceptual model is based on site-specific reconstruction and the description of the contamination transfer model. For each source, a schematic table describes the route of transfer of potential contamination and the following information:

- Name of the company;
- Site and type of business/production;
- Description of the area;
- Hydrogeological description;
- Type of pollutants (current and previous activities);
- Conceptual Model (sources, transfer and targets);
- Results of preliminary analysis of soils, land, groundwater, marine waters.

FIGURE 3 Florio's factory (green); Gas station (red); Waste Water discharge (purple); Boat repair (orange)

Sediment characterisation

A preliminary characterisation was carried out by analytical investigations (of chemical and physical parameters), considering only superficial sediments collected in four sampling stations deemed as representative of the harbour area having extension of about 100x90 m. The main goal of the characterization of sedimentary bodies potentially contaminated is to determine the spatial distribution (horizontal and vertical) of the concentrations of contaminants within the identified critical areas. It is very useful to define the most appropriate remediation strategies. Another set of objectives can be pursued through characterization, such as:

- textural characteristics of the material;
- possible relationship between the distribution of contaminants and grain size of the particles;
- thickness of the sedimentary layers and the morphology of the rocky substrate;
- bioavailability and effects of contamination on marine organisms and their possible transfer;
- concentration of the contaminants along the water column in sensitive areas;
- natural or anthropogenic origin of trace metals, particularly in areas where there are geological formations with abnormal levels of them.

In the present work we have chosen a deterministic strategy [11, 12], which provides the positioning of sampling stations in areas where accumulation of pollutants takes place. Four sampling stations were chosen near the dock in front of Piazzale Marina (Figure 4), which is the first barrier hindering the deposition of coastal sediments. Frequent siltation of the structure is due to the anticlockwise circulation inside the harbour generated during mistral winds.

A Van Veen grab (bucket-type) with a capacity of about 5 liters was used for sampling of superficial sediments. Samples were then collected from the bucket using sterile polystyrene/glass containers and stored in the refrigerator at 4 °C until laboratory analysis.

The physical analyses were conducted at the "Laboratory for the Exploitation of Raw Materials and Fluids" of Sapienza University of Rome. Grain size distribution was determined by using the UNI EN 933-1 method, through sieves type ASTM (American

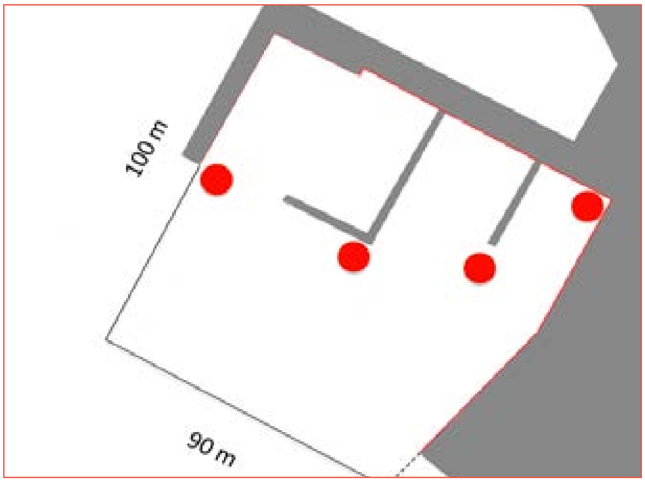

FIGURE 4 Sampling strategy for characterisation of about 10,000 m² of harbour seabed

Society for Testing and Materials) E 11-70. Mesh sieves with light 1000 μm, 500 μm, 250 μm, 180 μm, 125 μm, 63 μm and 38 μm have been used. All particle fractions were subsequently dried at 105 °C, weighed and classified.

The chemical analyses were carried out at the "Laboratory for the Exploitation of Raw Materials and Fluids" of Sapienza University of Rome, with regard to heavy metals determination, and at the laboratory of the Technical Unit Characterization, Prevention and Environmental Remediation (UTPRA/GEOC) of ENEA Casaccia Research Centre, for TBT, PAHs, PCBs and hydrocarbons ($C > 12$) determination. No microbiological analyses were performed on the samples. A detailed description of the methodology used is reported in the work of Ferrantini [13].

Technical and economic analysis of remediation technologies

A detailed technical and economic analysis of the treatment and remediation technologies was conducted on the basis of literature review [14], budget estimation (market research) and results of tests carried out on other contaminated sites. The most reliable sources of data and information have been catalogued, classified and, for each technology, a range of costs was determined.

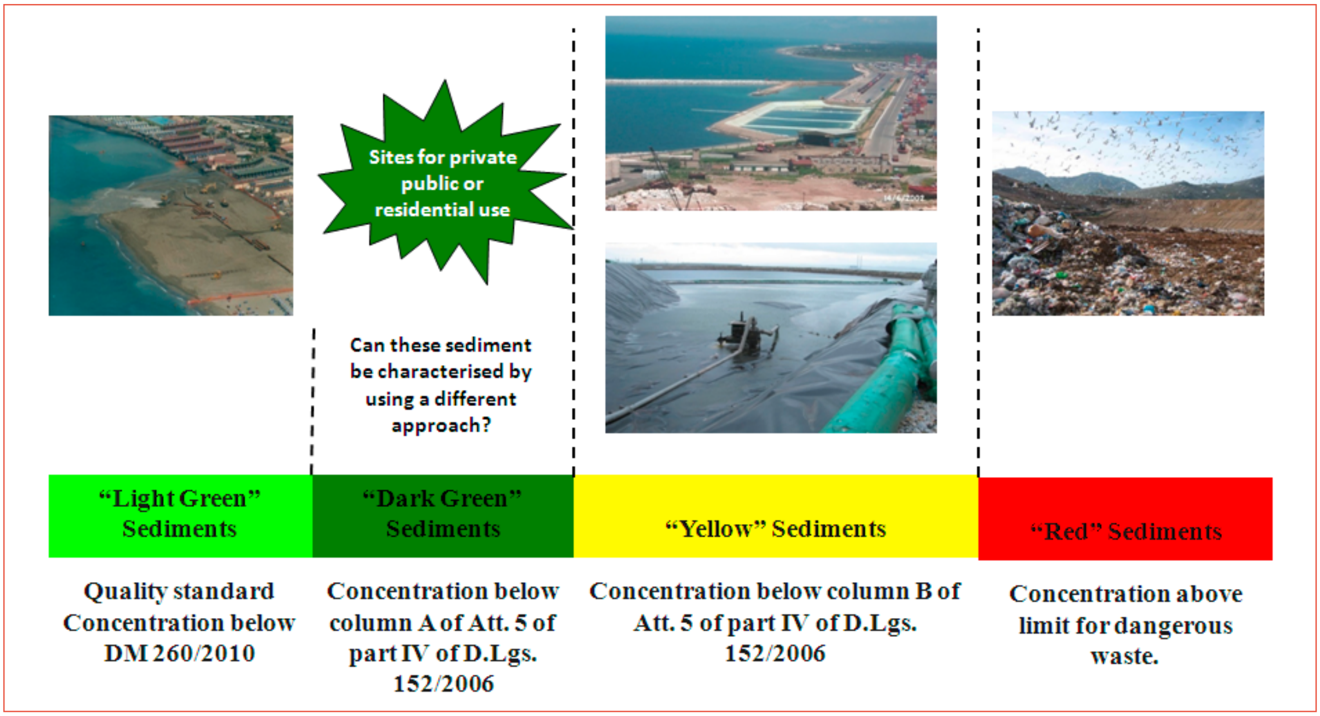

FIGURE 5 Frequent sediments management options in relation to different thresholds of contamination

Classification of sediments and management scenarios

Classification of sediments and management options are related to their level of toxicity and contamination. Usually three different colours are adopted to show with "green", "yellow" and "red" sediment dredged material that can be respectively used for beach nourishment, or disposed within Confined Disposal Facilities and landfill. In the present paper, a new "dark green" colour is adopted for sediment that shows contamination values between the quality standard suggested for coastal water directive (DM260/2010) and the contamination standard indicated by column A of Att. 5 of D.Lgs 152/2006. A schematic management option scheme is reported in Figure 5.

At the end of analytical investigation, the material has been classified by identifying exceedances of the thresholds for green areas and public housing. From available information a preliminary draft has been prepared, taking into account the outcome of various scenarios resulting from a more detailed environmental characterization. A detailed review of technologies available for the remediation of contaminated sediments has been conducted, and some of them were considered eligible for the case study. In the present paper, all the steps required to implement the dredging operations were considered, as follows:

1. Boundaries of the harbour;
2. Preparation of the characterization plan;
3. Sample collection;
4. Analytical investigations;
5. Processing of the obtained data;
6. Dredging and transport;
7. Storage and handling;
8. Checks of bottom depths after excavation;
9. Dredging of hot spots;
10. Cost-benefit analysis of different scenarios for sediment reuse.

Results

Conceptual model

The implementation of the conceptual model allowed to identify four potential sources of contamination, facing the harbour basin: the gas station in front of the quay, the Florio industries where tuna processing was performed, the *Camperia*'s building (where boats storage and maintenance was performed and, finally, a discharge of untreated wastewater. A flow diagram of conceptual model for contamination is reported in Figure 6.

Sediments characterisation

The characterisation of superficial sediments allowed to determine both physical and chemical properties of particles. The grain size revealed a percentage of silt and clay of about 1% and a D_{50} of approximately 0,215 mm (Figure 7). The analytical tests detected a moderate exceedance of limits, indicated in columns A and B of Annex 5 to Part IV of Legislative Decree no. 152/2006, for Cadmium, Arsenic, Lead, Tin, IPA and TBT. The exceedances have led to classify sediments with "yellow" color, i.e. with values of analytical tests that fall within the 90% limit imposed by the column 5 of Annex B to Part IV of Legislative Decree no. 152/2006 (Table 1) [15].

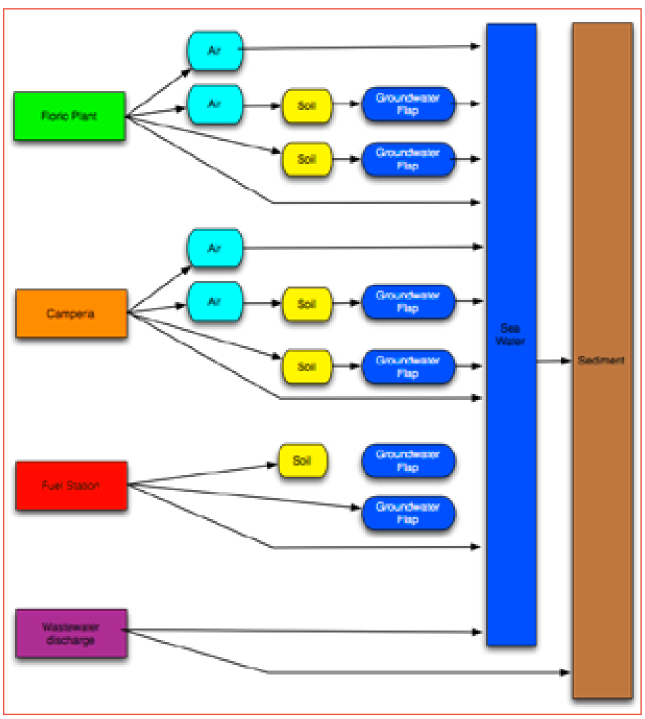

FIGURE 6 Conceptual model of contamination for sediments within Favignana's Harbour

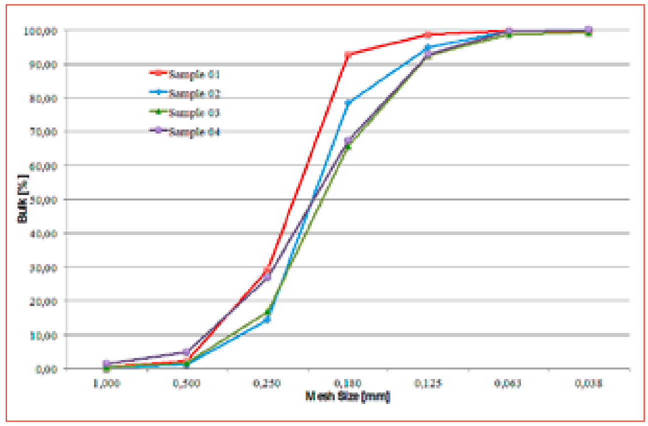

FIGURE 7 Cumulative grain size determined for each of the all 4 samples

Technical and economic analysis of remediation technologies

In the present work, the list of technologies considered are biological, physical-chemical and electro-thermal. The most common know-how is organised following the approach proposed by Bortone and Palumbo (2007), in order to identify the Best Available Technologies (BAT) for each different treatment approach. A summary of results is presented in Table 2, which shows the range of costs in €/m^3 and possible investment costs.

Classification of sediments and management scenarios

A preliminary project was prepared in order to allow the local authorities to allocate the necessary budget for dredging operations within Favignana's Harbor according to the procedures indicated by the national legislation (e.g. characterisation of sediment up to 1-2 m of depth). The project considered all phases of sediment removal and management, and particular attention was given to the presence of protected marine species, such as *Posidonia oceanica* meadow. Therefore, two options were identified, considering different volume

		Sample 1	Sample 2	Sample 3	Sample 4
Arsenic (As)	(mg/kg)	16,0	10,0	15,0	15,0
Cadmium (Cd)	(mg/kg)	1	1,0	1,0	1,0
Chromium (Cr)	(mg/kg)	3,1 ± 0,3	3,5 ± 0,2	3,4 ± 0,2	3,5 ± 0,2
Copper (Cu)	(mg/kg)	4,5 ± 0,3	6,7 ± 0,1	3,6 ± 0,3	4,0 ± 0,1
Mercury (Hg)	(mg/kg)	0,014 ± 0,2	0,015 ± 0,2	0,015 ± 0,2	0,013 ± 0,2
Manganese (Mn)	(mg/kg)	24,3 ± 0,7	25,1 ± 0,4	22,1 ± 0,5	22,2 ± 0,5
Nichel (Ni)	(mg/kg)	4,0	3,0	3,0	7,0
Lead (Pb)	(mg/kg)	51,9 ± 3,9	27,3 ± 3,7	24,1 ± 4,2	16,8 ± 1,9
Pond (Sn)	(mg/kg)	7,0	13,0	7,0 ± 1,3	10,0
Zinc (Zn)	(mg/kg)	5,5 ± 0,1	5,3 ± 0,2	5,4 ± 0,2	6,1 ± 0,1
Σ PCB	(mg/kg)	0,00188	0,00168	0,00198	0,00314
Hydrocarbons > 12	(mg/kg)	20,50	17,90	14,10	15,10
TBT	(mg/kg)	0,013	0,002	0,003	0,002
Naphthalene	(mg/kg)	0,02047	0,01934	0,05532	0,00172
Acenaphthylene	(mg/kg)	0,00366	0,00317	0,01107	0,00033
Acenaphthene	(mg/kg)	0,00266	0,00157	0,00201	0,00280
fluorene	(mg/kg)	0,00466	0,00548	0,03512	0,00203
Phenanthrene	(mg/kg)	0,08615	0,08095	0,95973	0,04596
Anthracene	(mg/kg)	0,02237	0,02621	0,31414	0,01595
Fluoranthene	(mg/kg)	0,15712	0,19309	1,38100	0,08831
Pyrene	(mg/kg)	0,12960	0,16220	1,21418	0,07168
Benzo (a) Anthracene	(mg/kg)	0,08118	0,11568	0,49921	0,05538
Chrysene	(mg/kg)	0,08605	0,12345	0,50628	0,06198
Benzo (b) Fluoranthene *	(mg/kg)	0,10484	0,13916	0,57700	0,07399
Benzo (k) Fluoranthene	(mg/kg)	0,04437	0,06000	0,22512	0,03077
Benzo (a) Pyrene	(mg/kg)	0,11939	0,15600	0,80023	0,07965
Indeno (1,2,3-c, d) Pyrene	(mg/kg)	0,05606	0,06779	0,31878	0,03753
Dibenzo (a, h) Anthracene	(mg/kg)	0,01749	0,01837	0,06260	0,01053
Benzo (ghi) Perylene	(mg/kg)	0,05075	0,06078	0,28455	0,03356
Σ PAH	(mg/kg)	**0,98682**	**1,23324**	**7,24635**	**0,61218**

TABLE 1 Concentration of contaminant determined in samples

of sediment to be dredged (option 1: 22,000 m^3; option 2: 12,400 m^3), different level of contamination ("green" or "yellow" sediments), and possible presence of about 50% in volume of biomass buried below the sandy seabed [16, 17]; Figure 8.

Subsequently, four management scenarios based on beneficial reuse of sediments were predicted; all of them exclude landfill disposal. For each management scenario, a cost-benefit analysis was prepared, considering several information and results of specific quotation in order to determine reliable costs of:

- Characterisation, (characterisation plan, sampling, analysis and data elaboration);
- Dredging (mob de-mob, turbidity curtains, monitoring and after-dredging analysis);
- Transport (capacity load of trucks, daily rent of vehicles and number of trips);
- On-shore deposit (preparation, impermeabilisation);
- Treatment (soil washing, land farming);
- Other costs (safety, taxes and unexpected costs).

So, the following scenarios were identified in order to have an economic, social and environmental advantage (Figure 8). They can be briefly described as follows:

A - Sport Facilities: execution of an area dedicated to sports activities, such as beach volley and/or beach soccer;

B - Coastal restoration: accommodation of sediments at the cliff's foot along 110 m of back shore;

C - Harbour layout: building of a Confined Disposal Facilities (CDF) in order to spill over the dredged contaminated sediments and enlarge the current Harbour layout;

D - Sediment sale: sale of dredged sediments to proper industrial sectors.

Discussion

Dredging within Favignana's Harbour is periodically needed to ensure the safety of navigation and an adequate depth through time. With the present layout, the entrance to the harbour is often compromised by

TECNOLOGY		€/m³ in situ	Investment costs	Notes
Relocation (incl. dredging, transport, disposal)		1,5-5		
Capping		4-6		
Up-land disposal	Outdoor	10-75	Isolation, added mat	Depend on scale and local taxes
	CDF	8-36		
Mechanical dewatering Belt press /Filter press (incl. Waste Water Treatment)	Belt press / Filter press	7-31	Equipment	Fixed installation
		9-42	Equipment	Mobile installation
Geotubes		4-13	Equipment	Excl WWT
Sand separation (>50% sand)	Settling basins	1-8		Exc dewatering
	Hydrocyclones	3-11	Equipment	Excl dewatering, disposal fines, Waste Water Treatment
		7-26		Including dewatering and Waste Water Treatment
METHA treatment (incl capital cost and personal)		18	Equipment	Large scale and long term
Active lagooning and ripening		10-25	Equipment, land	
Landfarming		5-15	Land	
Bioreactor		50-100	Equipment	
Artificial Cement		35-50	Equipment, added mat	
In situ immobilisation/stabilisation		60-100	Equipment, added mat	SSI
In situ consolidation		10-20	Equipment	Vacuum with horizontal drain
Thermal desorption		25-45	Equipment, Energy	Excl dewatering
Chemical extraction		55-150	Equipment, added mat	
Thermal immobilisation (incl. treatment)		16-58	Equipment, energy	Without product valorisation
Washing	With chemical additives	45-70		
	Without chemical additives	10-20		

TABLE 2 Cost of main treatment technologies and investment. Modified from Bortone and Palumbo [10]

the waves and their propagation within the basin, particularly during Mistral winds. Navigation is limited, especially close to the docks, due to sand transport under the effect of anticlockwise circulation that reduces the depth of the seabed to the extent that some emerging beach can be observed during wintertime. To solve this problem, two strategies can be followed.
The first one is a structural modification of the harbour layout, changing the position and the extension of the present piers, which would modify the water circulation (i.e. oxygenation), but would probably create significant impacts on the *Posidonia oceanica* meadow. In case of damage, a compensation strategy should be planned (see Cappucci *et al.*, this volume), but on the other hand the dock surface and the number of vessels would be increased.

