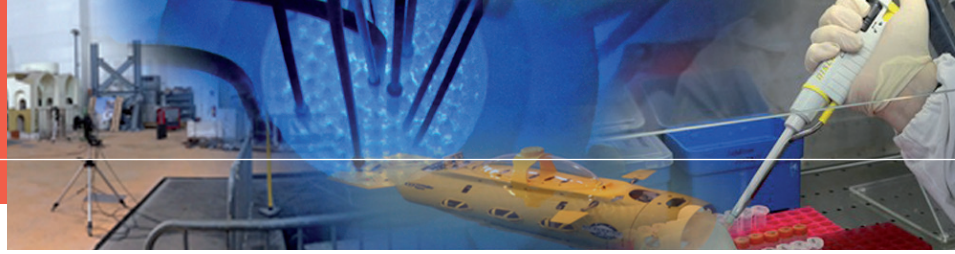

Multifunctional structure made with seagrass wrack: A patent of the GE.RI.N project

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*

DOI 10.12910/EAI2015-074

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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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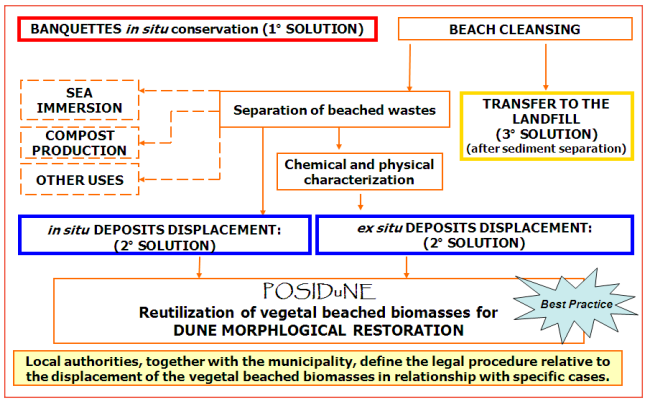

FIGURE 1 Flow diagram of management options for seagrass wrack (POSIDuNE, 2014). The dashed lines represents the potential solutions that have been implemented during GERIN

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).

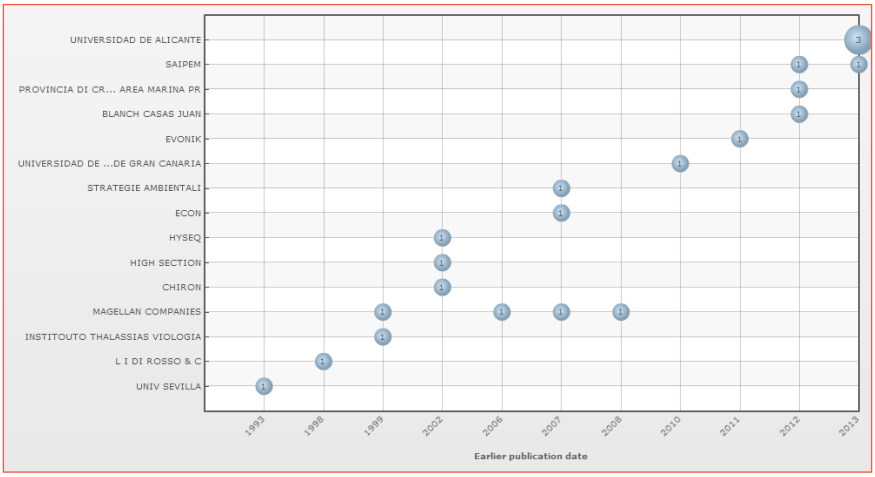

FIGURE 2 Main patents on conservation, transplanting and reuse of *Posidonia oceanica*

