Stazione Zoologica Anton Dohrn Napoli

BLUE MARINE FOUNDATION

AEOLIAN ISLANDS PRESERVATION FUND

Characterization of Posidonia oceanica *meadows in the Island of Salina (POMIS)*:

Establishment of a long term monitoring network.

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1.-INTRODUCTION

The project:

The Aeolian archipelago is composed of seven volcanic Islands facing the north-eastern coast of Sicily in the Tyrrhenian Sea: Alicudi, Filicudi, Lipari, Panarea, Salina, Stromboli and Vulcano. The archipelago is of great natural and cultural value, with an economy based mainly on fishery and tourism. The establishment of new initiatives for preserving the natural heritage of the islands and for fostering their sustainable economic growth and development is of great importance for the future of the Aeolian society.

The POMIS project arouse from the growing concern about the progressive decline that *Posidonia oceanica* meadows are experiencing in the Mediterranean Sea during the last decades as a consequence of the increasing human pressure and the environmental changes associated to global climate change. In this frame, the Stazione Zoologica Anton Dohrn (SZN), one of the oldest and famous marine research Centre in the world, in collaboration with the Blue Marine Foundation, a charity dedicated to creating marine reserves and establishing sustainable models of fishing, and the Aeolian Preservation Fund, dedicated to preserve the natural values of the Aeolian Islands, have launched an initiative to characterize and monitor in the long term the conservation status of *P. oceanica* meadows around the Island of Salina.

The main goals of the project are:

- Start-up of a monitoring network to determine the long term evolution and the state of health of the *P. oceanica* meadows of the Salina Island, by measuring appropriate biological descriptors with an annual frequency.
- Monitoring of invasive species, in particular the invasive tropical algae *Caulerpa cylindracea* and *C. taxifolia*, in the coastal area and their effects on native habitats, especially on meadows of *Posidonia oceanica*.
- Starting a database, in which the information obtained will be included, that will represent an useful and dynamic tool for the management of key marine habitats of the Salina Island.

Seagrasses:

Seagrasses are a group of marine plants that, similarly to marine mammals, have returned to the sea after their evolution on land, colonizing most coastal areas around the world. With an estimated global generic value of US$ 2.8 × 10^6 yr^{-1} km^{-2}, seagrasses form some of the most valuable ecosystems on earth. They are considered "ecosystem engineers", that form essential habitats for economically important fish and crustaceans, and provide crucial ecological services, including nursery grounds, sediment trapping and stabilization, nutrient filtering from coastal inputs, and carbon sequestration. Primary productivity of seagrasses and their associated epiphyte community rivals or even exceeds many cultivated terrestrial ecosystems, supporting densities of fish and invertebrates significantly higher than those of unvegetated benthic habitats.

Seagrass ecosystems are being lost globally at an unprecedented rate, due to climate change, acidification and local and global disturbances. The decline in seagrass cover entails the reduction or even loss of biodiversity, primary productivity, local fishing grounds and an increase in coastal erosion. Taken together, loss of these ecosystems will lead to severe ecological and socio-economic consequences.

From the nearly 60 species of seagrasses described worldwide, five are present in the Mediterranean Sea: *Posidonia oceanica*, *Cymodocea nodosa*, *Zostera noltii*, *Zostera marina* and *Halophila stipulacea*, which is a tropical species introduced into the Mediterranean from the Red Sea, through the Suez channel.