The second approach is to plan maintenance through periodic dredging operations around the dock of *Cala Principale*. In both cases, particular attention is required to protect the *Posidonia oceanica* meadow and marine life during dredging by using turbidity curtains.
The four classes considered in Figure 3 and Table 1 are better described as follows:

1. "Light green" - this material can be beneficially used for beach nourishment or other intervention along the coast, in direct contact with the seawater as no contaminants are found and all concentration are below the thresholds indicated for quality standards of marine coastal water.
2. "Dark green" - These sediments have concentration levels higher than the limit of intervention, but lower than the thresholds of private public or residential sites. Seabed dredging is not mandatory, but in case of removal they should not be in direct contact with the seawater.
3. "Yellow" - These sediments have concentration values between private, public or residential sites and industrial areas. They should be dredged urgently and disposed within Confined Disposal Facilities (CDF).
4. "Red" – These sediments are highly contaminated and concentration values are above the limit for dangerous waste. Immediate removal should take place to avoid transfer of contamination from the seabed to the water column, flora and fauna. Subsequent disposal should be guaranteed according to current legislation.

Due to the low level of contamination determined in the present study (Table 1) and the volume to be dredged (Figure 6) the overall cost for interventions is expected to be between ~50.000 € and ~1 Ml €, depending on the extent of treatment to be adopted (soil washing, dewatering, land farming, desalination). The results of this preliminary work allowed ENEA to propose three possible types of interventions on the territory (Figure 9): Sports facilities; Coastal restoration; Harbour (scenarios A, B, C of Figure 8), as we assumed that the large part of dredged material will be classified as dark green sediment. Sediment sale has not been considered due to the heterogeneity of physical and chemical characteristics.

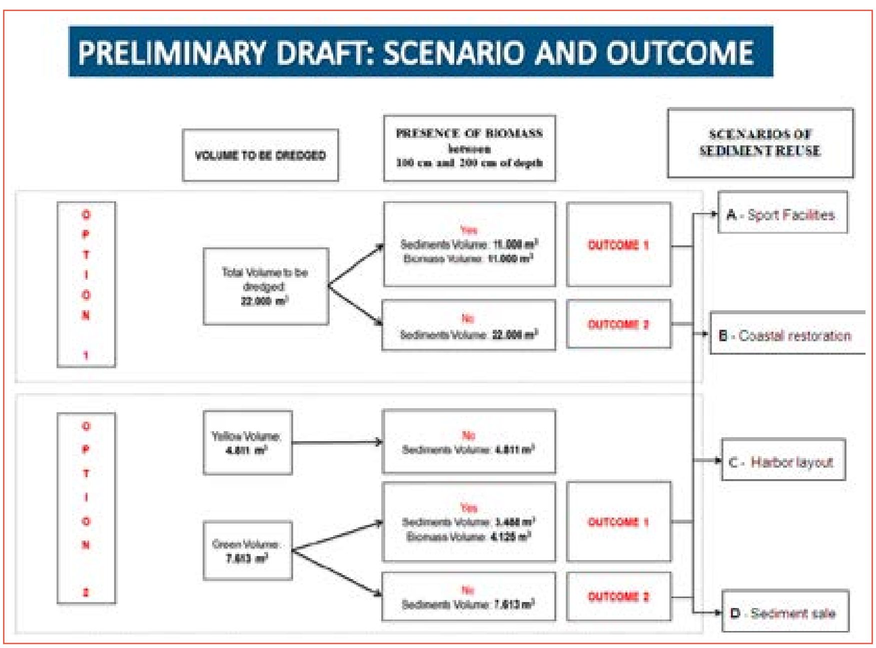

FIGURE 8 Schematic flow diagram which describes the possible options of contamination, subsequent dredging volume and management scenarios

Conclusions

Handling, treatment and reuse of sediments are topics that encompass many disciplines, which are necessary for the successful implementation of the dredging operations aimed at a beneficial reuse of sedimentary natural resource. Therefore, the regulatory framework is very complex. The Italian legislation is continuously evolving, but still does not consider risk analysis as a decision tool for dredging the contaminated sediment. Law no. 27 of 24th March 2012 sets out the criteria for the classification of sediments and their possible reuse or disposal. These changes and the Ministerial Decree of 7th November 2008 offer a more comprehensive regulatory

A. Sport facilities B. Coastal restoration C. Harbor layout

FIGURE 9 Pictures of some of the management options chosen in relation to the volume and quality of sediments to be dredged from Favignana's Harbour

framework for contaminated sites, but areas outside the contaminated sites of national interest still require a specific attention, as specified by § 8, art. 48 of the Italian Legislative Decree of 24th January 2012 [7]. In Favignana, where the Marine Protected Area is almost uncontaminated, dredging of sediment from the Harbour whit low contamination levels is necessary to facilitate sailing. Following the presentation of the preliminary results obtained in the present study, the local authorities showed interest in the following management scenarios:

a) nourishment along the coast; these sediments should be classified with a "light green" color, due to concentration levels similar to those indicated for the quality standard of marine waters;
b) on-shore recreational activities like soccer and beach volley fields; these sediments should be classified with a "dark green" color, due to concentration of contaminants below the thresholds indicated for public and private soils, and chlorides should be previously reduced to avoid aquifer salinization.

Both of them were appositely designed to favor the reuse of sand after treatment and to increase the amount of goods and tourism services. The possibility to realized beach nourishment will be strongly influenced by eco-toxicology behavior and the presence of the *Posidonia oceanica* meadow in shallow water (close to the shore line and within the active zone of the submerged beach), meanwhile the low level of chemical contamination (PAH) is promising for dredged sand to be reused on shore after reduction of salt content.

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Coastal morphology and dynamics of two beaches of Favignana

Results of an investigation on the coastal morphology and dynamics of two pocket beaches of Favignana, Cala Azzurra and Lido Burrone, are presented. Four detailed hydrographic surveys were performed using multibeam echo sounder with sidescan sonar and differential marine GPS. Surveys were repeated in different periods following the same navigation project. Moreover, incident wave climate and coastal hydrodynamics were investigated using state-of-the-art numerical models. Results of in-situ activities indicate little bathymetric variations among different surveys and suggest a substantial stability of submerged beach profiles limited to surveyed area.
Slightly greater bathymetric changes and a generally more intense coastal dynamics were observed at Cala Azzurra compared to Lido Burrone. Simulations of wave propagation and nearshore circulation currents provided results consistent with field observations

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Introduction

Favignana is the major of the Aegadian Islands (Figure 1), where tourism pressure is concentrated the most. The marine area surrounding the islands presents an extraordinary biodiversity and the largest *Posidonia oceanica* meadow in Europe; in 1991, the area was declared Marine Reserve to preserve its fragile and valuable natural resources.
The coastline of Favignana island is about 32 km long and is composed of an extremely large extent of rocky shores. A very limited number of small sandy beaches is present, mainly along the south-eastern coast of the island; the present study focuses on Cala Azzurra and Lido Burrone beaches, much appreciated by tourists and having a high landscape and economic value.
As regards coastal morphology, both sites show the typical features of a pocket beach, i.e. a pebbly or sandy beach confined in plan by two bedrock headlands [1, 2]. The exchange of sediment between a pocket beach and the adjacent shores due to long-shore transport is generally little, depending on the incident wave climate and seaward extension of the headlands. When

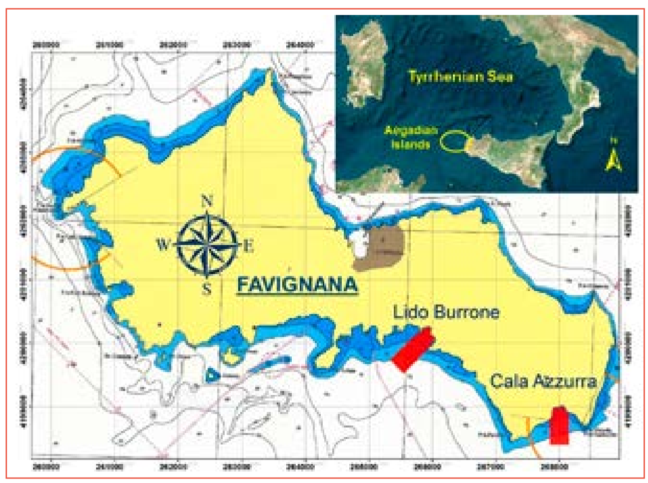

FIGURE 1 Geographic setting of study areas (coordinate system UTM33N-WGS84)

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the closure depth of the site (i.e., the maximum water depth of significant sediment transport, depending on wave climate) is located within the headlands, long-shore sediment exchange is negligible. In this case, the pocket beach can be regarded as a closed sediment cell, where sediment supply to the beach is essentially due to shoreward cliff erosion (if comprised of soft rock), or stream discharge (if present).

A large body of literature exists on the dynamics of pocket beaches [3, 4, 5, 6, 7, 8]. As regards plan-view geometry, a number of planform parameters and ratios are used in literature to describe and classify the coastal morphology and estimate the equilibrium status of the beach [9]. Due to the limited sediment transport at ends, the coastline generally tends to align itself with prevailing incident wave fronts, assuming a typical seaward concave plan shape that can be approximated by a logarithmic spiral or different mathematical functions. The resulting coastline configuration, corresponding to ideal conditions of stability, is a classical and appreciated conceptual scheme for coastal stabilization projects. The coastline orientation – i.e. the orientation of the line connecting the edges of the beach – is a typical parameter used to empirically describe coastline adaptation to incident waves. In general, if coastline orientation is aligned with the line connecting the headlands of the bay, a relative stability of the beach is to be expected, while coastline rotation can be regarded as a morphological response to changes in approach angles of prevailing incident waves. Assuming a substantial stability in terms of long-shore sediment processes, the dynamics of a pocket beach is frequently dominated by cross-shore modelling of beach profile. As well established in literature [10, 11, 12], for a given profile geometry and sediment grain size, cross-shore modelling can result in beach accretion or erosion depending on incident wave conditions. In case of high energy incident waves, offshore sediment transport (destructive forces) prevails, resulting in coastline retreat; on the contrary, with milder wave activity, the onshore transport (constructive forces) prevails and the result is a coastline advance (Figure 2). Cross-shore modelling processes are generally reversible, and the effects are alternations between two typical beach profile shapes, referred to as "storm", "winter" or "bar-type" profile, and "ordinary", "summer" or "berm-type" profile, respectively [13, 14].

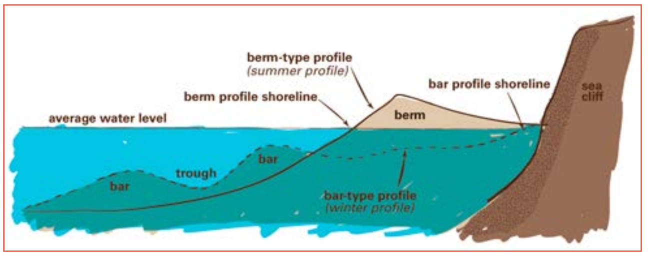

FIGURE 2 Typical features of cross-shore beach profile modelling
Source: Exploring Florida. A Social Studies Resource for Students and Teachers, University of South Florida

Sometimes, however, beach changes can be permanent and non-reversible. This occurs when sediment supply from the backshore is reduced or interrupted, typically for man-induced causes as land-use change, modification of hydrographic network, sediment extraction from riverbed, destruction of dunes, construction of seawalls and other hard structures [15, 16, 17]. Other possible cases of barely reversible beach changes can be due to sediment delivered by streams during extreme flood events, as reported for the Elba Island, [18, 19]. These are not the cases in Favignana, given the absence of an organized river network.

In the framework of a wider research program, an extensive investigation of coastal morphology and dynamics was performed at Cala Azzurra and Lido Burrone sites during the period 2012-2014. First results of the work, including an outline of materials and methods and partial data analysis, have been synthetically presented in a previous paper [20]. Besides any scientific interest, the results of the projects will contribute to create a knowledge base aimed to implement measures for sustainable tourism and management of marine resources.

Materials and methods

Hydrographic surveys

Four hydrographic surveys were performed at Cala Azzurra and Lido Burrone, in the following periods: November 2012 (Survey 1), July 2013 (Survey 2), September 2013 (Survey 3), and May 2014 (Survey 4).

The temporal planning of surveys was defined in order to

describe the seasonal variability of the beach morphology as completely as possible, compatibly with the timetable of the project and suitable sea and weather conditions.
Survey equipment and instrumentation are listed below:

- Multibeam echo sounder with sidescan sonar Odom Echoscan (30 beams, acoustic frequency 200 kHz, swath angle 90°);
- Marine Differential GPS Trimble SPS461, dual antenna, for position and heading measure;
- Trimble HydroPro software for survey planning and navigation;
- Communication Technology GeoPro/SwanPro software for multibeam and sidescan sonar data acquisition;
- Triton BathyPro, Triton ISIS Sonar and Golden Software Surfer software for data processing and presentation.

Figure 3 shows some of the above listed resources.
As regards compensation of measurement errors, the echo sounder is provided with a Teledyne TSS dynamic motion sensor (DMS) for random errors due to heave, pitch and roll. The heading information for yaw compensation is obtained by simultaneous GPS acquisition at two antennas aligned along the main axis of the vessel. Patch tests [21] were performed per each operation day, to compensate the systematic errors due to mounting offsets of the transducer.

Survey vessel and personnel for marine operations were provided by the Marine Reserve Management Authority (*Area Marina Protetta Isole Egadi*). The transducer was mounted at the port side of the vessel, using a flange pole and an *ad-hoc*-designed steel framework.
As regards the navigation project, survey lines normal to the shoreline were adopted, oriented to North for Cala Azzurra and 45°N for Lido Burrone, respectively. Line spacing was defined, considering the multibeam swath angle, in order to obtain, at nominal depth of 10 m, a 100% bottom coverage with 50% overlap between parallel consecutive swath lines. Overall, 30 transects were adopted for both sites, with 10 m line spacing. The orientation and spacing of survey lines is the result of an optimal compromise between swath angle and resolution of the instrument, maneuverability of vessel and safety of navigation, and allowed to maximize the surveyed area, also considering the bottom morphology and the presence of rocks and other obstacles in the nearshore zone.
The offshore limit of navigation lines was planned in order to extend the survey beyond the depth of closure d_c of the active beach that, according to Hallermeier [22], can be estimated as follows:

$$d_c = 2.28\,H_s - 68.5\frac{H_s^{\,2}}{g\,T_s^{\,2}}$$

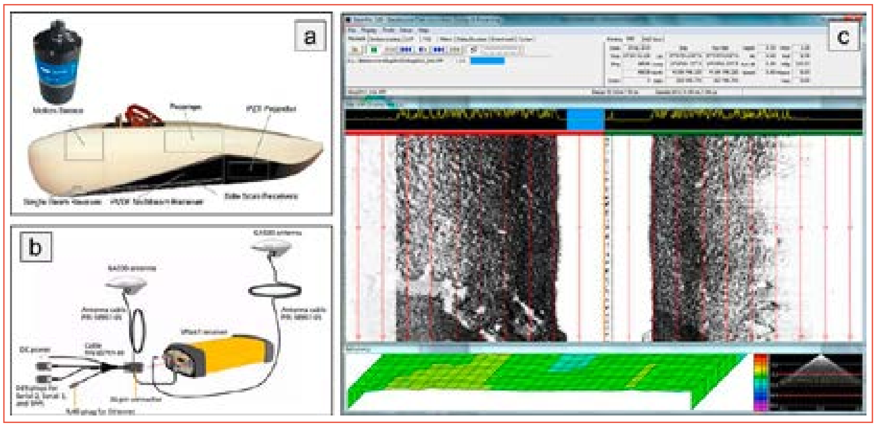

FIGURE 3 Main resources used for hydrographic surveys. a) Multibeam and sidescan sonar transducer with dynamic motion sensor. b) Marine DGPS dual antenna for position and heading. c) Example of multibeam echo sounder and sidescan sonar data acquisition during survey operations

In the above formula, g is the gravitational acceleration, while H_s and T_s are, respectively, the significant wave height and period representative of incident wave conditions exceeded only 12 hours per year (exceedance probability 0.137%).
Based on the statistical analysis of incident wave climate discussed in the next section, the values $H_{s(12hr)}$=4.55 m and $T_{s(12hr)}$=9.28 s were derived, resulting in a depth of closure d_c=8.70 m.
A well-established extension of the Hallermeier formulation is to relate the depth of closure

FIGURE 4 Satellite view of Cala Azzurra and Lido Burrone sites and cross-shore survey lines

to storm wave conditions associated to a given recurrence frequency or return period, based on the analysis of extreme events [23, 24]. In the present study, a 25 years return period was adopted and, following Gumbel's distribution, values of H_s=6.21 m, T_s=10.39 s were estimated, resulting in a depth of closure d_c=11.66 m.

Based on the above considerations, survey lines were extended in the offshore direction beyond a depth of about 12 m, according to the available nautical charts provided by the Hydrographic Institute of Italian Navy. In Figure 4, the navigation projects are shown for each site; survey lines are numbered from CA01 to CA030 toward East for Cala Azzurra and from LB01 to LB30 toward South-East for Lido Burrone. The average length of the transects is 500 m at Cala Azzurra and 700 m at Lido Burrone.

Bathymetric data were processed using BathyPro and Surfer software. Post-processing tools and data filters were applied for error compensation and spike detection. Then, using algorithms for spatial interpolation, digital models of the sea bottom were built, with grid spacing consistent with spatial density of data. Finally, beach profiles, contour maps and 3D surface were derived for presentation of data and further elaborations.

All data were projected and presented in the UTM33N-WGS84 coordinate system.

Wave climate and coastal hydrodynamics investigation

Incident offshore wave climate, nearshore wave conditions and wave-induced coastal circulation at study areas were investigated using available wave data and mathematical models.

The offshore wave climate was derived from historical data measured from July 1989 to March 2008 at Mazara del Vallo recording station of the Italian Sea Wave Measurement Network [25]. Wave data were transferred to a virtual buoy located off Cala Azzurra and Lido Burrone sites, at 100 m depth. At this aim, a geographic transposition method [26] was used, based on comparison among effective fetches measured, respectively, at real and virtual station. Offshore wave data were processed to estimate mean annual wave climate, in terms of joint occurrence frequency of wave height and direction. A statistical analysis of extreme waves was also performed to derive sea state parameters associated to different values of the return periods, based on suitable probability distribution functions.

Offshore wave conditions were transferred shoreward using state-of-the-art numerical models. Namely, different modules of MIKE 21 suite (DHI Water & Environment) were applied to simulate wave refraction, diffraction, breaking and to evaluate radiation stress components [27, 28]; finally, using the two-dimensional, depth-averaged hydrodynamic module [29], the surface elevation and nearshore currents due to incident waves were simulated.

Numerical simulations were performed using interpolated bathymetric grids with different resolutions, considering the model formulation, spatial data density, required accuracy and computational effort. Offshore bathymetry was derived by the official nautical charts provided by the Hydrographic Institute of Italian Navy, whereas survey data were used for detailed simulations in the nearshore shallow water zone.

Results and discussion

Macro features of coastal morphology and dynamics

From general observation of beach morphodynamics at Cala Azzurra and Lido Burrone site, some qualitative differences can be noticed.

As regards Cala Azzurra, two small sandy bays can be observed in Figure 4 (hereafter referred to as "western bay" and "eastern bay"), separated by a central rocky headland. Emerged beach is flat and narrow, with a maximum width of about 8 m at western bay and 12 m at the eastern bay. In order to reduce the risk of landslides, the entire backshore slope is protected by a geotextile net revetment, with a significant reduction in sediment supply to the beach. Moreover, at the western bay, a quarry stone seawall is present at the toe of the slope, increasing wave reflection onshore.

As historically reported and observed during the monitoring project, the impact of wave storms on Cala Azzurra beach can induce severe modifications (Figure 5), with huge coastline retreat and, sometimes, with complete disappearance of the emerged beach at western bay, where changes can take place in very short times (days or even hours).