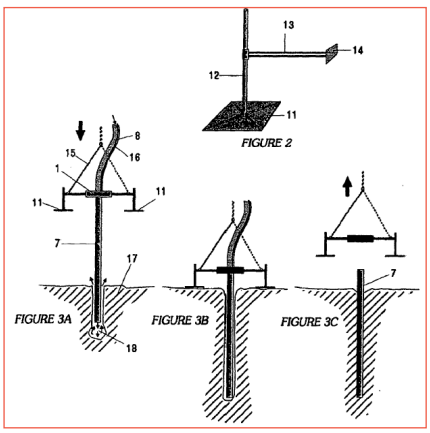

FIGURE 3 Modified Figure 2 (top) and Figure 3 (down) from license EP–897034 B1

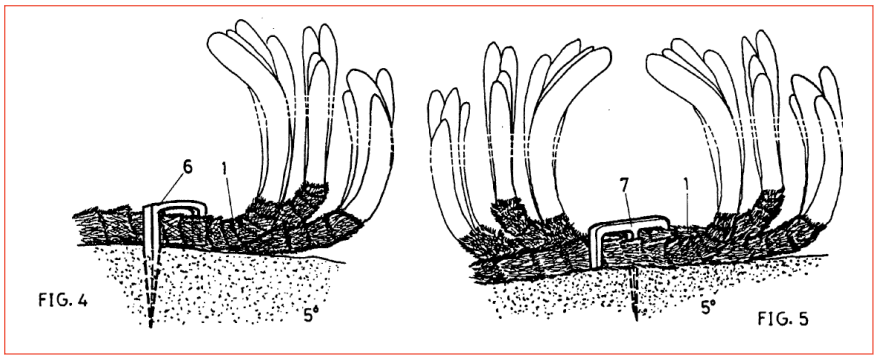

FIGURE 4 Modified Figure 4 (left) and Figure 5 (right) of licence ES 2 069 504

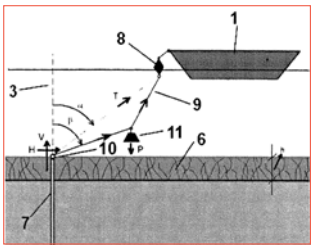

FIGURE 5 Modified from licence ES 2259524

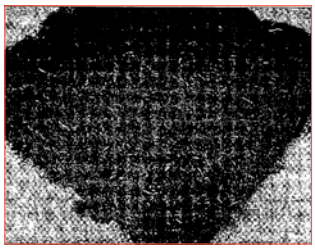

FIGURE 6 Modified from licence EP 2 078 452 B1

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).

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.

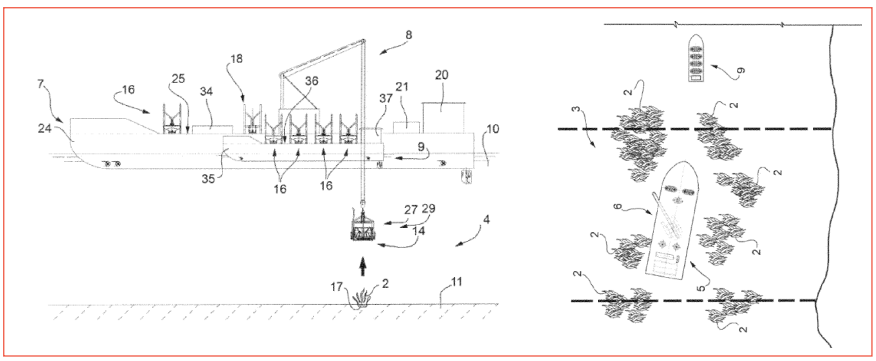

FIGURE 7 Modified from Figure 1 (left) and Figure 13 (right) of licence EP 2510770A1

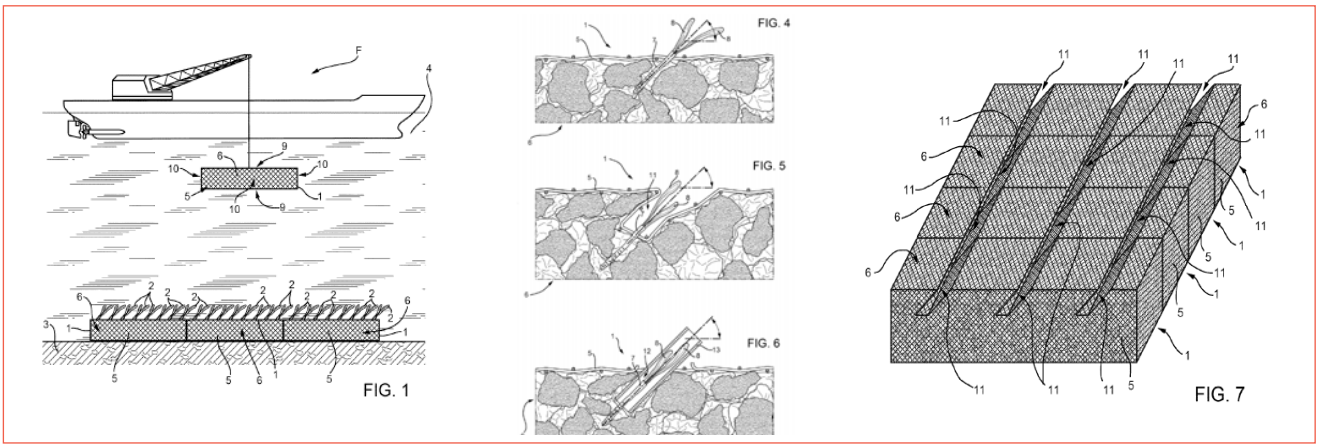

FIGURE 8 Modified from Figure 1,4,6,7 of licence EP548435 A1

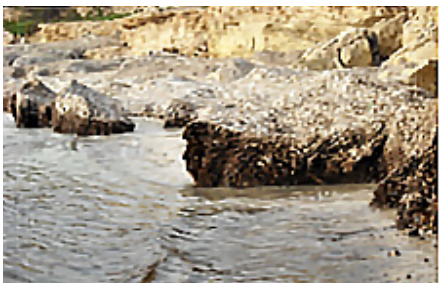

FIGURE 9 *Posidonia oceanica* wrack on a pocket beach of Favignana

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).