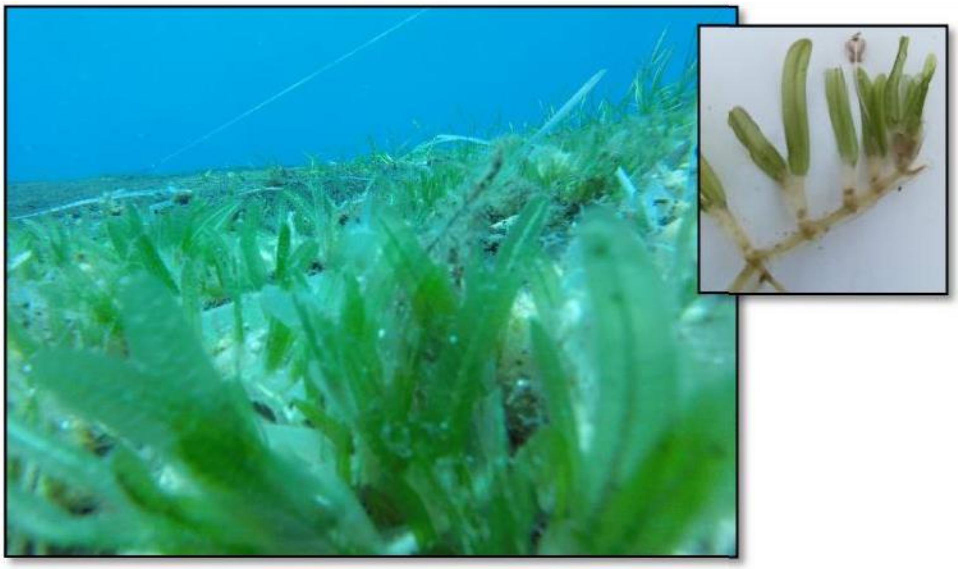

Figure 1. The seagrass *Halophilastipulacea* growing on soft bottoms of the Salina Island. The presence of the species has been observed on sites where *P. oceanica* meadows showed signs of damage due to frequent boat anchoring. The species is of tropical origin and is progressively distributing toward the western Mediterranean most likely due to seawater warming associated to global climate change.

In the Mediterranean basin, the most abundant species are *P. oceanica* and *C. nodosa*. The former is endemic to the Mediterranean Sea, while the latter also grows in adjoining areas of the Atlantic Ocean (from southern Portugal to Senegal).The two species have important differences in their biological and ecological attributes, and while *P. oceanica* is a large-sized species with one of the slowest growing rates in the plant kingdom and with individuals that can persist from centuries to millennia, *C. nodosa* is a pioneer, fast-growing and colonizing species of medium-size. *P. oceanica* meadows are one of the most important habitats in the Mediterranean Sea due to their abundance and extension and to the role they play in the marine ecosystem.

***Posidonia oceanica*:**

P. oceanica is distributed along the coasts of the entire Mediterranean basin and forms highly productive ecosystems that fulfill important ecosystem services:

- They are the most productive habitat in the Mediterranean Sea, being the main source of organic matter and oxygenation.
- The play a key role in coastal nutrient cycling and are responsible for maintaining the quality and clarity of coastal waters, which is key to preserve the touristic interest on the Mediterranean countries.
- In shallow waters, they form barrier reef-like structures that maintain the coastal sediment balance; their dense leaf canopies and the accumulation of fallen leaves on beaches reduce wave energy and currents, protecting the coast from erosion.
- As habitat-forming species, they provide habitat for hundreds of species of flora and fauna, many of them of commercial interest, being thus of great importance for the maintenance of local and traditional fisheries.

- Recently, it has been demonstrated that *P. oceanica* meadows play a major role in the fixation and sequestration of blue carbon (carbon stored in coastal vegetation). The organic structure (i.e. matte) formed by the high primary production of *P. oceanica* contains a very important accumulation of the fixed organic matter constituting a long-term carbon sink. It has been estimated that up to 89% of CO_2 emissions produced by Mediterranean countries through combustion of fossil hydrocarbons since the beginning of the industrial revolution are sequestered within the existing *P. oceanica* meadows.

Value of *P. oceanica* meadows has been recently estimated to reach172 € m^{-2} y^{-1}, almost 2 orders of magnitude higher than the value estimated for seagrasses in general. These estimations did not include all the services that meadows offers and which are of great value (e.g. carbon sequestration). For instance, the organic carbon retained in *P. oceanica* meadows all around the Mediterranean is estimated to cost between 138 – 1120 billion €, considering that a ton of carbon dioxide in Europe is paid around 15€ in the carbon market. This represents additional 6 – 23 € to each m^2 of meadow, being this value associated to the capacity to sequester carbon from 9 to 35 times higher than one square meter of tropical forest soil.

Figure 2. The seagrass *Posidonia oceanica* growing on the Island of Salina.