As regards Lido Burrone, two coves can be distinguished just as for Cala Azzurra (Figure 4), but here emerged beach is present only at the south-eastern side; the emerged beach is relatively flat, with a width comprised between about 10 m at ends and 30 m in the middle. Based on historical reports and direct observations, the effects of coastal modelling due to waves impact are generally milder compared to Cala Azzurra, with rather limited coastline retreat and noticeable beach width even under severe wave conditions (Figure 6).

At both sites, sediment samples were collected in the emerged and submerged beach. Results of grain size analysis indicate little

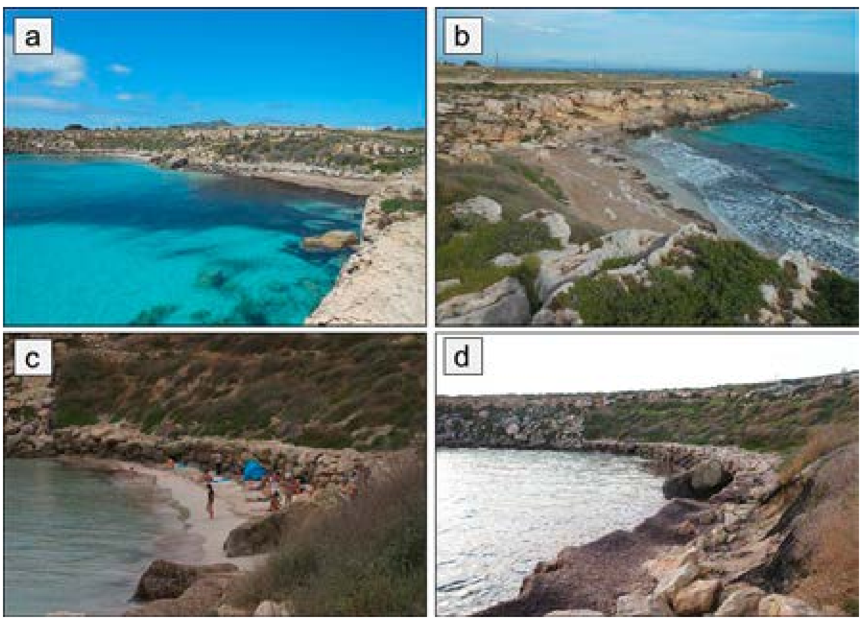

FIGURE 5 Cala Azzurra. a) Overview of the site; the western beach on the left and the eastern bay on the right are visible in the picture. b) View of the eastern bay. c) View of the western bay, with emerged beach (May 2012). d) View of the western bay, with beach completely eroded (November 2012)

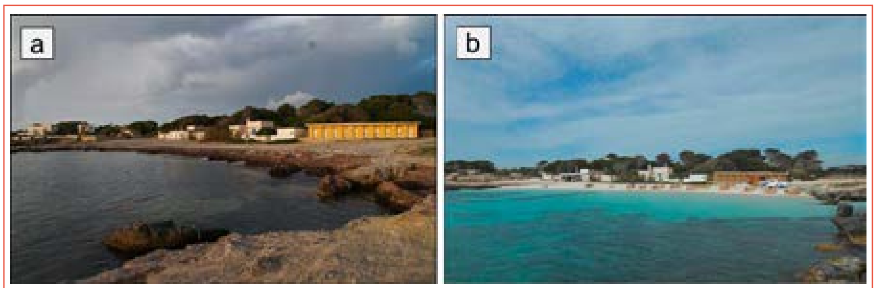

FIGURE 6 Lido Burrone beach. Picture a was taken in late autumn (November 2012), picture b in spring (May 2014). A huge amount of Posidonia oceanica banquettes is visible at the shoreline in picture a, owing to high energy incident waves; however, the emerged beach maintains a noticeable width

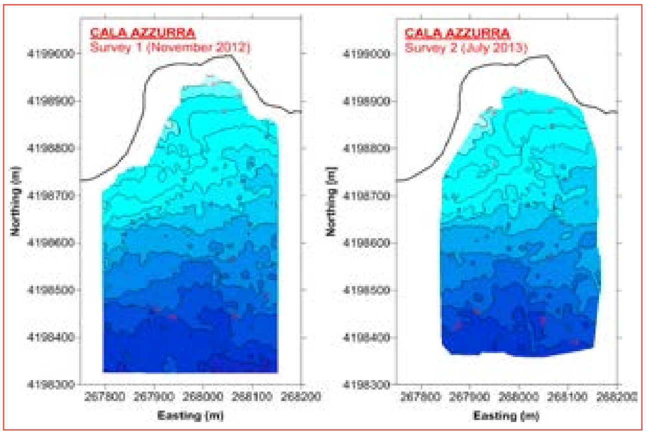

FIGURE 7 Bathymetric maps of Cala Azzurra derived from Survey 1 and Survey 2 data

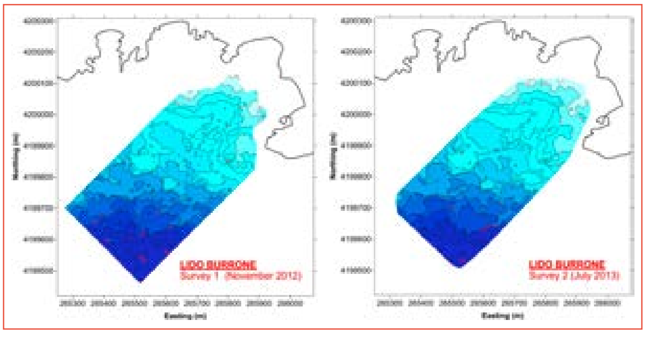

FIGURE 8 Bathymetric maps of Lido Burrone derived from Survey 1 and Survey 2 data

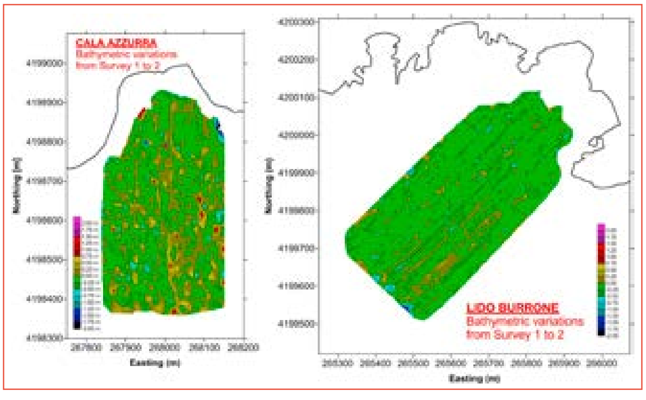

FIGURE 9 Bathymetric variations estimated from Survey 1 to Survey 2

variations in median grain diameter d_{50} along beach profile and little difference between the two sites. So, as an approximation, consistently with the purpose of the present work, a constant value of d_{50}=0.20 mm was assumed for both Cala Azzurra and Lido Burrone beaches.

Bathymetry of submerged beaches

Based on survey data, a quite complex morphology of submerged beach was observed at both sites. Mean slope of submerged beach can be estimated as 2.5% at Cala Azzurra and 1.8% at Lido Burrone.

For example purpose, bathymetric contour maps derived from surveys 1 and 2 are plotted in Figures 7 and 8. Depending on instruments operation and safety of navigation, the minimum investigated depth is about 1.5-2.0 m.

Examples of bathymetric changes estimated by two consecutive surveys are plotted in Figure 9. Positive bathymetric variations indicate sediment deposition, being the opposite for bottom erosion. To a large extent, slight bathymetric variations can be noticed between the surveys at both sites, whereas only in a few limited areas bathymetric changes of 1 m in absolute value can be observed. Overall, Cala Azzurra showed greater bathymetric variations than Lido Burrone. Similar results were obtained comparing data from the other surveys.

However, for a correct interpretation of results, considering the various sources of uncertainty in data acquisition and processing, bathymetric differences lower than 0.30 m in absolute value should be regarded as negligible.

In Figures 10-13, beach profiles extracted from measured data at selected cross-shore transects are plotted. As regards Cala Azzurra, profile CA09 is representative of the western bay, whilst CA21 corresponds to the eastern bay. As regards Lido Burrone, profile LB10 is taken near the North-West end of the site, where emerged beach is absent, whilst LB23 corresponds to the part of the bay where emerged beach is present.

As already observed from contour maps, submerged beach has a quite complex geometry and bathymetric changes among different surveys are relatively small. In particular, survey data do not seem to indicate a clear seasonal regime of submerged beach profiles.

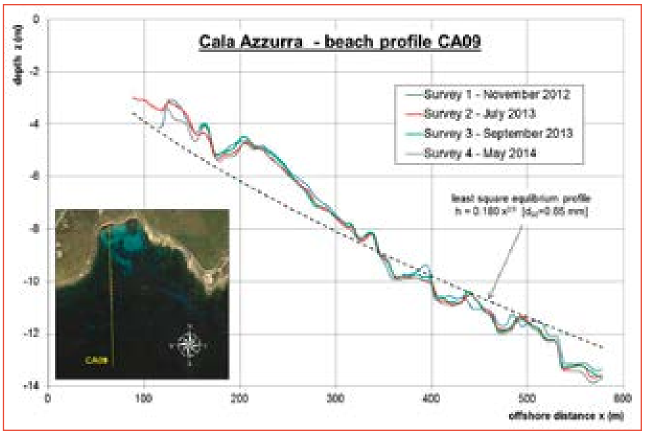

FIGURE 10 Cala Azzurra, transect CA09. Surveyed beach profiles and theoretical equilibrium profile

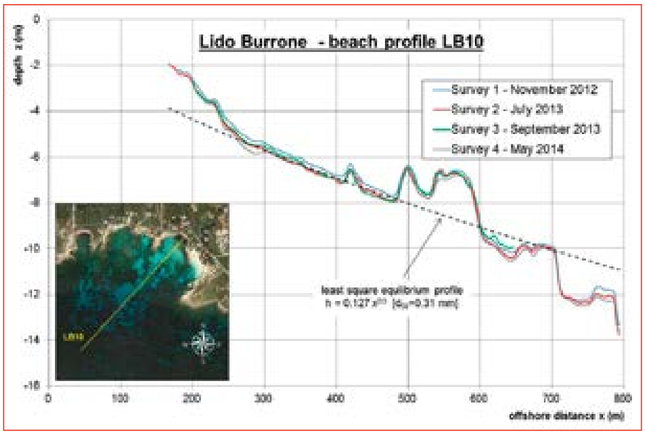

FIGURE 12 Lido Burrone, transect LB10. Surveyed beach profiles and theoretical equilibrium profile

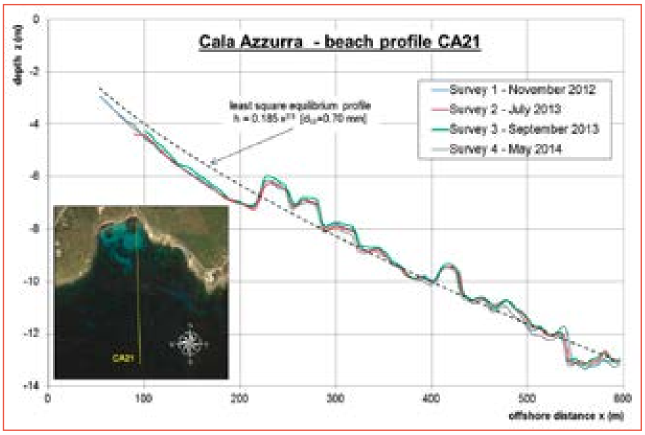

FIGURE 11 Cala Azzurra, transect CA21. Surveyed beach profiles and theoretical equilibrium profile

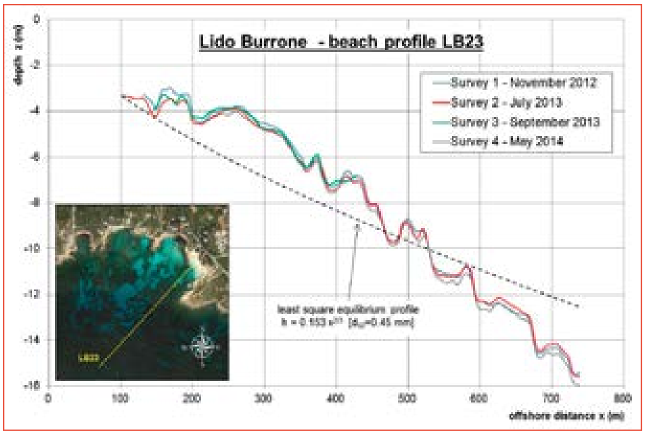

FIGURE 13 Lido Burrone, transect LB23. Surveyed beach profiles and theoretical equilibrium profile

For each of surveyed transects, theoretical equilibrium profiles which best fit measured data were derived using the least squares method. In the ideal case in which there is no net cross-shore sediment transport, i.e. same magnitude of constructive and destructive forces, beach profile tends to assume a concave configuration, classically described by Dean [30] with a power function:

$$h = A \cdot x^{2/3}$$

where *h is* the water depth, *x* is the offshore distance from shoreline and *A* is a scale parameter that increases with sediment size. The use of equilibrium profile to compare measured data is to be considered as a first approximation, consistent with a qualitative description of the coastal morphology and dynamics. Main criticisms to this approach can be: (a) the equilibrium profile concept is applicable to uniform sandy beach profile, disregarding the possible presence of rock and differences in seafloor coverage, and (b) the Dean formulation can be considered to progressively become less realistic as the depth of submerged profile increases (i.e., starting from 6 m depth).

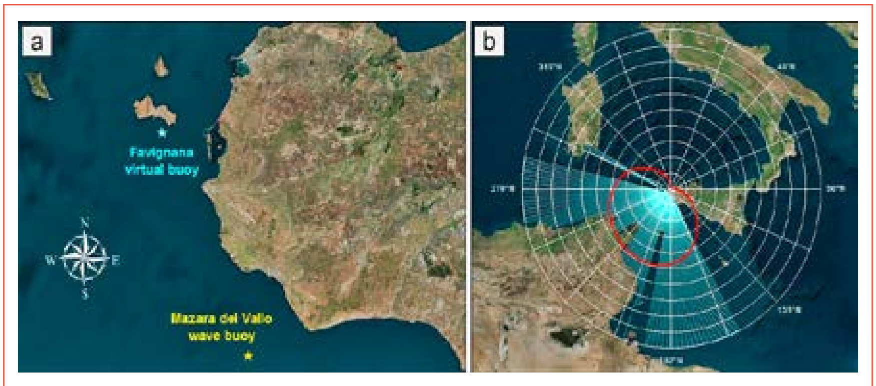

FIGURE 14 a) Positions of the real and virtual stations used for geographical transposition of wave climate. b) Polar plots of geographic and effective fetches at virtual buoy off study areas

Considering all the above considerations, for all surveyed profiles, the best-fit values of scale parameters *A* were estimated; all values correspond to ideal values of d_{50} greater than that of the actual sediment (0.20 mm). Limited to the only sections of coast where emerged beaches are present, theoretical mean values of d_{50} can be estimated as 0.68 mm at Cala Azzurra western bay, 0.72 mm at Cala Azzurra eastern bay and 0.47 mm at Lido Burrone beach.

Considering the minor bathymetric variations observed during the project period, results seem to suggest an overall stability of the submerged beach profile greater than that expected from the actual sediment size distribution. It can be reasonably hypothesized that this is due to presence of rock or to the stabilizing effect of *Posidonia oceanica* on the sea bottom, though more investigations are needed to confirm this hypothesis.

In particular, it should be necessary to investigate in detail the nature of sea bottom materials and its coverage and further extend measures in the emerged beach and in the nearshore zone, where intense sediment dynamics is to be expected.

Wave climate and coastal hydrodynamics

In Figure 14, the positions of Mazara del Vallo wave buoy and Favignana virtual buoy used for geographic transposition of wave data are plotted. In the same Figure, polar graphs of geographic and effective fetches estimated at virtual buoy are shown; the highest values of geographic fetch are comprised in the directional sectors 150-190°N and 260-290°N. A rose plot of the offshore annual wave climate derived from geographic transposition is depicted in Figure 15. Two directional sectors for prevailing incident waves can be distinguished: the first comprises the south-eastern quadrant, whilst the second is centered on south-western direction.

Considering the coastline geometry and orientation, it can be assumed that only the waves comprised in the sector 120-300°N are likely to propagate shoreward and reach the study areas. Based on the above considerations, the directional sector can be divided in two prevailing

Directional sector	Relative frequency	Direction of mean annual wave energy flux
120-300°N (complete sector)	100%	250°N
120-180°N (SE sector)	30%	158°N
190-300°N (SW sector)	70%	257°N

TABLE 1 Main offshore wave climate parameters

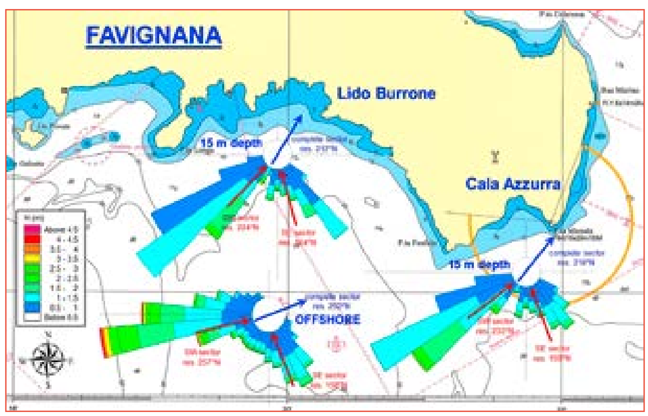

FIGURE 15 Rose plots of estimated offshore annual wave climate and wave climate obtained by simulation of wave propagation at Cala Azzurra and Lido Burrone sites (reference depth 15 m)

waves sub-sectors, namely the sector 120-180°N, with 30% relative occurrence frequency, and the sector 190-300°N, with 70% relative occurrence frequency. For both the complete sector and each sub-sector, the resultant vector of offshore annual wave energy flux was evaluated; results are summarized in Table 1. Based on the direction of annual wave energy flux, the above directional sub-sectors were referred to as SE sector and SW sector, respectively.

Offshore waves were transferred shoreward using different numerical models. First, MIKE 21 NSW (Nearshore Spectral Waves) module was applied to simulate wave propagation from deep water to intermediate depth off the Cala Azzurra and Lido Burrone site. Bathymetry was derived by available nautical charts. Considering the spatial resolution of data and the formulation of the model, rectangular grids with $\Delta x=30$ m and $\Delta y=100$ m were adopted for simulations, with x-axis directed shoreward.

For example purpose, Figure 16 illustrates one of the simulations performed for offshore wave direction 260°N. It can be observed that the wave fronts rotate due to refraction. Results of all simulations are condensed in the rose plots of wave climate at 15 m reference depth, shown in Figure 15. Consistently with wave refraction and with coastline and bathymetry configuration, a general wave height reduction and rotation of wave direction southward are noticed; the sheltering effects of headlands for waves propagating from the western quadrant is also evident, especially at Lido Burrone.

FIGURE 16 Example of wave propagation from deep water toward study areas. Vectors indicate the wave direction. Offshore wave direction is 260°N

Offshore directional sector	Relative frequency	H_m (m)	T_m (s)	Direction of mean annual wave energy flux
120-300°N (complete sector)	100%	1.01	5.17	219°N
120-180°N (SE sector)	30%	0.83	5.26	159°N
190-300°N (SW sector)	70%	1.04	5.53	233°N

TABLE 2 Main results of wave propagation at Cala Azzurra site (15 m depth)

Offshore directional sector	Relative frequency	H_m (m)	T_m (s)	Direction of mean annual wave energy flux
120-300°N (complete sector)	100%	0.96	5.37	212°N
120-180°N (SE sector)	30%	0.86	5.11	161°N
190-300°N (SW sector)	70%	1.00	5.46	224°N

TABLE 3 Main results of wave propagation at Lido Burrone site (15 m depth)

As a general observation, compared to Lido Burrone more intense wave conditions can be estimated at Cala Azzurra.

For each sector of offshore wave direction, resultant vectors of mean annual wave energy flux at 15 m depth were calculated. Significant heights (H_m) and periods (T_m) of the ideal waves representative of the annual wave climate in terms of wave energy flux and steepness, i.e. the so-called "morphological waves", were also estimated. Results are summarized in Table 2 and Table 3.