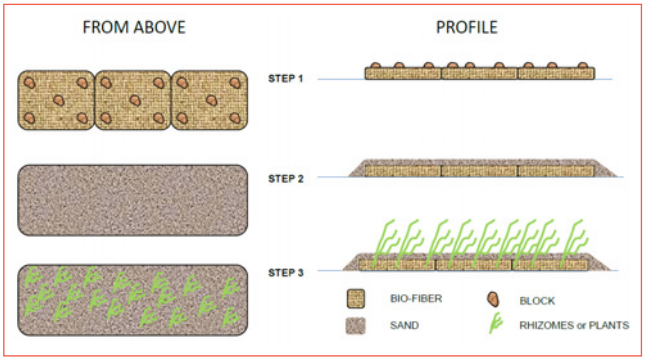

FIGURE 11 Positioning of the bio-mats on the seabed in three steps

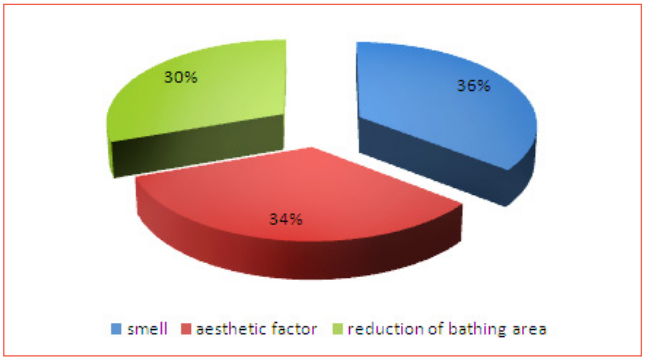

FIGURE 12 Results of the questionnaire prepared by ENEA and filled by 682 tourists

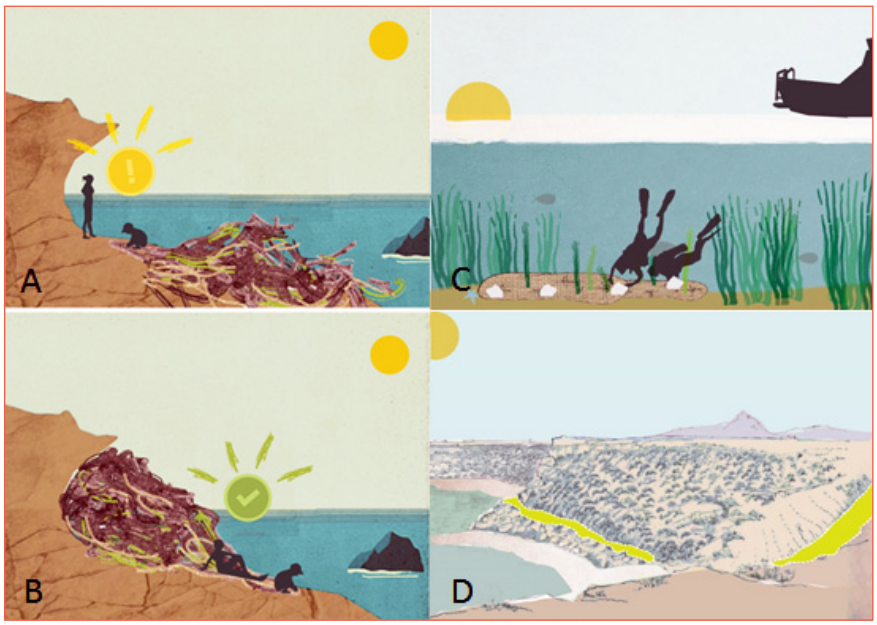

FIGURE 13 A and B) Schematic representation of in situ deposit displacement carried out in Favignana to avoid access of tourists close to unstable rocky shores and positioning of mats on rocky outcrops to increase the beach. C) Example of immersion of the bio-mats on the seabed. D) Example of application 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

Special thanks are due to all the staff of the Marine Protected Area of Egadi Islands and to Mr. Nicolò Ponzè, Pietro Patti Genovese and Giuseppe Cammareri for their huge effort and competence during the "*in situ*" survey and sea immersion of the bio-mats.

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