P. oceanica is extremely sensitive to moderate-to-high disturbance often associated with highly human-impacted coasts and its beds have suffered a progressive regression, mostly due to the enhanced water turbidity associated to eutrophication processes. The geographic and depth distribution of *P. oceanica* is tightly linked to light penetration in the water column. Shoot density is rapidly decreasing, up to 50% over a few decades and increased turbidity and pollution have resulted in a squeeze of the beds that, in some cases, have withdrawn between 10 and 20 m depth. The strong decline of the *P. oceanica* populations in the Mediterranean is historically linked to a variety of human activities:

- Illegal trawling on bottoms less than 50 m depth is one of the original causes of degradation of deep meadows, due to the direct and strong physical impact associated with the activity and to the indirect effect associated to sediment resuspension that buries plants and reduces the amount of available light below the minimal light requirements of the species.
- The construction of coastal infrastructures (e.g. ports, breakwaters, etc…) that modify coastal dynamics and affect the sedimentary conditions, impacting meadows development.
- Boats' anchoring also causes significant damage on this key habitat. The mechanical effect of anchors removes plants and creates wounds on the meadow that are subsequently eroded by the hydrodynamic forces produced by waves and currents.

- Dredging activities for the provision of sediments for the construction and maintenance of artificial beaches also produce similar impacts.
- The toxic effects on plants and marine organisms and the alteration of water quality caused by chemical contamination are also important causes of meadow degradation.
- Increased organic matter content in the sea bottom as a consequence of aquaculture practices alters the physico-chemical condition of the sediments rendering them toxic for marine plants.
- Trophic chain alterations due to overfishing or excessive input of nutrients can favor the proliferation of particular species (e.g. algae, sea urchins), with the potential to produce cascade effects leading to meadow degradation.
- Small changes in seawater salinity, mainly associated to the seawater desalination industry, affect plant vitality and survival being the cause of meadow degradation in several Mediterranean areas.
- Introduction and spread of invasive species, as for instance the seaweed species *Caulerpa cylindracea* and *C. taxifolia,* which are potential competitors for resources of marine plants, may have adverse effects for the health and distribution of the meadows.
- The effects associated to the ongoing global climate change (e.g. seawater warming and acidification, rising sea levels) are also causing the regression of seagrass meadows worldwide and their affects are expected to be more pronounced in the Mediterranean due to its small size and limited exchanges with larger oceanic basins.

The number of documented cases of meadow regression due to the direct and indirect effects of the above mentioned human activities, single or in combination, are increasing. It is, therefore, urgent to acquire a correct knowledge on the evolution of *P. oceanica* populations in time in order to develop adequate conservation and management measures that guarantee their sustainable functioning in the future.

In the European Union (EU), seagrasses have been legally recognized in the Water Framework Directive (WFD, Directive 2000/60/EC) as key coastal ecosystems. Seagrasses have been identified as bioindicators and Biological Quality Elements (BQEs). *P. oceanica* is included in the Red List of marine threatened species of the Mediterranean and meadows are defined as "priority" natural habitats on Annex I of the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora.

Monitoring network:

Environmental monitoring is the repeated observation of an ecosystem with the main aim to detect changes in its structure and ecological status and, to provide environmental management agencies with useful information and knowledge to guaranty its conservation. A monitoring network of seagrasses is composes of a network of sampling stations distributed along the coast of a given region in which a series of measurements are conducted each year. In the Mediterranean, the first experience in seagrass (i.e. *P. oceanica*) monitoring was developed on the 80s by French researches of the *GIS Posidonie*. In 1984 they created a network of 33 stations for monitoring the biological status of *P. oceanica* meadows all along the Mediterranean coast of France.

Currently, many countries worldwide have their own seagrass monitoring network adapted to the particularity of the species and the habitat they form. Since the end of the XX century, many monitoring programs are grouping together for creating regional and/or global monitoring networks with the ultimate aim to preserve seagrass meadows and to increase scientific knowledge and public awareness about this threatened and valuable ecosystem. At the global level, Seagrass-Watch (http://www.seagrasswatch.org) and SeagrassNet (http://www.seagrassnet.org/) integrate hundreds of sites distributed along the coasts of dozens of countries for the long-term ecological monitoring of seagrasses. At the Mediterranean level, there is not a regional integration of the existing networks, which are operating for decades in most

Mediterranean countries, but some initiatives are currently ongoing on that direction as for instance the POSIMED project (http://posimed.org/).