At both sites, MIKE 21 PMS (Parabolic Mild Slope Waves) was used to simulate wave propagation and breaking from 15 m depth to the shore and to calculate the radiation stress components. Finally, MIKE 21 HD (Hydrodynamic) module was used to simulate the wave-induced currents in the nearshore, based on results from previous simulations. Bathymetric survey data were used for simulations with PMS and HD modules, and finer bathymetric grids ($\Delta x=\Delta y=5$ m) were adopted. Wave conditions used for simulations corresponds to morphological waves representative of SE and SW sectors, as reported in Table 2 and 3.

Figure 17 and Figure 18 illustrate results of nearshore wave propagation provided by PMS module, described by directional wave vectors.

The radiation stress components derived by PMS module results were used as input in the HD module to simulate nearshore hydrodynamics induced by incident morphological waves. Results of HD simulations are

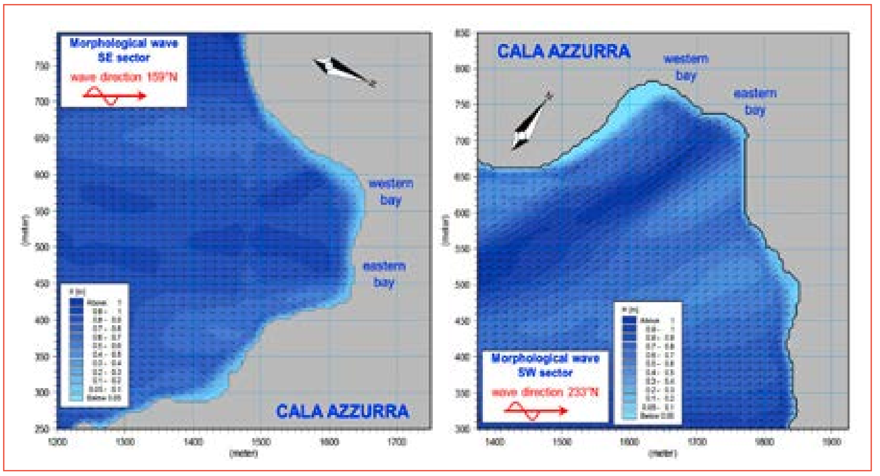

FIGURE 17 Simulation of nearshore wave propagation at Cala Azzurra. Incident wave conditions correspond to morphological waves for SE and SW sectors at 15 m depth

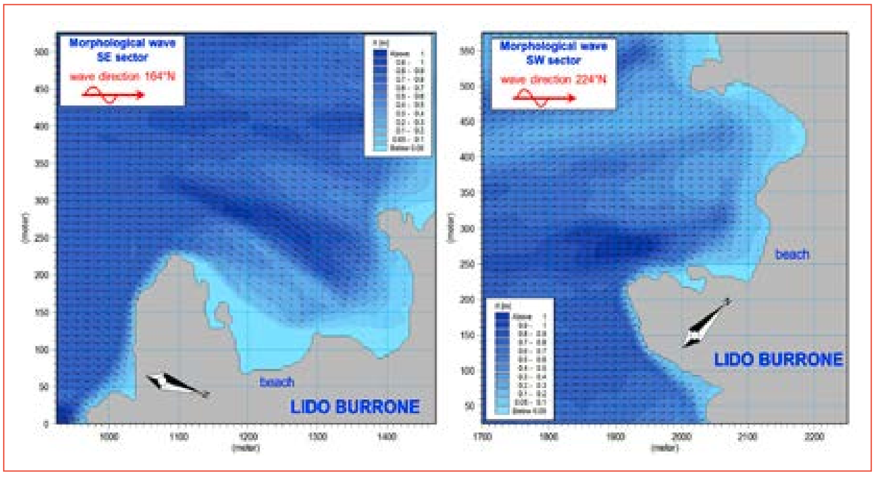

FIGURE 18 Simulation of nearshore wave propagation at Lido Burrone. Incident wave conditions correspond to morphological waves for SE and SW sectors at 15 m depth

depicted in Figure 19 and Figure 20 in terms of time-averaged surface elevation, whilst Figure 21 and Figure 22 illustrate the wave-driven nearshore circulation currents.
At both sites, offshore-directed return currents can be noticed in the middle of the nearshore area. Nearshore currents are strongly affected by the coastline geometry and seabed morphology and, as expected from what discussed above, more intense hydrodynamic conditions are observed at Cala Azzurra compared to Lido Burrone.
From nearshore circulation patterns, a general transport toward the eastern ends of both sites can be noticed. This seems to suggest a certain potential sediment supply to the Cala Azzurra eastern bay and to the Lido Burrone beach, where, in fact, permanent emerged beach can be observed. The above observation, however, takes into account only average incident wave conditions and is not to be considered exhaustive of the complex sediment dynamics of study area.

Conclusions

In-situ activities and model studies performed during the project provided a detailed knowledge of coastal morphology and dynamics of Cala Azzurra and Lido Burrone coastal sites.
The main results can be summarized as follows:

1. Both sites present a quite complex bathymetry.
2. Limitedly to surveyed areas, an overall stability of submerged beach was observed, with little bathymetric variations among different surveys. A clear seasonal regime of beach profiles was not noticeable from survey data, even if this aspect should be better clarified by further investigation on sea bottom geology and coverage.
3. Results of the hydrodynamic study are consistent with field observations.

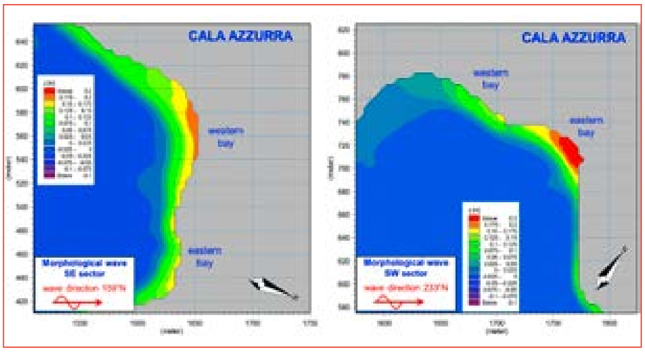

FIGURE 19 Simulation of mean surface elevation induced by morphological waves at Cala Azzurra

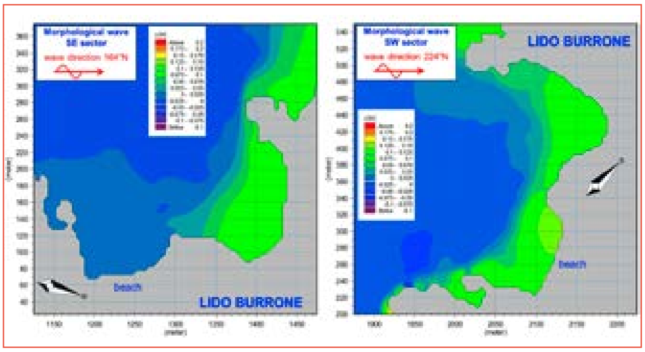

FIGURE 20 Simulation of mean surface elevation induced by morphological waves at Lido Burrone

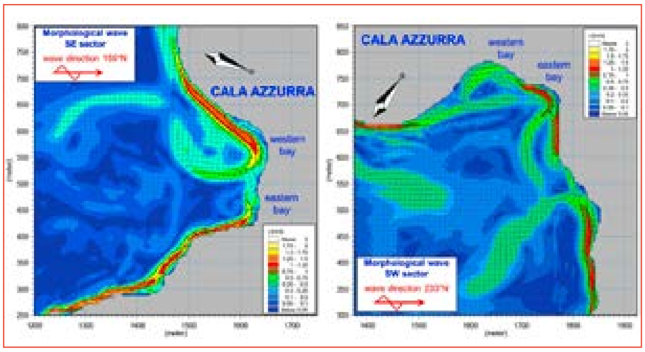

FIGURE 21 Simulation of nearshore circulation currents induced by morphological waves at Cala Azzurra

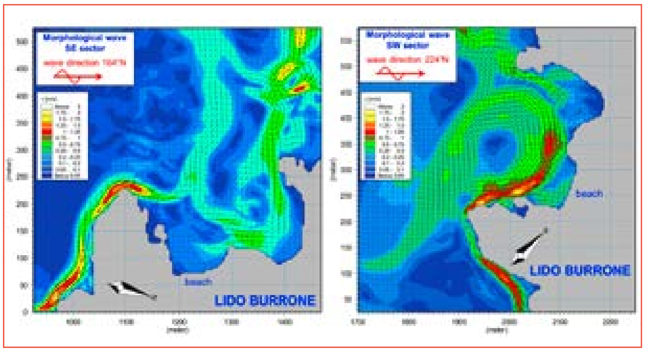

FIGURE 22 Simulation of nearshore circulation currents induced by morphological waves at Lido Burrone

4. In general, more intense coastal dynamics and hydrodynamic conditions were observed at Cala Azzurra compared to Lido Burrone.

The results are interesting not only for the purpose of the project, but also because they can be considered as representative of the typical morphology and dynamics of the pocket beaches, that is a key issue in coastal sciences.

Further studies could be suggested in order to better investigate the possible causes for the evidences observed in field activities. In particular, assuming that the *Posidonia oceanica* coverage has undoubtedly positive effects on sea bottom stability, its role could be investigated by means of measures, experimental and mathematical model studies, including the description of coastal hydraulics and sediment dynamics.

Acknowledgements

Hydrographic surveys and field activities were performed in cooperation with the *Area Marina Protetta Isole Egadi* Management Authority. The contribution by Stefano Donati (director), Daniela Sammartano, Monica Russo, Giuseppe Cammareri and Alessandro Agate is gratefully acknowledged. ●

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Cliffs and quarries in the eastern coast of the Favignana island (Sicily, Italy)

Favignana Island (Sicily, Italy) is a historical and environmental attraction site frequented by tourists especially during the long warm season of the year. Over several centuries the sea cliffs constituted by calcareous sandstone outcropping in the east side of the island have been exploited for the production of building stone. Currently the quarries used for the rock extraction as well as the natural cliffs are undergoing extensive erosional and gravitational processes. Besides putting at risk the safety of the people attending the area, the widespread rock falls are likely to threaten sites of great historical and anthropological value that, once destroyed, can no longer be reconstructed. The rock mass quality assessment and slope displacements monitoring of cliffs were conducted with the aim of identifying the most active areas and providing support to the local authorities in the implementation of effective and sustainable mitigation measures. If adequate measures are taken in the future, operators and users of the tourist circuit will have the opportunity to enjoy these amazing sites with a lower landslide risk

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Introduction

Sea cliffs often constitute environmental monuments of rare beauty. Notwithstanding an apparent imperturbability, these massive erosive landforms are subject to continuous evolution due to the action of gravity and aggressive exogenous agents. The geomorphologic evolution along these steep slopes, often highly fractured, mainly occurs with the detachment and movement of blocks extremely variable in size. Rock falls, topples and slides from the cliffs commonly involve single small-volume blocks and, albeit more rarely, huge rock bodies as well. Depending on several different characteristics of the cliffs and of the triggering landslide mechanism, the average coastal erosion rate can reach several decimeters per year [1]. Although these processes are not the most dangerous landslide events, their magnitude in terms of volume and velocity of the paroxysmal phase may constitute a real hazard for human beings, buildings and infrastructures in the near-shore areas [2].

A high percentage (35%) of the coastline delimiting the Italian peninsula and islands is constituted by steep sloping cliffs, plunging into the sea or separated from it by a thin strip of sandy or gravel beach, or a bank of fallen blocks [3]. In some Italian regions (e.g. Liguria, Campania, Calabria, Sicily and Sardinia) this percentage is significantly higher and the erosion processes of the cliffs constitute a serious problem. Nevertheless, the increasing thermoclastic processes and the local stress condition at the foot of the cliffs as a result of the ongoing climate change, and particularly of the variation in temperature regimes and fluctuations in

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the Mediterranean sea level, may induce an intensification of the erosion rate of the Sicilian high coastal areas [4].

Some of the most popular places of Favignana Island are bays characterised by cliffs overlooking an astonishing sea. Rock falls along the cliffs are common and involve the underlying beaches. The low human activity in these areas actually reduces the risk condition that remains concentrated during the long warm season of the year, when tourist frequentation is considerable. In addition, the quarries opened in some of these bays, locally called "pirrere", constitute a cultural heritage of great anthropological value that, once destroyed, can no longer be reconstructed.

This paper reports a brief description of the investigation on the cliffs and quarries of the eastern coast of Favignana Island (western Sicily) where a quaternary calcareous sandstone diffusely outcrops. The cliffs monitoring and the slope movements assessment carried out during the study are aimed to identify the most active areas. The study results may contribute to the mitigation of the geomorphological risk in Favignana Island and greatly support the local authorities' policies in the implementation of mitigation measures. Given the characteristics of the sites, inserted into the largest European marine protected area, the intervention measures must be characterized by a high degree of environmental sustainability. If valid, effective and sustainable measures are taken in the future, operators and users of the tourist circuit will have the opportunity to enjoy these amazing areas with a lower landslide risk.

FIGURE 1 Bivalves (left) and cross-bedded layers (right) in the calcareous sandstones

FEATURES	VALUE
Specific gravity (G_s)	2,7 g/cm^3
SiO_2 content	<1%
$MgCa(CO_3)_2$ content	1-3%
Average grain size	0,3 mm
Total porosity (n)	40-50%
Compressive strenght (σ)	20-30kg/cm^2

TABLE 1 Geotechnical characters of calcarenites

Study area

Favignana is the largest of the Egadi Islands, located off the northwest coast of Sicily, near the cities of Trapani and Marsala. It extends for approximately 19 km^2 and is surrounded by a 33 km of indented and mainly rocky coastline, marked by natural and anthropic cavities. The island is mostly flat, except for the mountain ridge that runs through it from north to south (M.te Santa Caterina, 314 m a.s.l.).

Favignana Island mainly consists of Mesozoic-Tertiary carbonates unconformably overlain by Middle-Upper Pliocene marls and shales followed by Pleistocene biocalcarenites and Tyrrhenian calcarenites [5,6,7]. The Mesozoic-Tertiary carbonates outcrop in the western and central part of the island. The lower Pleistocene biocalcarenites outcrop in the eastern part of the island, generating a wide flat plate with nearly horizontal layers. In literature, its thickness ranges between 5 and 35 m [8], though a quarry in the inner part of Cala Rossa ("Niuro vecchio" and "Niuro nuovo" caves) shows a vertical development of more than 50 m entirely in the calcarenites. The facies association suggests different depositional environments (Figure 1) from the nearshore-beach zone (close to the Mt. Santa Caterina) to the shoreface zone (in the eastern part of the Island). The Middle-Upper Pliocene marls and shale locally outcrop between the base of the calcarenite cliffs and the sea surface, partially hidden by a significant boulders deposit.

The calcarenite shows relatively high values of the porosity [9] (Table 1) related to the low diagenetic process, the low cementation (spathic calcite with meniscus structures) and to the textural characters (equi-dimensional, well sorted, loosely packed, low fine grained matrix). The value of the compressive strength offered in literature, and confirmed through some field measurements with a Schmidt hammer, indicates a weakly cemented carbonate rock.

There are three systems of faults that displace both the Mesozoic-Tertiary and Pleistocene deposits. A very recent tectonic activity involves Tyrrhenian sediments and more recent continental deposits, as revealed by kinematic indicators of NW-SE, NE-SW and W-E strike-slip fault [10] and of differential uplift [11].

The study is focused on three bays, "Cala Rossa", "Cala del Bue Marino" (Figure 2) and "Cala Azzurra", located in the eastern side of the island. In these three bays, the Pleistocenic biocalcarenites form some cliffs with height ranging from few meters (Cala Azzurra and central part of Cala Rossa) up to over 30 meters. These areas are classified as high and very high landslide hazard [12].

The cliffs of Cala Rossa and Cala del Bue Marino are separated from the sea by a narrow strip of talus deposits, whereas at Cala Azzurra a low angle slope and a beach separate the old cliff from the present shoreline, assuming respectively the shape of a seasonal sea cliffs and a coastal slope [13]. In the west side of Cala Rossa and Cala Azzurra, this wide rock slab lies on the plastic clays belonging to the Pliocene formation. The contact between the two formations can be recognised here above the sea level, while in the east side of the two bays and in Cala del Bue Marino area the surface is presumably below sea level. The overlapping of hard rock masses on a more plastic substratum leads to mechanical instability due to the diverse response of the materials to perturbations, such as seismic input, weathering, erosion or man-made excavations [14]. The resulting mass movements can be classified into two different but strictly interconnected typologies: lateral spread and rock blocks fall [15].

FIGURE 2 Rock blocks fallen at Cala del Bue Marino

The good resistance brought the biocalcarenite, improperly called "tuff", to be extracted in several hypogeal and open air quarries and used as building stone. The exploitation of the Favignana sandstone is ancient, but it reached its maximum development mainly between 1700 and 1950. Many buildings were constructed in Tunis with the "tuff" of Favignana, and Messina was rebuilt with it after the 1908 earthquake. After the World War II the "tuff" went out of the market and the mining areas were abandoned to a degradation process which increased the risk of block collapse.

Methodology

A geomechanical analysis and multi-system monitoring of the cliffs of Cala Rossa, Cala del Bue Marino and Cala Azzurra were carried out in this study between April 2012 and April 2014.

The geomechanical investigations were focused on the recognition of the rock mass joint setting and of the lithotecnical characteristics of the calcarenites in the three coves. The geomechanical characterization of the calcarenite was carried out via a traditional geomechanical field survey performed according to the ISRM standard. Twenty-five geomechanical stations were completed in the three coves (7 in the west side of Cala Rossa, 13 in the east side of Cala Rossa, 3 at Cala del Bue Marino and 2 in Cala Azzurra). Field mapping of rock discontinuities is the most common approach for the analysis of cliffs shaped on hard rock. This classical geomechanical investigation allows to characterize the main joints in terms of dip, dip direction, spacing, opening, presence of gouge material, persistency, relationship with average slope face orientation and other factors. The poles of the measured joints were plotted using the "Georient" open source software and the Schmidt equi-areal

FIGURE 3 3D joint meter installed on the giant joint of the plateaux of the west side of Cala Rossa (left) and the removable deformeter during the measurement survey

stereographic projection (lower hemisphere). Furthermore, the mechanical features of the rock mass, including the mineralogical characteristics and the rock compressive strength, were assessed with field instruments (Schmidt Hammer sclerometer) and laboratory experiments (thin sections, point load test, etc.). On the basis of the geological and geomechanical features, the values of Beniawsky/Romana (RMR/SMR) and Sicily Region classifications [16] were assigned to each station. The latter proposes a simplified approach generating an aggregate of some geomorphological, environmental and historical parameters with the mechanical characteristics typical of the traditional classification.

The monitoring activity was performed through the use of direct and indirect instruments.

A direct measurements systems was implemented with mechanical joints gauges of different kind (tell-tale, removable joint-meters, 3D joint-meters; Figure 3) in relationship with the different characteristics of the walls, discontinuities and types of movement to be recognised (one-dimensional or three-dimensional). These three mechanical join-meters systems allow to measure relative displacements between two reference pins or two anchors positioned across the joints with a resolution of a hundredth of millimeter (tenths of millimeter for the tell-tales). Overall 70 mechanical joint-meters were installed, distributed along the cliffs overlooking the sea of the three bays and also within the numerous cavities that open inside the cliffs.

The indirect measurements were carried out through Terrestrial Laser Scanner and GPS instruments. While this latter allowed to monitoring displacements of single points located at the edge of the cliff, the former acquired information about a cloud constituted by millions of points representative of the whole vertical face of the cliffs highlighted by the laser beam.