One of the most relevant new features that monitoring networks have included in the last two decades is the participation of voluntary divers as a way to integrate the environmental education in their programs. The participation of voluntary divers brings the citizens closer to scientific issues of interest and increases the level of environmental awareness in the society.

Figure 3. Logo of some global (Seagras-Watch and SeagrassNet) and regional (PosiMed) seagrass monitoring networks.

The feasibility of seagrass monitoring networks is based on a series of basic requirements. The temporal scale of programs should be long enough to allow detecting changes within the natural cycles of the population dynamics and to allow interpreting their significance and direction. Programs should also include a wide number of stations that represent different environmental conditions (e.g. depth, orientation) and threats in the area (e.g. ports, trawling, anchoring). The provision of data must be done using strong and effective sampling methodologies. These methodologies should preferably be standardized and easily to reproduce in order to reduce error level when comparing measures conducted by different persons or between sites and times. The descriptors used in the programs should be easy to measure and should reflect the ecological status of meadows. These requirements should guarantee the reliability of the data collected for their use for scientific and management purposes.

General objectives of the POMIS project

The project has two main general objectives:

a) Scientific: obtaining scientific data to assess the long-term evolution of the meadows of *Posidonia oceanica* growing around the Island of Salina.

b) Policy: development of an environmental tool to support the management and conservation of the marine environment of the Aeolian Archipelago.

In the future, it would be expected the project to add a new general objective, the Social one, through the participation of volunteer divers in the follow-up scientific tasks, fostering an approach of citizens to scientific topics and increasing the level of environmental awareness of society.

Specific objectives

a) Start-up of a monitoring network to determine the evolution to long term and the state of health of the underwater meadows of the Salina Island, by measuring appropriate biological descriptors with an annual frequency.

b) Monitoring of invasive species, and in particular the invasive tropical algae *Caulerpa cylindracea* and *C. taxifolia* in the coastal area and their effects on native habitats, especially on meadows of *Posidonia oceanica*.

c) Creation of a database with the information obtained that can be useful for the management of marine habitats.

Future specific objectives to be added to the project include:

d) Implement and coordinate a volunteer network that participates in the development of the Program.

e) Develop training actions for volunteers in the monitoring network that ensure the scientific quality of the data obtained.

2.-METHODOLOGY

Hypothesis

The working hypothesis in the establishment of a monitoring network in the Salina Island is to determine the state of health of *P. oceanica* meadows and their long term evolution in order to detect potential threats that may influence their conservation status. Through the analysis of the inter-annual variability of selected meadow descriptors it is possible to determine population trends, which can be summarized in three different status: stable, regressive or progressive. Meadows can be stable if they do not evidence significant changes in time or if these changes fluctuate without a clear temporal trend. On the other hand, if the temporal dynamic of descriptors showed a clear positive trend then the meadow is considered to be in progression. Finally, meadows are experiencing regression if the inter-annual variability of the descriptors showed a negative trend.