Laser scanner survey [17] were performed using a laser scanner (Riegl Z360) integrated with a high resolution digital camera (Nikon D100; Figure 4). Two Laser Scanner acquisitions (October 2012 an October 2013) were performed in all the three bays, positioning the instrument in four stations in Cala Rossa, four in Cala del Bue Marino and five in Cala Azzurra. In order to compare subsequent temporal scanning [18, 19] and re-calibrate the instrument with a precision of mm, eight fix targets and ten mobile targets around the scan points (scanpositions) were materialized as a Cartesian coordinates system.

The GPS monitoring techniques was applied only in Cala Rossa with the aim of identifying the movement of single points along the cliffs with high accuracy.

FIGURE 4 Laser scanner instruments during the acquisition survey in Cala Rossa

FIGURE 5 The local GPS network and one of the measurement points

The GPS network is composed by four stable vertices (A, B, C and D in Figure 5), while in proximity of the edge of the cliffs four sites were chosen, considered potentially unstable after a geomorphological survey (E1, E2, O1 and O2). The GPS network was linked with the Italian Geodetic Network (IGM95), by the geodetic point "Punta San Leonardo" located close to the Favignana's urban area. The uncertainty of these vertices was very contained, reaching a maximum of +/- 2 mm in plane and +/- 3 mm vertically.

Results

The biocalcarenitic slab shows a high degree of fracturing especially in the front portion of the cliffs and the boulder deposits at their foot constitute a clear indicator of the current activity. Several blocks of different sizes seems to be in condition of high instability and in proximity of falling. In addition to the geomorphological indicators, at least two block fall events recorded during the 24 months of the study testify the high activity of the west cliff of Cala Rossa. The first is the block of approximately 0.3m^3 collapsed on the morning of October 26, 2012 from the west cliff of Cala Rossa and recorded by the Laser Scanner monitoring. The second is the sudden collapse of a boulder on which a reference pin for the removable joint-meter measuring was installed. Its last data read in June 2013 indicated a movement of 0,72mm from the installation in October 2012 (1mm/month).

From the front slope towards the interior of the slab, the rock fracturing condition becomes less intense, with spacing ranging from less than 1m up to more than 2m or more. This may be appreciated both in the plateaux above the cliffs and within the several quarries opened inside it. Nevertheless, in the inner part of the west side of Cala Rossa cliff, upon the plateaux and approximately 25 meters from the edge, two major discontinuities have been recognized, longer than 100 meters, 50 cm open and with 40 cm of offset. These joints seem to reach the contact with the underlying clays, isolating a huge block of approximatively 30 thousand m^3 (Figure 6).

Structural analysis confirms the presence of two main joint families: NNW-SSE and NE-SW (Figure 7 and 8). The NNW-SSE joint set seems to have a significant relevance in the structural asset of the area and in the development of the instability proneness. Especially where this joint set is parallel to the slope face, it is possible to recognise an advanced lateral detensioning deformation process. Less significance seems to have the sub-horizontal stratification planes. Taking into account the attitude of the main measured joint, two failure mechanisms have been assumed for the movements in the front part of the cliffs: rock topples and rock wedge slides.

The results of the geomechanical analysis of the 25 stations, implemented in the GIS project, are showed in the rock quality maps (RMR, SMR and SR) that constitute a preliminary assessment of the rock fall susceptibility of

FIGURE 6 Giant joint of Cala Rossa

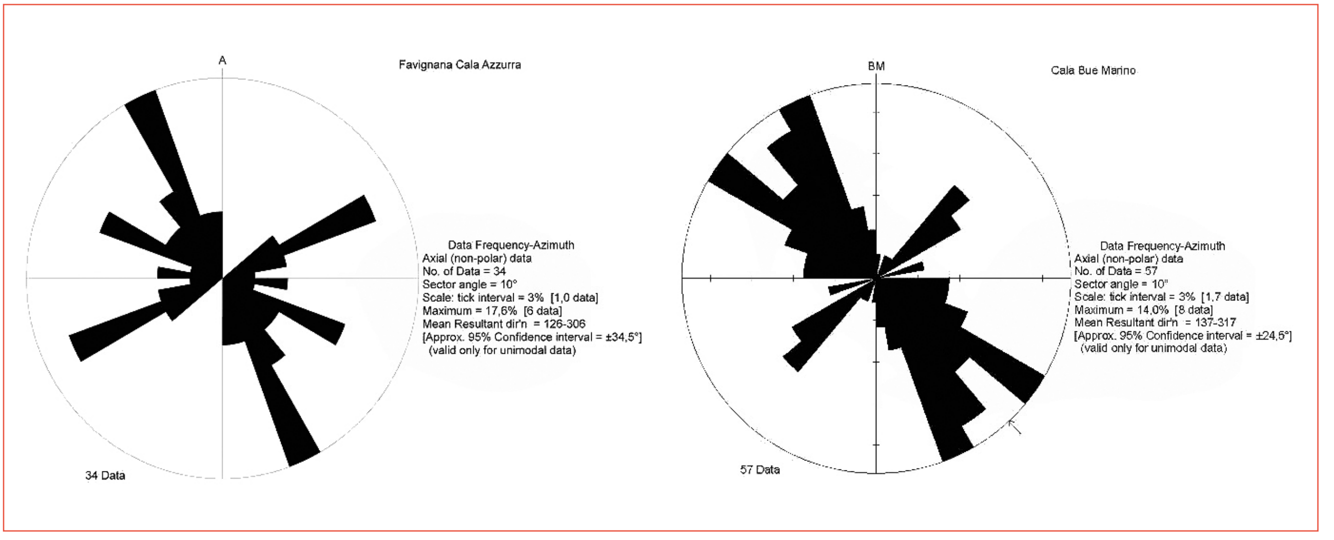

FIGURE 7 Discontinuities plot of Cala Azzurra (left) and Cala del Bue Marino (right)

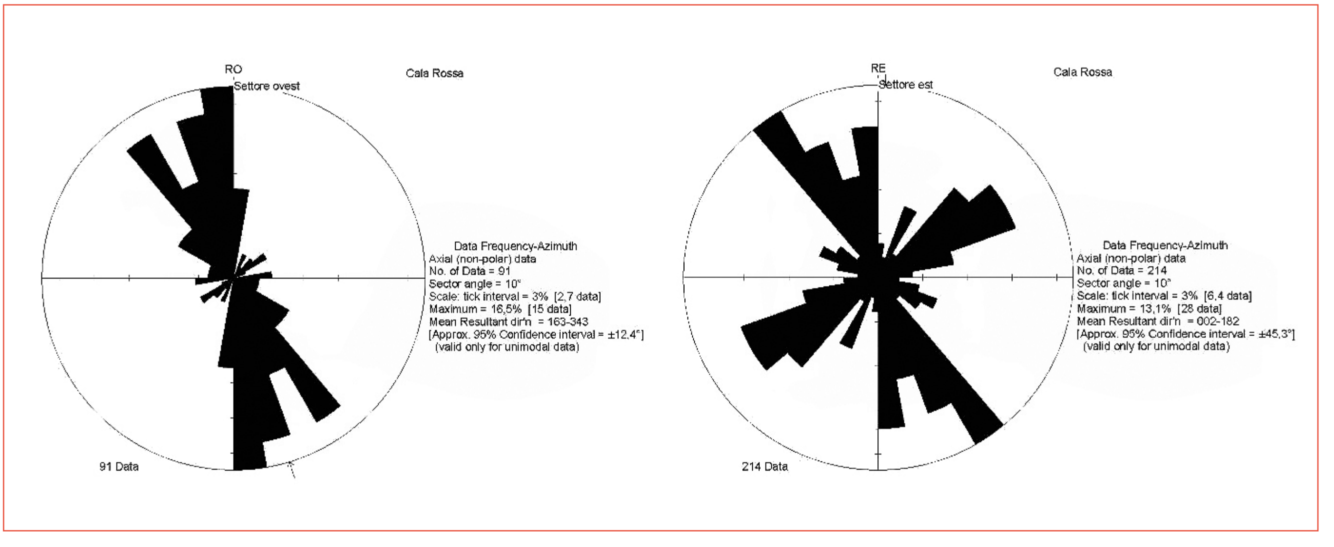

FIGURE 8 Discontinuities plot of the two side of Cala Rossa (West on the left and Est on the right)

the cliffs in the study area. The comparison between the traditional classification of Beniawsky/Romana (RMR/SMR) and the recent experimental classification of Sicily Region (SR) showed a moderate agreement in the results (Figure 9).

The movements measured by the mechanical joint-meters installed in the three bays are generally lower than 1mm (Figure 10). Only eight measurement points showed variations over the 24 months exceeding 1 mm and only 1 is greater than 5 mm (RE3M2, a joint in the central part of Cala Rossa).

From the preliminary GPS data, consisting in the first survey realised in October 2012 and the following of May 2013 and April 2014, some horizontal millimeter

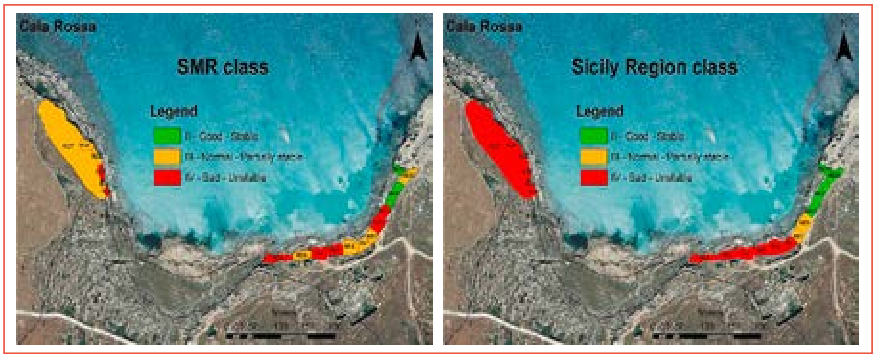

FIGURE 9 Maps of Slope Mass Rate (left) and Sicily Region classification (right)

movement of the four unstable vertices may be observed, but always inside the error ellipse and without an apparently defined trend. Only for E2 and O2 vertices it is possible to observe a vertical millimeter movement, even if inside the ellipse error, that denotes a presumable subsidence trend. The data acquired during the fourth survey, performed in June 2015 and still under processing, will allow to compare a more significant dataset and better understand the behaviour of the cliffs.

Minimal changes have been recorded in the point clouds acquired during the two Laser Scanner surveys of October 2012 and May 2013. However the comparison of the different images acquired is still being processed.

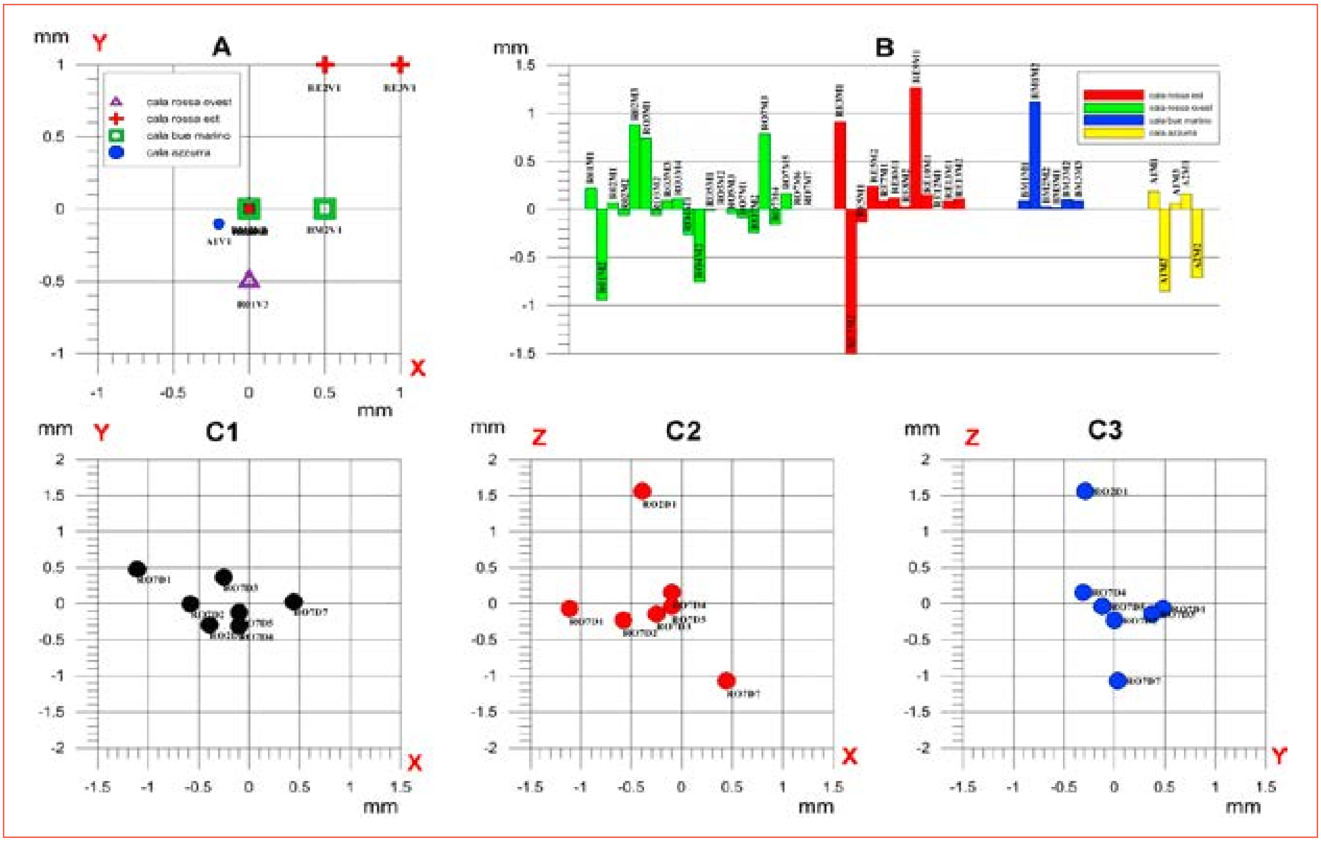

FIGURE 10 Displacements measured with the mechanical joints gauges: tell tales (A), removable joint-meters (B) and 3D joint-meters (C1, C2 and C3)

Discussion

The geological model representative of the study area is mainly characterized by the presence of the rigid body of calcarenite above the plastic clays. The clay deformations, also related with the sea waves action, induce stress condition in the overlying limestones and development of fracturing processes. The pre-existing neo-tectonic shear zones are a controlling factor for the development of the failure surfaces and of the gravitational processes. These processes develop as lateral spreading along the contact surface between the two formations and fall s.l. in the detensioned front portion of the cliffs. The position of the contact surface between the two formations above or below sea level and the consequent exposition or protection of the clays to/from the sea waves action is presumably a further controlling factor for fracturing and landslide processes.

The lack of significant movement registered by the integrated monitoring system in the periodic acquisition during the 24 months study can be easily explained with the discontinuous and impulsive behaviour of the rock collapsing processes, and does not exclude the possibility of future single or massive movements. The deepening of the deformation dynamic inevitably requires the upgrading of the current monitoring network with the installation of more sophisticated joint meters in the most critical sites, with in continuum acquisition, data logging and remote communication.

The rock mass rating of the cliffs attributed to the different measuring stations (Figure 9) shows good agreement between the SMR and SR classifications, even if the latter appears to be more conservative. It is notable that attributing the SMR and SR classes demands to take into account the geometrical relationship between the most significant joint planes and the slope orientation. Even though the analysed cliffs of three bays have strongly indented forms, due to natural and human causes, in this study only an average value of the slope orientation has been used. Consequently, the SMR and SR classes assigned to a station are affected by a certain level of approximation.

The working group plans to make few more additional field observations and deepen the elaboration of the data already acquired. An improvement of the landslide hazard assessment will be implemented on the basis of the predisposing parameters, such as the stability condition of the slopes [20, 21]. The characterization of the joint discontinuities will strengthen by the execution of the automatic and semi-automatic elaborations of the Laser Scanner images and of an innovative geophysical survey (nanoseismic monitoring) [22].

Conclusions

The geomechanical survey and analysis confirm the presence of potential instability conditions in the three bays of the study area. Consequently, a significant hazard level has been recognised in several measurement stations, mainly in Cala Rossa and Cala del Bue Marino. The monitoring systems have registered no significant displacements in the observed areas. Nevertheless, several cliff areas show evidence of impulsive dynamics. On this basis, identifying appropriate actions is absolutely crucial to prevent accidents to the users of these beautiful natural places and to avoid that the most significant quarries are further abandoned to an inexorable degradation process.

Removal of the most unstable blocks, local rock nailing and protection boulder walls at the foot of the cliffs are all interventions that can reduce the general unstable conditions in the higher hazard level sectors of the cliffs. In the most critical areas, as the west side of Cala Rossa, a partial prohibition of access is strongly recommended. Furthermore, improving the current monitoring system is a necessary prerequisite for future adoption of an early warning system.

By providing information about the hazard level and the displacements along the cliffs of the three bays, the present study results are an effective contribution to the local authorities in charge of implementing mitigation measures. The enhancement of the safety level of these areas is an essential step for a sustainable and safety tourism exploitation in the island. This is the way to ensure that what was left of the quarries can become an economic resource again, while respecting the historical and the environmental context.

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Underwater itineraries at Egadi Islands: Marine biodiversity protection through actions for sustainable tourism

Sustainable tourism is recognized as a high priority for environmental and biological conservation. Promoting protection of local biological and environmental resources is a useful action for conservation of marine biodiversity in Marine Protected Areas and for stimulating awareness among residents and visitors. The publication of two books dedicated to the description of 28 selected underwater itineraries, for divers and snorkelers, and a website with underwater videos represent concrete actions by ENEA for the promotion of sustainable tourism at the Marine Protected Area of Egadi Islands (Sicily, Italy). 177 species were recorded at Favignana, and around the same number at Marettimo and Levanzo islands: among those species, some of them are important for conservation and protection (e.g. *Astrospartus mediterraneus*), some of them are rare (i.e. *Anthipatella subpinnata*) and with a high aesthetic value (e.g. *Paramuricea clavata*, *Savalia savaglia*), while others are invasive (e.g. *Caulerpa cylindracea*)

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Introduction

Sustainable tourism represents an important reason for promoting historical, cultural and environmental features of countries where those features are not promoted and popularized enough. This situation typically occurs in Italy and especially in remote areas, such as small islands, which suffer high pressures acting on vulnerable terrestrial and marine environments, usually caused by a mass and aggressive tourism for limited periods of the year. Seasonal anthropogenic pressures due to beach resort activities, illegal practise of professional and sport fisheries, and domestic pollution as consequence of urbanization are all factors affecting marine ecosystems and thus threatening biological resources.

The Marine Protected Area (MPA) of Egadi Islands, including Favignana, Marettimo and Levanzo islands, is the target area for ENEA project "Ecoinnovazione Sicilia", funded by the Italian financial act in 2010, which aimed to define specific actions for promoting sustainable tourism (http://egadi.santateresa.enea.it/). The MPA was originally established by the Italian Government in 1991 and then its management transferred from the Ministry of Environment to Favignana municipality in 2001. In recent years, the MPA has realized important actions on conservation and promotion of the coastal marine environment, with particular attention to environmental education, research and promotion of sustainable development for all economic local activities.

The main tool for conservation of marine biodiversity is to promote the importance of protection of local biological and environmental resources so that there is co-operation from all users in preventing or

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minimising potentially adverse activities. Within this context, ENEA aims to develop and realize actions for sustainable tourism. By popularizing marine biological and environmental special features, knowledge will be increased thus generating further awareness among residents and nearby populations and visitors, making the marine resources more easy to protect against non-sustainable tourism.

Among the special underwater features of the Egadi Islands, *Posidonia oceanica* meadows, included in the Habitat Directive (43/92/CEE), are one of the most important biocoenoses for their abundance and distribution all around the shallow seabed of the islands (~7.700 ha). In addition, on the deep rocky outcrops and shoals, the coralligenous community represents a Mediterranean habitat of high ecological importance. For its richness of species, the coralligenous community is well known both by fishermen, who have eligible sites for fishing on coastal and offshore rocky shoals, and by diving centres that often promote their activities in these habitats. However, the biodiversity associated with the coralligenous community and its landscape value, as well as the presence of species of aesthetic and conservation interest are not well known from either a scientific point of view or by the resident population.

Here, we present the project carried out by some researchers of the Marine Environment Research Centre (La Spezia, Italy) of ENEA aimed to realize actions for disseminating the knowledge on coralligenous and marine coastal rocky communities characterizing underwater habitats at Egadi Islands. The ultimate purpose of the work was to protect biological and environmental resources, promote awareness of the value of marine biodiversity among residents and encourage sustainable tourism around Egadi Islands.

Study area: The Marine Protected Area (MPA) of Egadi Islands

The Egadi archipelago, located a few km far from the west coast of Sicily, comprises three main islands, Favignana, Levanzo and Marettimo, and some minor islands (Formica and Maraone); at present it is the largest MPA in the Mediterranean, covering around 54 thousand hectares (Figure 1).

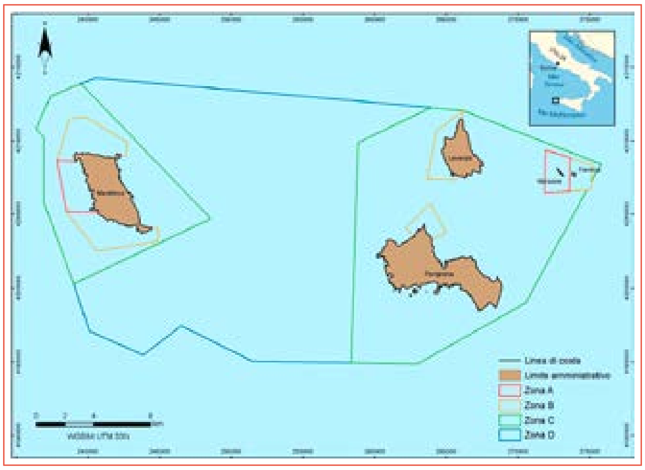

FIGURE 1 Map of the Marine Protected Area of Egadi Islands, with an indication of the different zones (A, B, C and D) of protection
Source: AA.VV. (2009), "Relazione finale. Analisi e valutazione dello stato degli ecosistemi marini delle zone A e B in 4 Aree Marine Protette anche al fine di valutare l'efficacia delle misure di gestione delle stesse", CoNISMa e Ministero dell'Ambiente e della Tutela del Territorio e del Mare

The archipelago includes an area of high natural-environmental interest, in particular the underwater environment has a high biodiversity due to its particular geographical position and hydrological conditions. Moreover, the coastal and underwater geomorphology shows peculiar features deserving protection. The seabed morphology of the inner continental shelf is characterized by the presence of topographical highs and submarine valleys as the results of tectonics, Holocene eustatic sea-level changes, subaerial (during Holocene high stand phases) and marine erosion processes [1, 2]. These processes are very active and influential around Egadi Islands where the sea currents are very high, especially along the submarine valleys [3]. The submerged caves and other topographical features caused by intense erosion mechanisms following storms and strong seabed currents are one of the most peculiar aspects that characterise the coastal area and the seabed of Egadi Islands. Around the archipelago there are several submerged rocky outcrops and wave-cut terraces generally limited by faults, with almost vertical sides and shaped by hydrodynamics [4]. Those morphologies are

located on the inner continental shelf between 19 and 50 m depth; they represent very interesting features from an environmental and geological point of view and also for the ecology and marine biology of benthos. Seabed sediments on the continental shelf around Egadi Islands are mainly constituted by heterogeneous mixtures composed by pebbles and gravels with medium to coarse sands, rich in bioclasts [5].
Among natural features of the sea bottom, as already mentioned, *Posidonia oceanica* meadows are the most important biocoenoses for their abundance and distribution all around the islands. *P. oceanica* meadows are one of the most important Mediterranean ecosystems and represent a high-value habitat for both their ecological role and the associated biodiversity. Seagrass beds are a high-productivity ecosystem: they produce oxygen, represent a reproductive and nursery area for several species, reduce the energy of the currents and waves on the submerged beach, and contribute to the stability of the sea bottom and beach protection [6, 7].
Moreover, the coralligenous community represents a habitat of high ecological importance for the richness of associated biodiversity and landscape value, as well as the presence of valuable species of natural and conservation interest.

Field work at Egadi Islands' MPA

In 2012 and 2013 some ENEA researchers explored 15 underwater pathways at Favignana Island (Figure 2), 11 at Marettimo (Figure 3) and two at Levanzo (Figure 4) by means of scuba diving.
For each pathway, underwater photographs were taken by using a NIKON D80 digital camera with SEA&SEA housing equipped with two SEA&SEA strobes. Underwater videos were recorded using a Sony full-HD video camera enclosed in an underwater housing with a wide-angle lens and two lamps. Information about species presence and distribution was recorded on underwater tablets. Only the conspicuous species visually recognized during diving inspections were reported; while diving, voucher specimens were collected to help their identification. Sea temperature, depth, orientation and a sketch of each path were recorded too.

FIGURE 2 Location of 15 underwater itineraries at Favignana Island

FIGURE 3 Location of 11 underwater itineraries at Marettimo Island

Research & development

FIGURE 4 Location of 2 underwater itineraries at Levanzo Island

FIGURE 7 Example of an underwater path for divers, with icons of most relevant species and videos
Source: http://egadi.santateresa.enea.it

Two illustrated books dedicated to underwater itineraries at Egadi Islands' MPA

All the information collected on each underwater itinerary (i.e., a list of species, bathymetric distribution of species, type of seabed, depth, orientation, and morphology of the path) were combined in a digital format and published [8, 9], (Figures 5, 6).

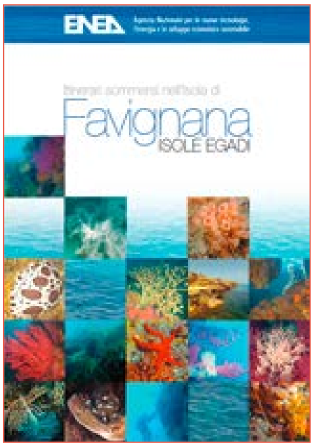

FIGURE 5 The book of underwater itineraries at Favignana Island
Source: Cocito et al., 2012

FIGURE 6 The book of underwater itineraries at Marettimo and Levanzo Islands
Source: Cocito et al., 2014

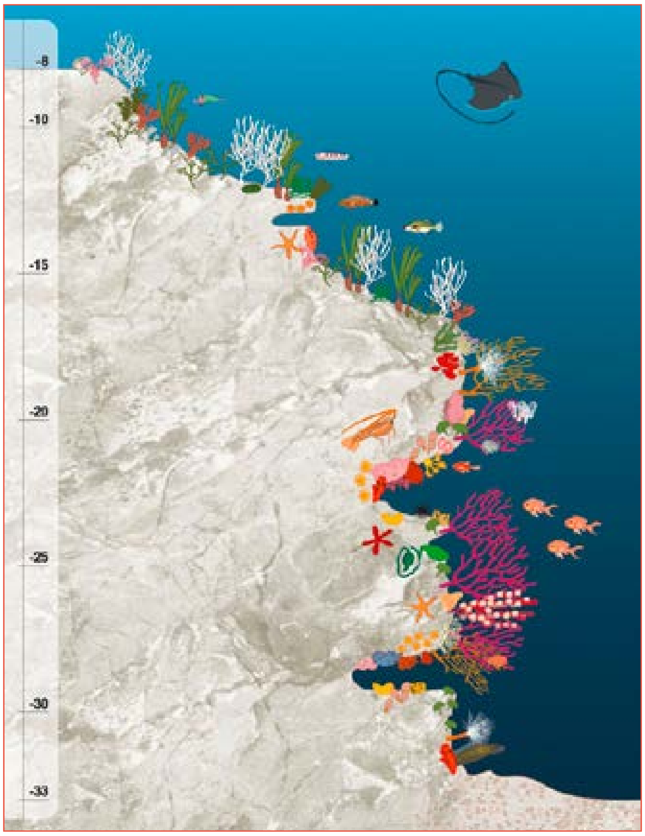

FIGURE 8 Example of an underwater transect, where all main species and features of the seabed are indicated
Source: Cocito et al., 2012

ENEA researchers provided all of the scientific content of the books by describing the coastal environment of Egadi Islands, the itineraries in terms of ecological and geological characteristics, and produced a comprehensive species list. A 3D drawing indicated with arrows the directions followed by divers and the presence of main, relevant species (Figure 7).

A further 2D drawing, representing a cross section of the itinerary, was realised with the aim of providing a detailed illustration of geomorphology of the site and presence and distribution along depth of the species characterizing that specific site (Figure 8).

Particular attention was paid to the legend with a detailed list of species, seabed characteristics and icons with fine morphologic details illustrating species. Different colours in the legend were used to represent different taxa (Figure 9). Those icons were used in the maps of paths and transects showing the dive observations.

Each underwater itinerary was described in detail from surface to bottom and information about the principal morphological characteristics (i.e. rock, shoal, cave or rocky wall), and other features (such as depth, current, exposure to adverse sea-weather conditions, visibility), useful to evaluate the difficulty level of dive, were provided.

Each itinerary was also provided with a score represented by stars: the score, from one to four stars, from low to excellent, was based on nature conservation relevance, thus considering biological relevance, species and habitat presence, species vulnerability and rarity, geomorphologic characteristics, aesthetic view of the itinerary.

Among the itineraries, the most common topographies observed are almost vertical rocky walls, together with rocks and shoals, reaching a maximum depth of

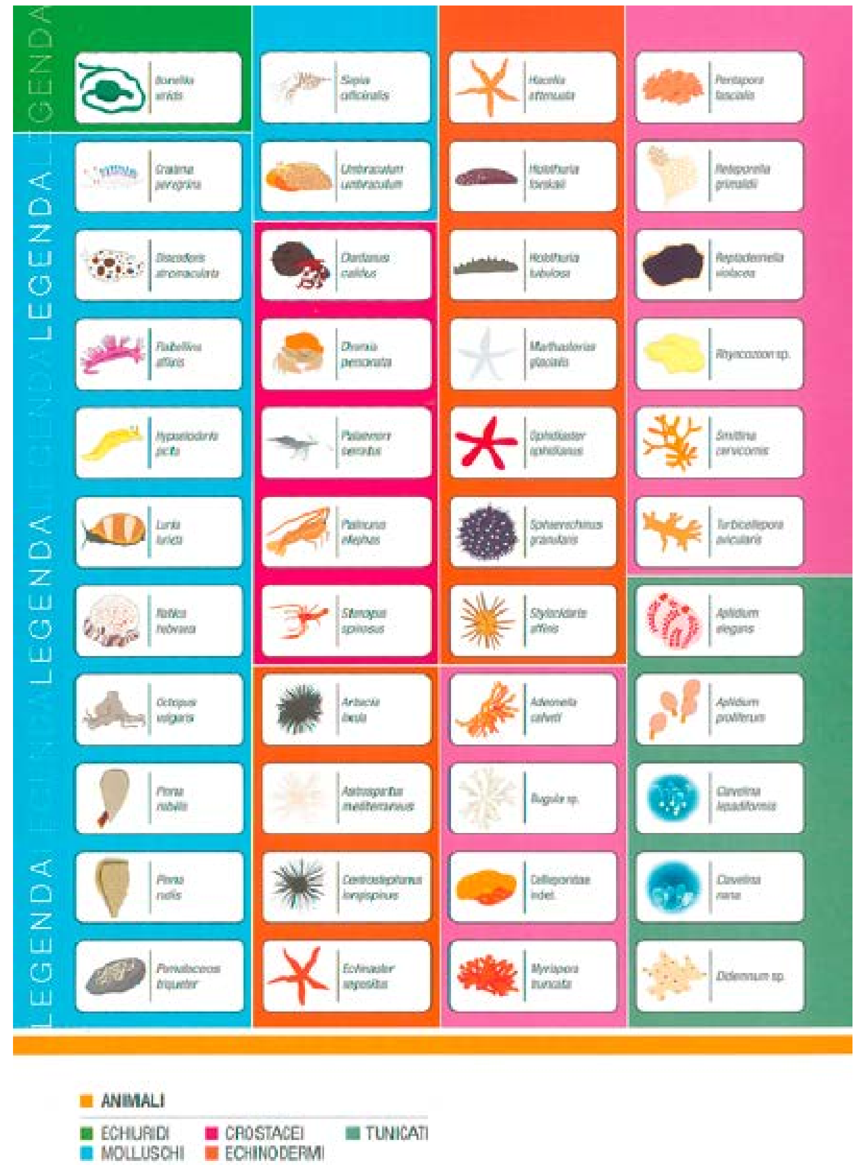

FIGURE 9 Example of legend, showing the detailed list of species and icons used in maps of paths and transects, representing species. Different colours in the legend were used to represent different taxa
Source: Cocito et al., 2014

42 m. More than half of the itineraries are of easy or medium difficulty, so open to a wide range of divers and snorkelers too.
Almost all underwater itineraries (22 out of a total of 28) are of high nature conservation relevance, rating them from good to excellent.
A total of 177 species (39 of algae and plants and 138 of animals) was recorded at Favignana, and 172 species (32 of algae and plants and 140 of animals) was found at Marettimo and Levanzo islands. Among the species found across the pathways, some of them are important for conservation and protection (i.e. *Astrospartus mediterraneus*), others are rare (i.e. *Anthipatella subpinnata*) and with a high aesthetic value (i.e. *Paramuricea clavata*, *Savalia savaglia*), while others are invasive (i.e. *Caulerpa racemosa*).

The Website dedicated to underwater itineraries at Egadi Islands' MPA

The two illustrated books [8, 9] were published in a website (http://egadi.santateresa.enea.it/) which was built using Joomla!® software (http://www.joomla.org), an open-source Content Management System (CMS)

FIGURE 10 The ENEA website (*http://egadi.santateresa.enea.it/*) dedicated to underwater itineraries at Egadi Islands

written in PHP (PHP: Hypertext Preprocessor) which uses MySQL or PostgreSQL database. The website, in addition to the content of the books, shows more photos and videos for each underwater path. The videos can be displayed both in low and in high resolution (1080p FHD) on any mobile device (iPad, iPhone, Android & Windows) (Figure 10).

The QR (Quick Response) codes were printed in the two illustrated books (Figure 11), linking them to the website http://egadi.santateresa.enea.it/, thus enabling to connect and display each underwater itinerary on mobile accessories.

FIGURE 11 The QR code shown in the two illustrated books, linking to the website and videos of underwater itineraries

Since its date of publication in 2013, the website, has been visited by more than 50 thousand visitors, meaning around 2000 visitors/month (with peaks during the summer period) and indicating a high interest of the underwater environment, having the possibility of getting a closer knowledge of it.

Final considerations

The publication of two books dedicated to the description and illustration of selected underwater itineraries, for divers and snorkelers, at Favignana, Marettimo and Levanzo Islands, and a dedicated website with underwater videos around selected sites of the archipelago, represent concrete actions by ENEA for the promotion of sustainable tourism. The main tool for the protection of the submerged environment is knowledge. The two illustrated guides and the website, based on easy and popular communication tools, aim to disseminate knowledge on the marine environment, which is often known by specialists only. These diving and snorkeling itineraries of Favignana, Marettimo and Levanzo islands highlight the beauty and special features of underwater environments. Addressed to locals, tourists and divers, and all people who love the

Egadi archipelago, these dive guides represent useful tools for professionals who work in and with the MPA of Egadi Islands. The list of marine sites of interest has been recently implemented through the publication of a diving guide also reporting archaeological itineraries around the Egadi Islands [10]. Sustainable tourism is recognized as a high priority tool for environmental and biological conservation. This project has been developed for residents, tourists and general users who wish to know more about marine biological resources, understand their importance and thus act for their conservation. Books and the website are therefore a tool for dissemination which stimulates the observation of the underwater environment, its natural features, as well as providing information to people who wish to undertake snorkeling and diving in a beautiful marine environment.

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Collaboration between research institutions and MPAs contributes to *Posidonia oceanica* conservation: The Egadi Island's experiment

Preliminary results on the collaboration between the ENEA's Marine Environment Research Center and the Egadi Islands' Marine Protected Area (MPA), aimed to evaluate effectiveness of artificial reefs in limiting the impact of trawling on *Posidonia oceanica* meadow at Favignana Island, are reported. The methods and parameters chosen for monitoring showed their reliability in training non-experienced personnel for data collection within the MPA. The proposed monitoring approach is of great value to the MPA interested in both gathering basic and long-term data on the health status of protected habitats and acquiring baseline information useful for the evaluation of protection and conservation actions

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Introduction

Declines in the cover of *Posidonia oceanica* (L.) Delile meadows have been recorded in many parts of the Mediterranean Sea, where the plant forms extensive meadows on rocks and sandy bottoms in clean water at a depth from less than 1 meter to over 40 meters [1]. Identified as a priority habitat type for conservation in the Habitats Directive (Dir 92/43/CEE), these meadows provide important ecological functions and services, and harbour a highly diverse community with some species of economic interest. Any decline in *P. oceanica* meadows could have serious economic implications, not only in terms of loss of biodiversity and ecosystem quality, but also of a decrease in fishing resources and an increase in coastal erosion.

Meadow declines have been attributed to several natural and anthropogenic impacts, illegal trawling fishing being one of the most important direct causes of large scale degradation of *P. oceanica*. Repeated passes of trawl gear over the seabed cause the mechanical degradation of meadows, reduce plant density and cover and this degradation changes the structure and dynamics of the associated biological assemblages. It has been reported that trawling gear can remove between 100000 and 360000 shoots/hour [2]. The slow re-growth of the plant further prolongs the impact of trawling, which sometimes can run into decades [3].

With the main objective of restoring *P. oceanica* meadows, restrictions on trawling over meadows have been reinforced in the last 15 years in Spain, Italy and France by the deployment of anti-trawling artificial

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reefs (AR) [4]. AR are heavy concrete constructions which can be armoured with extruding steel bars. These have been recognized as one of the most effective tools for integrated management and conservation of coastal resources after the establishment of Marine Protected Areas, particularly for *P. oceanica* habitat and its associated halieutic resource [5].
In order to limit the impact of trawling on the largest *P. oceanica* meadow in the Mediterranean, in 2013 the Egadi Islands' MPA authority, within the MASTER project, adopted protective measures by deploying AR within 50 m of depth in well-identified, sensitive areas. According to the Italian law, trawling is banned at depths lower than 50 m or at less than 3 nautical miles from the coastline. To measure the status and trends of meadows over time and analyze the changes of associated fish species, a long-term monitoring has been set up. Long-term monitoring is essential in any protective or recovery initiative in order to address its effectiveness [6]. Here the preliminary results on the collaboration between the ENEA's Marine Environment Research Center and the Egadi Islands' Marine Protected Area (MPA) are reported, presenting the results of the training activities (September 2012) and the preliminary results of monitoring activities carried out by the MPA divers in May-June 2013 (before the AR deployment) and February 2014. A brief discussion on the pros and cons of the methods employed is also reported.