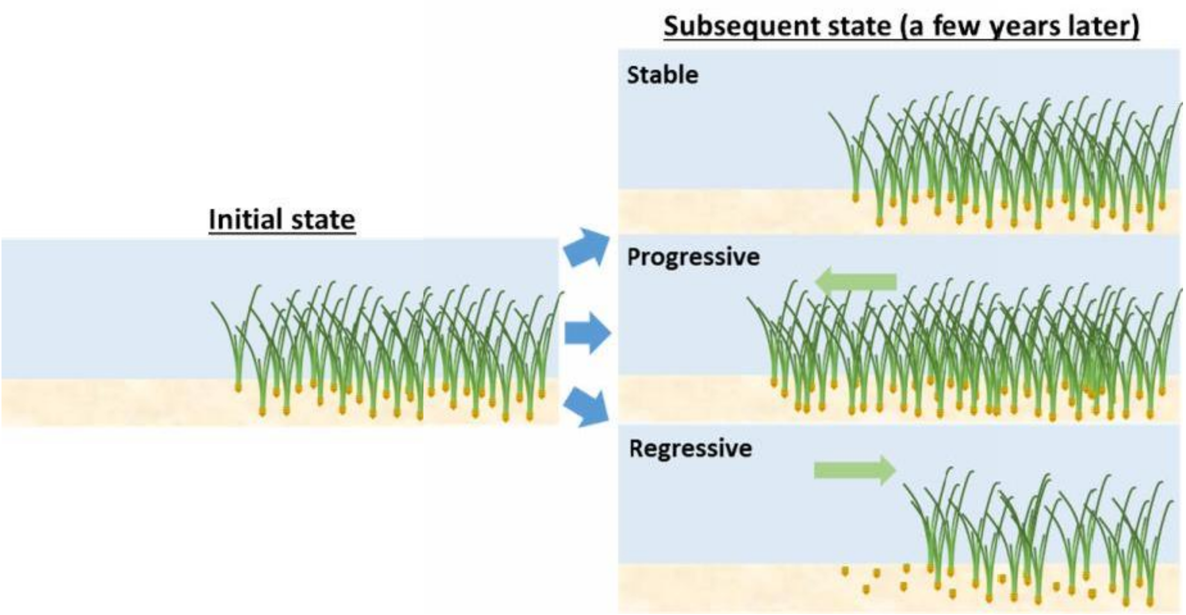

Figure 4. Possible conservation status of *P. oceanica* meadows on the basis of their population trends.

Sampling stations

Eleven sites were selected around the Island of Salina for establishing the network of monitoring stations. These sites were chosen to include different typologies of sea bottom (hard and soft), different depths and coastal orientations, in the monitoring program. Sites were also selected to encompass the potential effects of the three main human settlements in the Island (Santa Marina, Malfa and Rinella) and main coastal activities (e.g. ports, recreational boating and sailing). Sites away from the influence of direct human activities were also selected to be used as controls and sentinels for climate change.

Figure 5. Location of the 11 monitoring sites distributed around the Island of Salina (from Google Earth)

The installation of the monitoring stations and data collection were conducted by the working team during two weeks in the months of June and July 2018. Each station is composed of 4 fixed sampling points (Q1–Q4, Figure 6) in which the measures are taken, and one iron bar with a small buoy rising above the meadow canopy to locate and facilitate finding the station. In each sampling point, a 40 x 40 cm quadrat was installed using four angle irons inserted in the sea floor and linked at the sediment surface with a rope. Fixed quadrats were separated by 5-15 m, numbered with plastic clamps and marked with a small buoy. The distance and the angle between quadrats were recorded in order to facilitate sampling points finding and the reconstruction of the station, if needed.

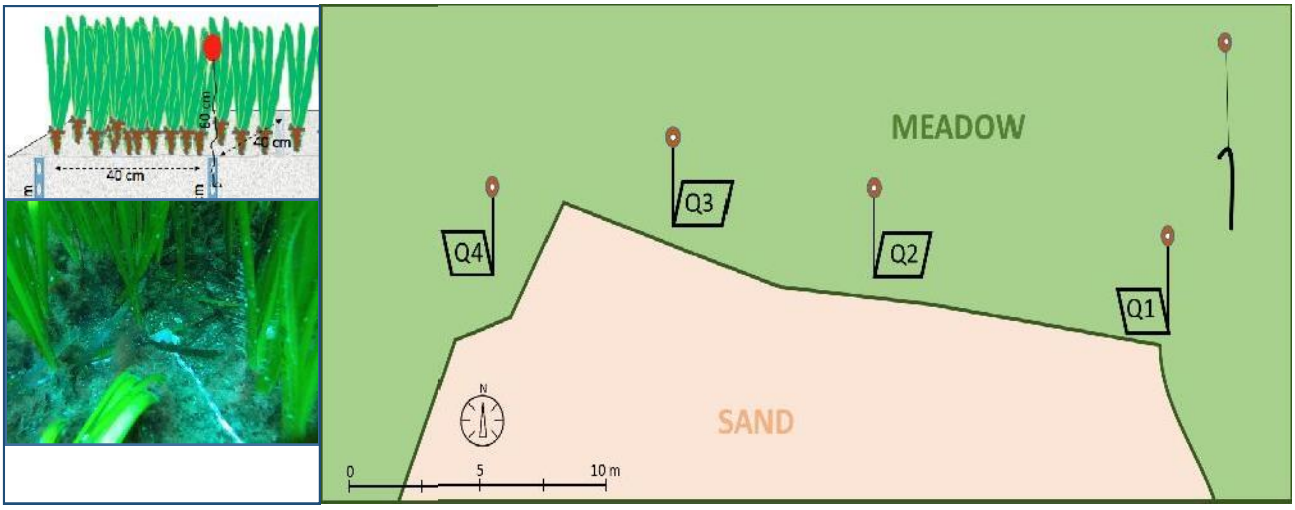

Figure 6. Scheme of a 40 x 40 cm fixed quadrat for plant density characterization (upper left panel). Four angle irons of 20 cm length are inserted into the sediment to make up the corners of the quadrat. Angle irons are joined with a rope to form the perimeter of the quadrat (lower left panel). Schema of a monitoring station with the four fixed quadrats (Q1–Q4) and the short iron bar with a buoy protruding from the meadow canopy to locate the station (right panel).

Sampling material

The material needed for underwater work included:

1. A mesh bag for transport the material
2. One 40x40 cm PVC frame subdivided in four 20x20cm quadrats
3. A 10-m measuring tape
4. A 50-m measuring tape
5. A 20cm length iron bar to fix the measuring tape
6. Underwater compass
7. A plastic ruler of 20 cm
8. A plastic tablet with an attached pencil and data sheet

The whole set was carried by each of the four scuba divers.

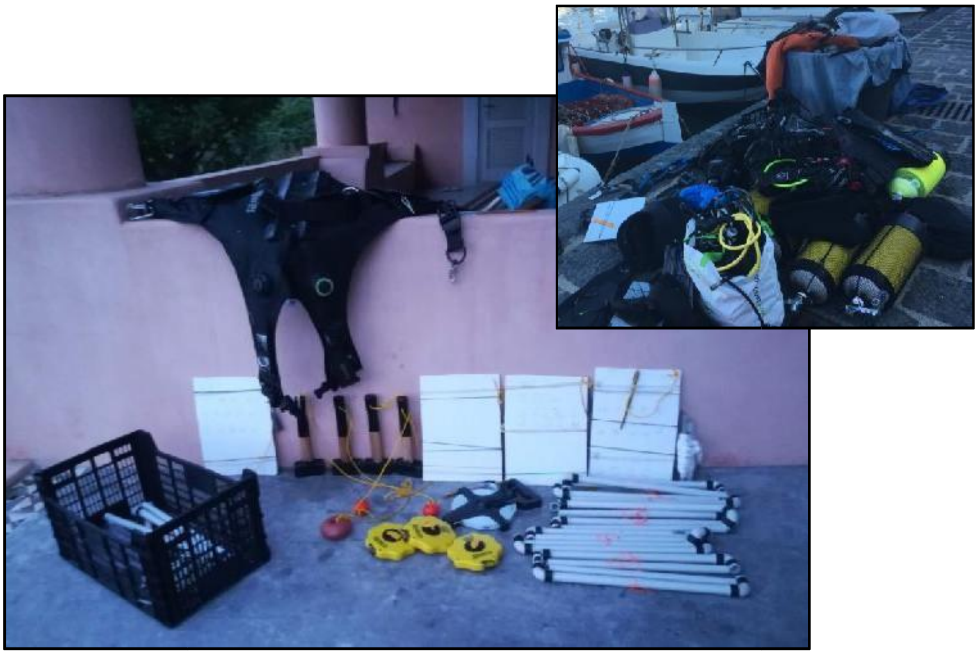

Figure 7. Material used during the course of the project for establishing monitoring stations and for carrying out meadow measures.