Materials and methods

AR were deployed in June 2013 in several localities chosen by the MPA authority around the Egadi Islands. Each AR unit was composed by a Technoreef® module called Stopnet, equipped with special hooks designed to trap nets and release cords or cables. Stopnet was placed in straight line running out from the coast, forming a barrier to illegal trawling activity.
An appropriate follow-up monitoring protocol to be applied by the MPA marine biologists was set up by ENEA researchers for measuring changes of both seagrass abundance parameters and associated pelagic and necto-benthic fish assemblages [7, 8, 9]. The protocol was defined to ensure an easy collection of basic data by non-experienced divers called for biannual (June and December) field activities to be performed in the same localities (GPS located), before (as reference) and after the AR deployment. Six localities around Favignana Island where chosen by the MPA authority for monitoring (Figure 1). In each locality, five sampling sites were randomly chosen along a 50 m transect parallel along the shore at 12 m depth. At each sampling site, *P. oceanica* canopy cover was visually estimated on a circle with a 5m radius. Shoot density was estimated by counting the number of shoots in six sub-quadrats (20×20 cm), randomly selected on a gridded quadrat of $1m^{-2}$. Shoot percent cover was calculated as the percentage of sub-quadrats containing *P. oceanica* shoots in a total number of 25 quadrats [10]. Along the same transect, abundance of fish species censused in the water column (hereafter called 'pelagic') and on the bottom (hereafter called 'necto-benthic') was estimated trough visual census performed by 2 divers at the same meteo conditions, and between 10 and 14 daytime. Visual census was made at a depth of 3, 6, and 12 m at the beginning and at the end of each transect and at two random, replicate points along the transect at 12 m depth. At each point, fish species abundance was evaluated, sampling a circular area (360°) with a diameter of 5 m. Hence 4 pelagic and 4 necto-benthic fish abundance was estimated. During the survey, seawater temperature (°C), visibility (m), wind direction, and current direction were recorded.
As the level of personal experience may bias the results of visual evaluation of *P. oceanica* cover and fish visual census, an intensive training was done in September 2012 by ENEA marine biologists for MPA divers, to standardize the procedures and the observers' ability to collect accurate data, before the official sampling started. For visual census of fish, underwater tablets with images of the most representative pelagic and necto-benthic species known for the area were fixed up. After a briefing on fish and *P. oceanica* counting methods, two non-experienced MPA divers were trained during a preliminary survey. Surveys were carried out in three days by two couples of divers, each formed by one MPA diver and one ENEA diver. The following dives were scheduled: Cala Rossa West (CRw) and Cala Rossa Center (CRc) the 3rd of September; Cala Rossa East (CRe) and Cala Monaci East (CMe) the 6th of September; Cala Monaci Center (CMc) and Cala

Monaci West (CMw) the 7th of September. Counting of *P. oceanica* shoots were made by one non-experienced MPA diver and one experienced ENEA diver within the same 15 replicate quadrats in each locality (Figure 2). Visual estimation of both *P. oceanica* leaf canopy cover and fish abundance was carried out in pair along the transects. Paired t-tests were used to compare the data acquired in September 2012 and analyze the differences between divers. Monitoring activities were then carried out by MPA divers in May-June 2013 (before the AR deployment) and in February 2014 (after the AR deployment).

FIGURE 1 Map of the 6 localities around Favignana Island chosen for long-term monitoring (© Google Earth)

FIGURE 2 Counting of *P. oceanica* shoots performed during training by one non-experienced MPA diver and one experienced ENEA diver within the 1 m² reference quadrat

Results

Training activity

P. oceanica shoot counts in the quadrats showed no significant differences (P>0,05) between experienced and non-experienced divers, although these latter showed tendency to underestimate the number of shoots per quadrat (Figure 3).

Data on visual estimation of *P. oceanica* canopy cover showed differences (P<0.05) between divers in the first three localities monitored, but in the following period the

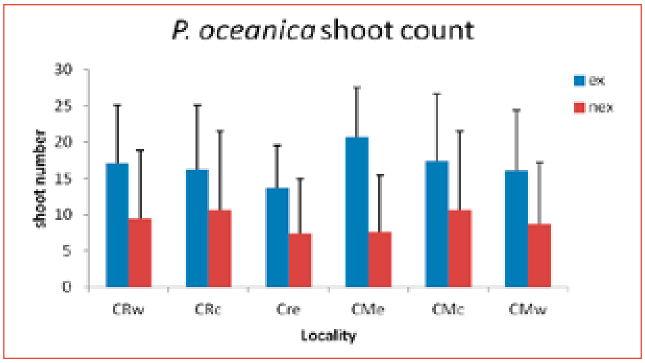

FIGURE 3 Mean number of *Posidonia oceanica* shoots counted by experienced (ex) and non-experienced (nex) divers in five replicate quadrats at each sampling locality. Standard deviations are indicated by bars

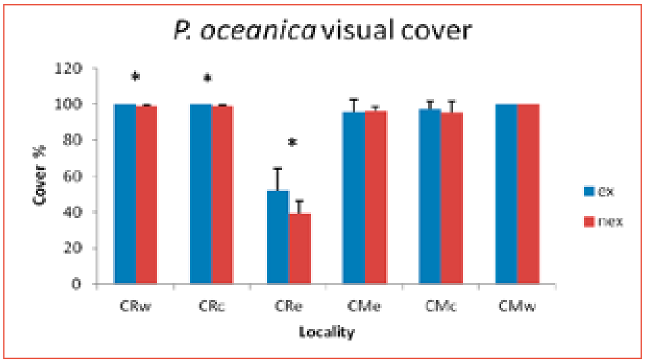

FIGURE 4 Mean percentage cover of *P. oceanica* evaluated by one experienced (ex) and one non-experienced (nex) diver in five replicates at each sampling locality. Asterisks (*) show differences (T-test for dependent samples, P<0,05) between observers. Standard deviations are indicated by bars

data collected by non-experienced (MPA) divers were similar to those from experienced (ENEA) divers (Figure 4). Fish abundance evaluation through visual census showed no differences (P>0,05) both in the case of pelagic (Figure 5) and of necto-benthic fishes (Figure 6). Despite the high variability in counts, abundance of some necto-benthic fishes was overestimated by the non-experienced observers.

Monitoring activities

In 6 localities, the visual estimation of *P. oceanica* canopy cover of the meadow ranged between 100% (Cala Monaci W) and 42% (Cala Rossa E) in 2012, between 99% (Cala Monaci E) and 58% (Cala Rossa E) in 2013, between 98% (Cala Monaci E) and 72% (Cala Rossa E) in 2014 (Figure 7). The mean shoot number · m^{-2} of the meadow ranged between 381 (Cala Rossa E) and 540 (Cala Monaci E) in 2012, between 370 (Cala Rossa E) and 500 (Cala Rossa W) in 2013, between 337 (Cala Rossa E) and 468 (Cala Rossa C) in 2014 (Figure 8). Generally, higher values of cover % corresponded to higher shoot number · m^{-2}, as recorded at Cala Monaci E, Cala Rossa E and Cala Rossa C.

On the whole, 32 fish species were censused during the monitoring activities performed in 2012, 2013, 2014 (Table 1). Most of them (21) were those recorded on the bottom, 11 were found in the water column (see Materials and Methods).

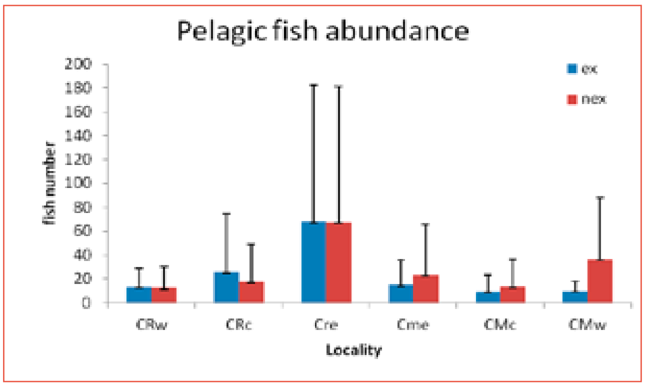

FIGURE 5 Mean pelagic fish species abundance evaluated by one experienced (ex) and one non-experienced (nex) diver in the six localities. Standard deviations are indicated by bars

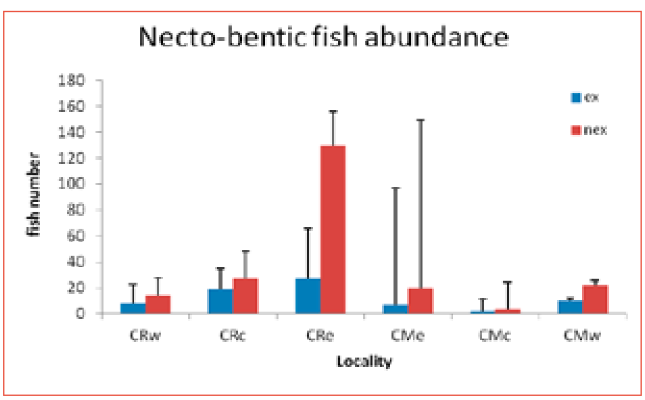

FIGURE 6 Mean necto-benthic fish species abundance evaluated by one experienced (ex) and one non-experienced (nex) diver in six localities. Standard deviations are indicated by bars

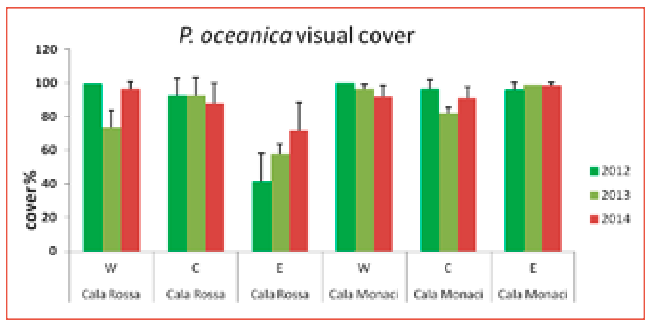

FIGURE 7 Mean percentage cover (± S.D.) of the meadow estimated in 6 localities in 2012, 2013, 2014

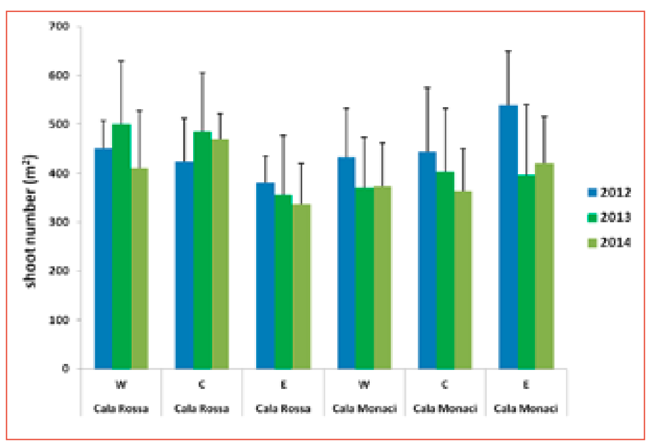

FIGURE 8 Mean shoot number· m^{-2} (± S.D.) counted in 6 localities in 2012, 2013, 2014

FAMILY/SPECIES

FAMILY/SPECIES
Atherinidae
Atherina sp.
Serranidae
**Epinephelus marginatus* (Lowe)
**Serranus cabrilla* (Linnaeus)
**Serranus scriba* (Linnaeus)
Apogonidae
**Apogon imberbis* (Linnaeus)
Carangidae
Seriola dumerilii (Risso)
Sparidae
Boops boops (Linnaeus)
Diplodus annularis (Linnaeus)
Diplodus sargus (Linnaeus)
Diplodus vulgaris (Geoffroy Saint-Hilaire)
Oblada melanura (Linnaeus)
**Sarpa salpa* (Linnaeus)
Spondyliosoma cantharus (Linnaeus)
Centracanthidae
Spicara smaris (Linnaeus)
Scienidae
**Sciaena umbra* Linnaeus
Mullidae
**Mullus surmuletus* Linnaeus
Pomacentridae
Chromis chromis (Linnaeus)
Sphyraenidae
Sphyraena viridensis Cuvier
Labridae
**Coris julis* (Linnaeus)
**Labrus merula* Linnaeus
**Labrus mixtus* Linnaeus
**Labrus viridis* Linnaeus
**Symphodus doderleini* Jordan
**Symphodus mediterraneus* (Linnaeus)
**Symphodus melanocercus* (Risso)
**Symphodus ocellatus* (Forsskål)
**Symphodus roissali* (Risso)
**Symphodus rostratus* (Bloch)
**Symphodus tinca* (Linnaeus)
**Thalassoma pavo* (Linnaeus)
**Xyrichtys novacula* (Linnaeus)
Bothidae
**Bothus podas* (Delaroche)

TABLE 1 List of 32 fish species censused in 2012, 2013, 2014. Asterisks (*) indicate necto-benthic fish species

In 2012, 29 fish species belonging to 12 families (Atherinidae, Serranidae, Apogonidae, Carangidae, Sparidae, Centracanthidae, Scienidae, Mullidae, Pomacentridae, Sphyraenidae, Labridae, Bothidae), where censused in the 6 localities (Tab. 2). The most numerous family was that of Labridae (10 species), followed by Sparidae (7 species), 3 species belonged to Serranidae, 1 of each species represented the other families. In 2013, 7 families (Atherinidae, Serranidae, Sparidae, Centracanthidae, Mullidae, Pomacentridae, Labridae) were recorded, 25 fish species in total (Table 2). The most numerous family was that of Labridae (12 species), followed by Sparidae (7 species). In 2014, the number of fish species was lower (17) when compared with the previous census (Table 2) and belonged to 6 families (Serranidae, Sparidae, Centracanthidae, Mullidae, Pomacentridae, Labridae), being Sparidae and Labridae the most represented ones (6 species). The other families were present with 2 species (Serranidae) or 1 species.

	Cala Rossa W	Cala Rossa C	Cala Rossa E	Cala Monaci W	Cala Monaci C	Cala Monaci E	TOTAL
September 2012	6 - 9	5 - 7	5 - 8	7 - 6	6 - 7	8 - 7	29
May-June 2013	5 - 1	11 - 7	12 - 7	6 - 2	7 - 5	4 - 6	25
February 2014	6 - 5	6 - 6	6 - 6	5 - 5	6 - 2	6 - 3	17

TABLE 2 Number of necto-benthic and pelagic fish species associated to the meadow censused in 6 localities in 2012, 2013, 2014

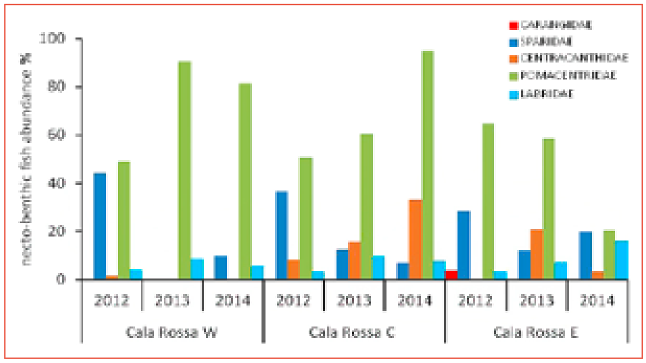

FIGURE 9 Abundance (%) of necto-benthic fish families censused at Cala Rossa W, Cala Rossa C, and Cala Rossa E in 2012, 2013, 2014

In 2012, the majority of pelagic species were Pomacentridae (94-98%), with *Chromis chromis* the most represented fish species. Differently, in 2013 no pelagic species were censused at 2 localities (Cala Rossa W, Cala Monaci W), whereas in the other localities Pomacentridae was the most abundant family, then Centracanthidae and Atherinidae. No pelagic species were seen in the column water in 2014 in all localities.
Among necto-benthic species, in 2012, 2013, 2014 Pomacentridae was the most abundant family at Cala Rossa localities (Figure 9), whereas at Cala Monaci localities many families contributed to fish assemblages. In 2013 and 2014, 3 localities of Cala Monaci displayed a different fish composition, Labridae contributing by 80% at Cala Monaci W to fish assemblages.

Conclusions

The results here reported, referring to the training activities carried out in September 2012 and the monitoring activities carried out in May-June 2013 and February 2014, have to be considered as the beginning of the ongoing long-term monitoring prefigured for at least 5 years to evaluate effectiveness of Stopnet AR in limiting the impact of trawling on *P. oceanica* meadow at Favignana Island. In February 2014, seagrass abundance parameters did not differ from those previously recorded and indicated high densities and cover such as those referred to good health meadows [5]. Differences in abundance (%) of necto-benthic fish families found during monitoring could be determined, in addition to the natural variability of fish assemblages [7], to sampling period. Performing periodic (seasonal) sampling activity is fundamental to establish the temporal distribution of fish assemblages and to estimate their quantitative variation among periods, even if the factors influencing the distribution are numerous and can apply at different scales [7].
Both the methods and parameters chosen for monitoring showed their reliability in training non-experienced personnel for data collection in MPA. One-week training for divers with a good basic knowledge on fish taxonomy and good diving skill is appropriate for a team to monitor areas of interest within the MPA. Our experience suggests that few, essential monitoring parameters can be easily collected by non-experienced divers in a few days, working at safety depths (no more than 15 metres). This approach is of great value to the MPAs interested in gathering continuous and long-term data on the health status of the protected environment and in acquiring baseline information for the evaluation of protection and conservation actions.
The proposed monitoring method should be replicated at least two times a year to gather significant and comparable data. Care should be devoted to accuracy in sampling the same site, in the same month and, at least for fish abundance evaluation, at the same hour of the day. Moreover, in order to evaluate the AR effectiveness it is mandatory that any follow-up monitoring program lasts for at least 5 years. Improving the proposed method with the collection of data on the physical-chemical water characteristics of the studied habitat could be easily achieved through the use of today's easy-to-use probes, that can be deployed by personnel onboard during dive time. Hence, the collected data can be stored in a database managed by the MPA and, if needed, shared with a scientific institution for data analysis and interpretation.
As far as we know, a first, clear indication of the 'indirect' dissuasive action performed through the AR deployment at Favignana is the 50% reduction of violations by illegal fishing trawlers recorded locally in 2014. Other management and conservation actions by the MPA and the Port authority -such as notification of illegal trawling sighting, fishing license suspension, in-the-field control, vessel position tracking control based on AIS data payment of penalty- could beneficially complement.

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Multifunctional structure made with seagrass wrack: A patent of the GE.RI.N project

ENEA and the Egadi Islands Marine Protected Area (MPA) have completed some experiments in order to recover and use seagrass wrack for the restoration of emerged and submerged coastal areas in Favignana Island (Western Sicily, Italy). A multipurpose facility built with beached biomass, comprising a casing made of biocompatible fibre and filled with wrack harvested from the beaches, has been implemented. The canvas has a mesh greater than a specific dimension, and biocompatible fibres have undergone transverse and longitudinal tensile strength. It is a structure made of natural materials and eligible for multi-purpose applications, that is used for the realization of "mats" stuffed with seagrass wrack, collected from emerged beaches. The results of such realisation under the GE.RI.N project were the increased carrying capacity of the beaches as the removal of beached biomass and the disposal of the structures on rocky shores enhance the available area for tourist recreation and bathing. The structures are also suitable as a substrate for the re-establishment of seagrass shoots on the sea bottom, which is essential for maintaining the presence of the meadow to reduce coastal erosion. As part of the GE.RI.N project, the patent number RM2014A000151, registered on March 24, 2014, has been deposited and is now available for licensing. A design implementation of the structure is under development in collaboration with the University of Rome Sapienza – Architecture Science in Product Design, as part of a degree thesis project, titled *Medonia*

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Introduction

The carrying capacity of pocket beaches can be significantly influenced by the presence of infrastructures, waste and other human activities on shore. In addition, during the winter, beached seagrass biomass (seagrass wrack) is deposited along the coasts: poorly tolerated by tourists, it is very often removed during the summer [1] [2]. Many national and international projects have recently investigated the possibility and feasibility to reuse seagrass wrack to avoid disposal of this natural bio-resource into landfill [2] [3] [4]. Many industrial applications have been investigated by several authors to produce cellulose [5], green composite and thermo-acoustic insulating material [6] [7].

The schematic flow diagram reported below (Figure 1), illustrates the possible management options of *Posidonia oceanica* wrack, emerged during the project POSIDuNE [8] and selected by the European Union as a "Best Practice" [9].

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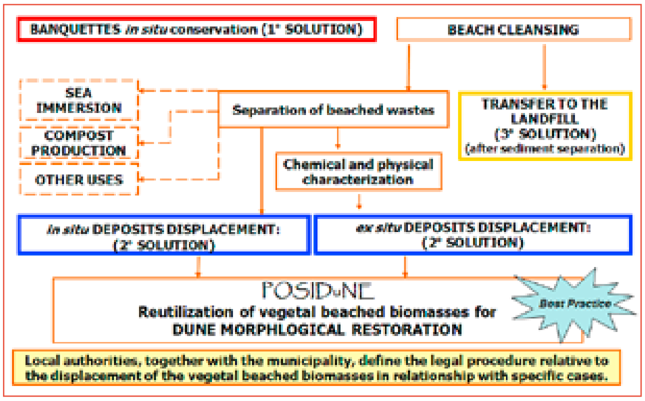

FIGURE 1 Flow diagram of management options for seagrass wrack (POSIDuNE, 2014). The dashed lines represents the potential solutions that have been implemented during GERIN

Such options are described in Circular no. 08123 issued by the Italian Ministry of the Environment on 17th March, 2006 that, for all the cases, constrains local authorities and municipalities to define the legal procedure for displacement of the vegetal beached biomasses in relation to specific cases [10].

From a technical point of view, many licences have been produced in the last 20 years concerning the use of new technologies for *Posidonia oceanica* conservation, management or transplanting on the sea floor. By using the keyword *P. oceanica,* a patent review was carried out on dedicated web pages [11] [12] [13] in order to detect and analyse 45 products deposited between 1944 and 2013. Twenty-one of these patents are dated back to the last two decades (between 1993 and 2013; Figure 2).

The most significant details of some patents deposited to date are briefly reported as follow.

In 1998, Dounas proposed an integrated planting system through the use of metal pipes on sandy seabed [14] (EP - 897 034 B1; Figure 3).

Meinesz *et al.* in 1993, through the company's Dragon-Sub Palma de Mallorca (Balearic Islands, Spain), applied a national patent (ES 2069504) that describes a detailed procedure to repopulate the seabed of seagrass by using individual metal supports to fix single plants on the sandy bottom (Figure 4). This paper [15] presents many similarities with the European patent presented by the same author through the University of Nice in 1992 and published in 1994 (FR 2695536 B1).

Vicente and Torres, Oficina Técnica de Edificacio of the Ciutata Vella (Valencia, Spain), in 2006 deposited a national patent (ES 2259524) on a mooring system for light boats, that is aimed at the preservation of the meadow in order to avoid damage to the biocenosis on the seabed (especially when colonized by seagrass *Posidonia oceanica* in particular) by using a system of lifting chains and ropes sealed on the sea floor [16] (Figure 5).

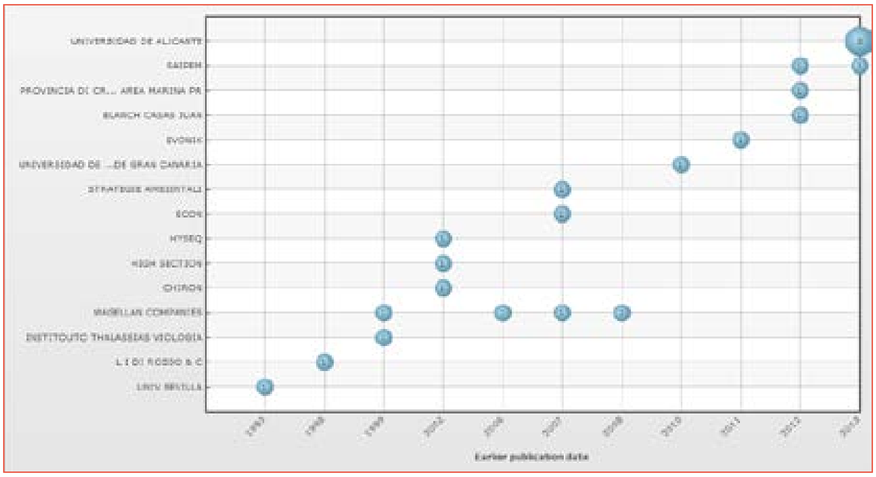

FIGURE 2 Main patents on conservation, transplanting and reuse of *Posidonia oceanica*

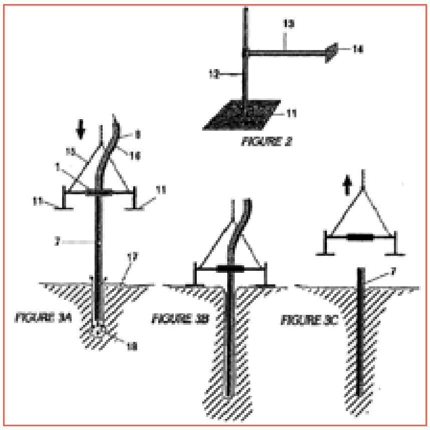

FIGURE 3 Modified Figure 2 (top) and Figure 3 (down) from license EP–897034 B1

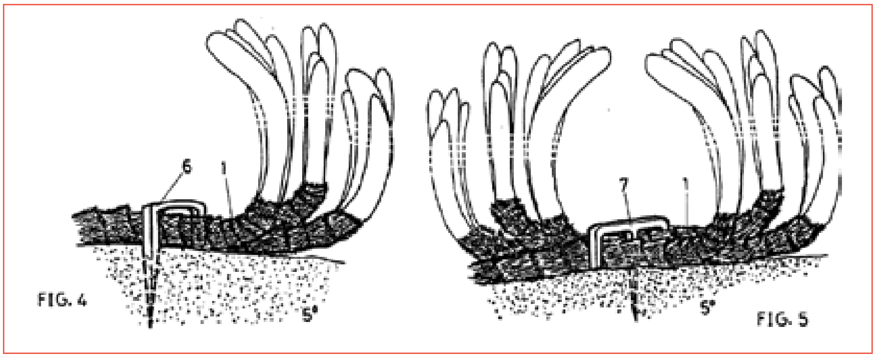

FIGURE 4 Modified Figure 4 (left) and Figure 5 (right) of licence ES 2 069 504

In 2013, Magliola et al. of Saipem SpA, presented a European patent (EP548435 A1) concerning the use of pre-fabricated structures, weighed down by blocks of limestone, that is located directly on the sea bottom through mechanical devices. Such structures form modules on which rhizomes, cuttings or plants of Posidonia can be replanted randomly, or in rows, through the use of plastic inserts [19] (Figure 8).

The GE.RI.N subproject, Natural Resources Management, as part of the "Eco-innovation Sicily" project, carried out by ENEA with the aim of developing technologies to promote sustainable tourism, has provided specific actions for use and restoration of beaches aimed at increasing the carrying capacity. Environmental sustainability and management of biological resources are two main deliverables of the projects.

Therefore, particular emphasis has been dedicated to the implementation of new processes and products derived by Banquettes management (Figure 9). The need to manage the beached biomass leads ENEA and the Municipality of Favignana, as the managing body of the Egadi Islands Marine Protected Area (MPA), to complete some experiments to reuse wrack for the restoration of emerged and submerged coastal habitats in Favignana Island.

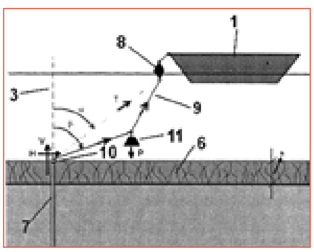

FIGURE 5 Modified from licence ES 2259524

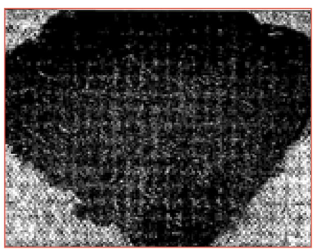

FIGURE 6 Modified from licence EP 2 078 452 B1

In 2010, Meier claimed a substrate of plant and/or soil for the germination, growth and/or cultivation of plants in emerged (crops) environment that contains different percentages of fibres deriving from *Posidonia oceanica, Posidonia australis* and/or *Cymodocea nodosa* (EP 2078452 B; Figure 6). There is no specific reference in this patent for sea immersion and the replanting and/or restoration of the meadow [17].

Faidutti *et al.* in 2012, through the company Saipem SpA (ENI Group, Italy), presented a method for the transplantation that involves the placement on the seabed of clumps of Posidonia through a complex automated system mobilised by a ship or a floating pontoon [18] (EP 2510770 A1; Figure 7).

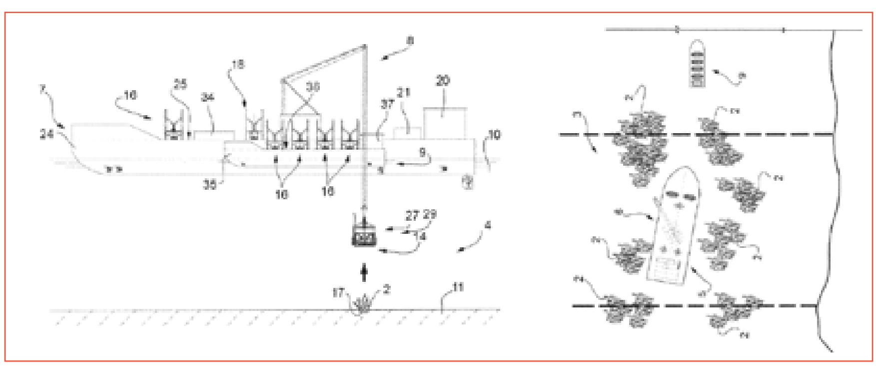

FIGURE 7 Modified from Figure 1 (left) and Figure 13 (right) of licence EP 2510770A1

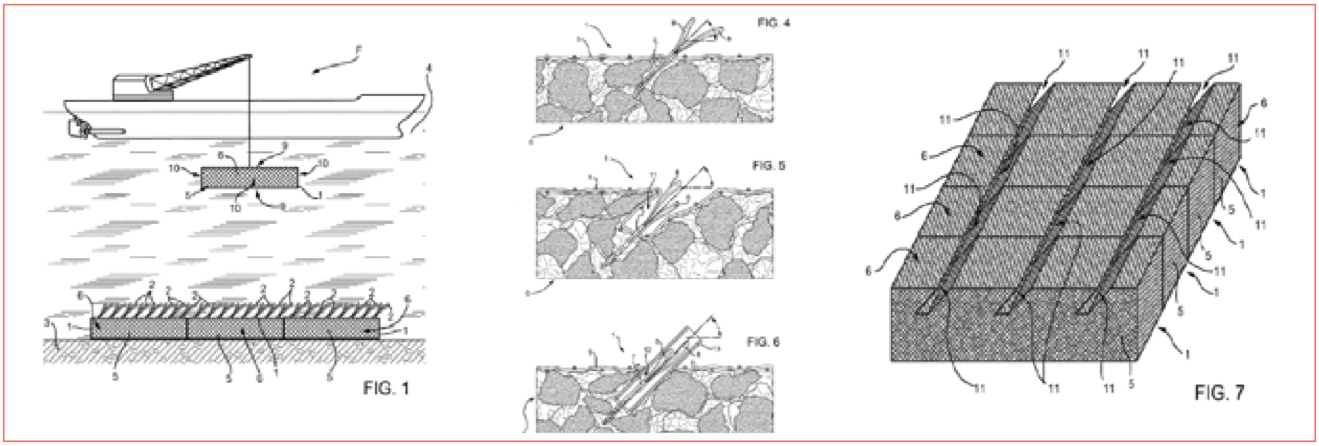

FIGURE 8 Modified from Figure 1,4,6,7 of licence EP548435 A1

FIGURE 9 *Posidonia oceanica* wrack on a pocket beach of Favignana

Material and methods

The first action of the project has been the analysis of the public environmental awareness, carried out in order to investigate if and how tourists could tolerate the presence of marine plants laying on the beaches of Favignana Island. Then, a procedure has been implemented in order to remove all the waste that may be present on the beach.

Afterwards, the recover and the use of vegetal biomasses has been carried out for:

1. beach restoration and improvement of the beach access;
2. compost production;
3. restoration of the meadows and the seabed showing signs of regression of Posidonia (due, for example, to the anchors or the illegal trawling at the coast).

In the present study, we describe a multipurpose facility, designed and built with beached biomasses covered by a casing made with biocompatible fibre padding and with biomass harvested from the beaches.

In Figure 10, three different steps of preparation of the structures are clearly illustrated. A first use of the structure is "*in situ*". On stretches of rocky coast adjacent to the point of collection, the "mattress" can be arranged in order to obtain an area useful for bathing and tourist recreation and to overcome those rocky outcrops that otherwise do not allow to take advantage of sharp and rough surfaces.

A second use, is to dive the structure, preferably below the closure depth (Figure 11), which can be calculated by using Hellermeier's equation [20] e [21].

Results

According to the study of ENEA, carried out in the summers of 2012 and 2013 through the distribution of a questionnaire and the appropriate data analysis, about 60% of the tourists visiting the Egadi Islands knows the ecological importance of the Posidonia seagrass. Nevertheless, for 33% of the tourists the beached debris of the seagrass represents a problem: they associate this debris to inconveniences related

FIGURE 10 Preparation of bio-mats (1). Collection of biomass (2). Filling and closing of bio-mats (3)

to an aesthetic factor (35%), to the smell (35%), and to the reduced area of beach (30%). Although these biomasses are essential to preserve natural habitats and to protect beaches from erosion, their presence is an inconvenience for a reduced, but still significant, part of visitors (Figure 12).

For this reason, on July 2013, the structures consisting of biodegradable coconut biomats, filled with the remnants of *P. oceanica* removed from the shore, were prepared following the methodology described above. Some beaches were partially freed by the deposits of marine plants, returning to full fruition during summer (period of greatest tourist visits).

The "mats", stuffed with seagrass collected from the beaches, make them eligible to avoid accessibility of tourists close to unstable and rocky cliffs (Figure 13a) and to cover on rocky and rough areas (Figure 13b). They are also suitable as a substrate for the restoration of the sea floor, and replanting the bottom of shoots of *P. oceanica*, essential for maintaining the presence of the meadow, was tested (Figure 13c). In addition, a preliminary requalification project was presented at CoastExpo 2013 (Remtech Conference), providing a solution to improve the accessibility to Cala Azzurra beach through the creation of natural and more comfortable walkways (Figure 13d).

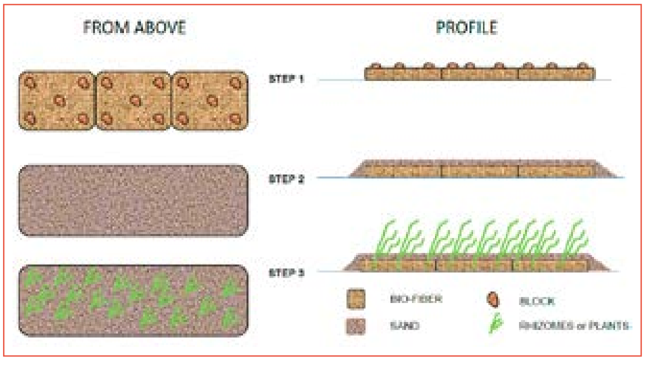

FIGURE 11 Positioning of the bio-mats on the seabed in three steps

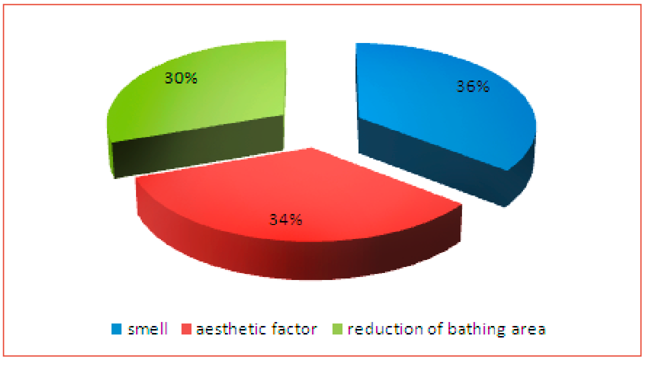

FIGURE 12 Results of the questionnaire prepared by ENEA and filled by 682 tourists

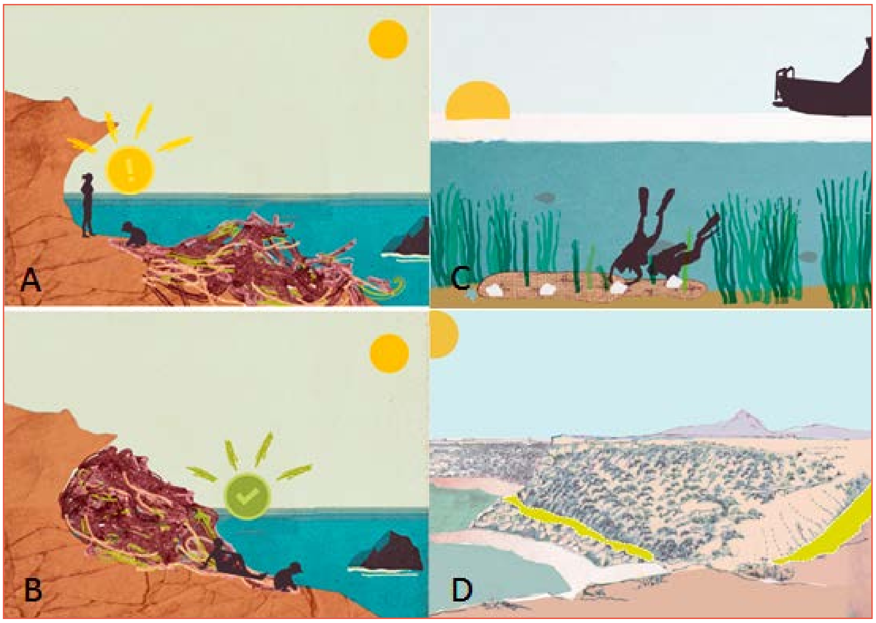

FIGURE 13 A and B) Schematic representation of in situ deposit displacement carried out in Favignana to avoid access of tourists close to unstable rocky shores and positioning of mats on rocky outcrops to increase the beach. C) Example of immersion of the bio-mats on the seabed. D) Example of application of bio-mats to create paths in Cala Azzurra (modified from Ingoglia, 1999) [21]

Discussion and conclusions

The work presented in this paper is a part of a multidisciplinary project related to the characterisation and the restoration of coastal areas. A natural structure has been realized in order to produce "mats" stuffed with seagrass collected from the beaches.

The choice of the product on the free market is subject to various factors and a wide variability of characteristics and price may occur. Nowadays, many products with similar characteristics are available on the market. They are made of jute, coconut and other natural fibres which provide jerseys with known weights per unit area, expected duration in humid or submerged environments, and other technical specifications that can lead to identify eligible materials to be used for different purposes.

A patent with several claims has been deposited, concerning the multifunctional structure made of beached biomasses realised under the GERIN Project. It may have different size and / or shape and is suitable on rocky areas and as a substrate for transplanting shoots and rhizomes and plants of *P. oceanica* and/or other vegetal species on the sea bottom. The most promising application of the multifunctional structure is onshore, where it can be used to increase the carrying capacity of beaches and rocky shores, to create walk-paths or deckchairs for recreational activities.

Such application, essential for maintaining the presence of the meadow, which is an indicator of the health status of the sea, is also crucial to reduce coastal erosion through the root system that holds the removal of sand during storms. In addition, the prospective for compensation strategies is promising, as many infrastructures and works are often not approved due to the environmental impact they may have on the *Posidonia oceanica* meadow, which is an ecosystem with a very high economic value. Therefore, if the monitoring of such intervention will confirm the positive trend of preliminary results, a new technology can be applied and/or implemented for seagrass replants by using the sea immersion approach.

Based on the adopted methodology, and the actions of management and environmental restoration described above, the GE.RI.N project was awarded with the Green Coast Award 2013. After this prestigious recognition, a collaboration between ENEA and the Science in Product Design Dept. of University of Rome "Sapienza" started on summer 2014 in order to create a new generation of biocompatible products that could increase the carrying capacity of rocky shores and create multifunctional structures for coastal areas with low environmental impact. In particular, De Simone

FIGURE 14 Three-dimensional rendering of biocompatible products for multifunctional structure and their potential use in coastal areas

[22], under the supervision of Prof. Cristallo, discussed a master degree thesis, titled *Medonia*, focusing on research and assemblage of biocompatible materials, and their applications in industry and designs [23]. Some of these applications, still under investigation, are illustrated in Figure 14.

Considering that in Italy about 28000 state concessions of coastal areas are given to private parties and most of them are facing many problems with the management of vegetal beached biomasses, the potential of green jobs and the economic benefits coming from the solution implemented under GERIN and suggested in *Medonia* are promising.

Acknowledgements

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