Descriptors

A seagrass descriptor is a characteristic of the plants or the meadow that reflects the state of health and conservation of the habitat. There is a wide set of descriptors at different levels of biological organization, from genes to the whole ecosystem, which are commonly used in science to define the biological status of seagrass meadows. For the purposes of the project we have selected a set of meadow structural descriptors that are easy to collect and cost-effective and that reflects changes in the ecological status and functionality of seagrass meadows. The selected descriptors include:

- Shoot density
- Meadow cover
- Shoot burial
- Abundance of key meadow species

Shoot density

Figure 8. Scuba diver counting shoots within a 40x40 cm fixed quadrat to calculate shoot density

Shoot density is the number of shoots per unit of surface area of the seabed. Due to the high number of plants within a meadow, which in shallow meadow stands can be higher than 1000 shoots m^{-2}, the descriptor is measured by counting the number of shoots within 40x40 cm quadrats and expressed as number of shoots per m^2. The descriptor reflects the abundance of plants and, when measured on the same quadrat in successive years, is a good indicator of ***P. oceanica*** population dynamics and of the evolution of the meadow structure. This measure is conducted twice in each of the four fixed quadrats and averaged to estimate shoot density of a particular meadow area.

Meadow cover

The descriptor meadow cover, which is also a measure of abundance, reflects the proportion of the sea bottom that is covered by plants. The descriptor is calculated through a visual estimation of the percentage of seabed that is covered by living plants. The estimation is done using a 40x40 cm square-frame subdivided into four 20x20 cm sub-squares. The percentage of meadow cover is estimated for each of the four 20x20 quadrats and then averaged. The measure is repeated on each meter along a 10-m measuring tape, and then averaged for the whole 10m-transect. In order to make the estimation comparable between different years, measuring tapes (i.e. transects) should be extended following a given angle from the fixed quadrat. Meadow cover is estimated for each of the four fixed sampling points (i.e. Q1 – Q4) and then averaged to represent the percentage of meadow cover of the site.

Figure 9. Scuba divers performing a visual estimate of the percentage of seabed covered by living plants to estimate meadow cover.

Shoot burial

The descriptor is an estimation of the degree of burial of plants and can give indication of changes in the sedimentary dynamics of the site. Shoot burial is characterized by measuring the vertical distance between the seafloor and the ligule of the outermost leaf of the shoot. The value of the measure and its sign depend on the net balance between plant vertical growth and the sedimentary dynamic of the site: i) the sign of the descriptor is positive when the seafloor is below the ligule; ii) the value is zero when the sediment surface is at the height of the ligule and; iii) the sign is negative when the ligule is below the seafloor and hence, buried inside the sediments. A clear progressive trend of the descriptor indicates changes in the sedimentary dynamics of the area. For instance, plants are progressively buried if excessive sedimentation occurs within the meadow, which represent a real threat for the species due to its high sensitivity to burial. On the contrary, under a situation of deficit in sediment accretion within the meadow or increased erosion, plants are progressively more exposed and thus, more vulnerable to high hydrodynamic and strong currents. This measure is conducted in five randomly selected shoots from the proximity of each fixed sampling point.

Abundance of key meadow species

The descriptor gives an idea of the presence and abundance of species of interest in the studied meadow. These species play a key role in the functioning the ecosystem (e.g. herbivores, feeding filters) or are considered unique, vulnerable or threatened. We have also included a few invasive species that have the potential to out-compete native species. The abundance of the selected species is recorded when they are found inside the 40x40 cm quadrats used along the 10 m transect for meadow cover estimation.

Sea urchins (*Paracentrotuslividus* and *Sphaerechinusgranularis*) are generalist herbivore echinoderms that feed on algae and seagrass leaves, as well as on plant debris, some sessile animals and organic particles from the water column. Their abundance within *P. oceanica* meadows is generally low but their populations can sharply increase due to increased organic matter inputs or the removal of their predators. Under such circumstances, sea urchins have the potential to alter the meadow structure through increased herbivory pressure.

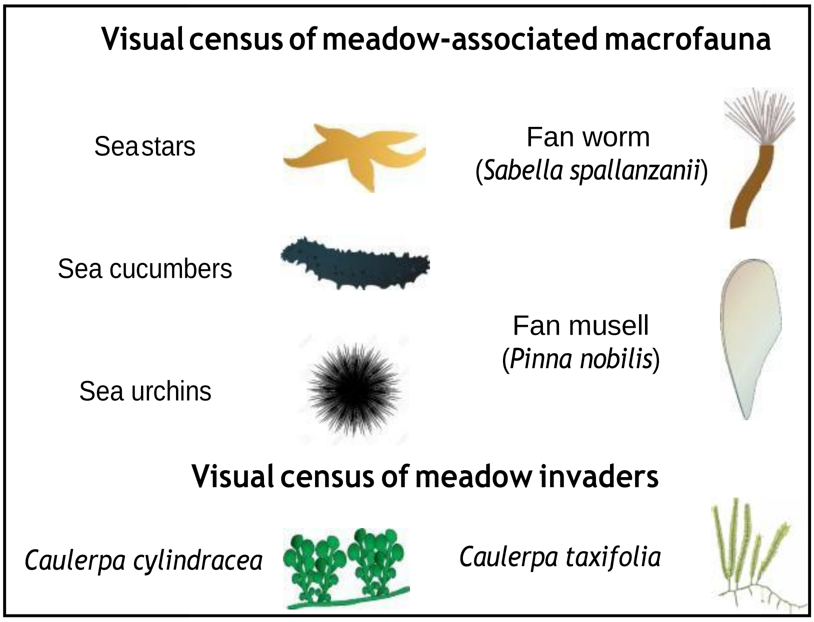

Figure 10. List of meadow-associated macrofauna and meadow invaders selected in the project.

Fan worms (*Sabella spallanzanii*) are polychaetetube worms with a filter feeding habit. They capture bacteria, plankton (zooplankton and phytoplankton) and suspended particles of organic matter with their feeding tentacles. They are considered common indicators of good water quality.

Sea cucumbers (*Holothuriasp*) are detritivous echinoderms that feed on organic particles adhered to sediments including microalgae. Their populations can grow under conditions of increased matter content in sediments being in such cases considered indicators of sediment quality.

Fun mussel (*Pinna nobilis*) is the larger bivalve mollusk in the Mediterranean Sea. The species is endemic of the Mediterranean Sea, where it lives along a bathymetic gradient from 0.5 m down to 60 m depth. The species has a filter-feeding diet and is abundant within *P. oceanica* meadows due to the high primary productivity of the meadows and their role in the retention of suspended particles. It is highly vulnerable to pollution and to the mechanical impact produced by anchoring and trawling. *P. nobilis* populations are experiencing mass mortality across a wide geographical area of the western Mediterranean Sea in the last two years, reaching 100% mortality rates in some regions (e.g. Levantine coast of Spain). The cause seems to be a digestive parasite, specifically a protozoan of the genus *Haplosporidium* that is putting them in danger of extinction.

Sea stars (*Ophidiasterseepositus*) are omnivore echinoderms that mainly feed on mollusks and brittle stars and carrion.

Caulerpa cylindracea and ***C. taxifolia*** are one of the major seaweed invaders in the Mediterranean. Since the beginning of the 90's they have rapidly spread all around the Mediterranean causing ecological and economic damage. Dense and healthy *P. oceanica* meadows are resistant to the invasion of these species, mainly due to the strong light reduction caused by the meadow canopy that limits the successful growth of the invaders. Disturbed meadows, however, are vulnerable to the spread of these species and most impacted *P. oceanica* meadows are at present colonized by at least one of these alien species. The production of allelopathic substances by these seaweeds has the potential to produce adverse effects on *P. oceanica* plants as well.

3.-RESULTS

STATION 1: TRE PIETRE

The monitoring station 1 is located in the southern coast of the Island of Salina at approximately 50 meters off the three small rocky reefs that give rise to its name, Tre Pietre. The bottom in the area is mainly rocky with a marked slope and with the presence of big boulders and stones produced by cliffs erosion. The four fixed sampling points constituting the station were distributed within a large meadow patch following the 15 meter bathymetric line. Installation of sampling points and the completion of the measurements was done on the 12th of June 2018. The geographical coordinates of the station are shown in Table 1.

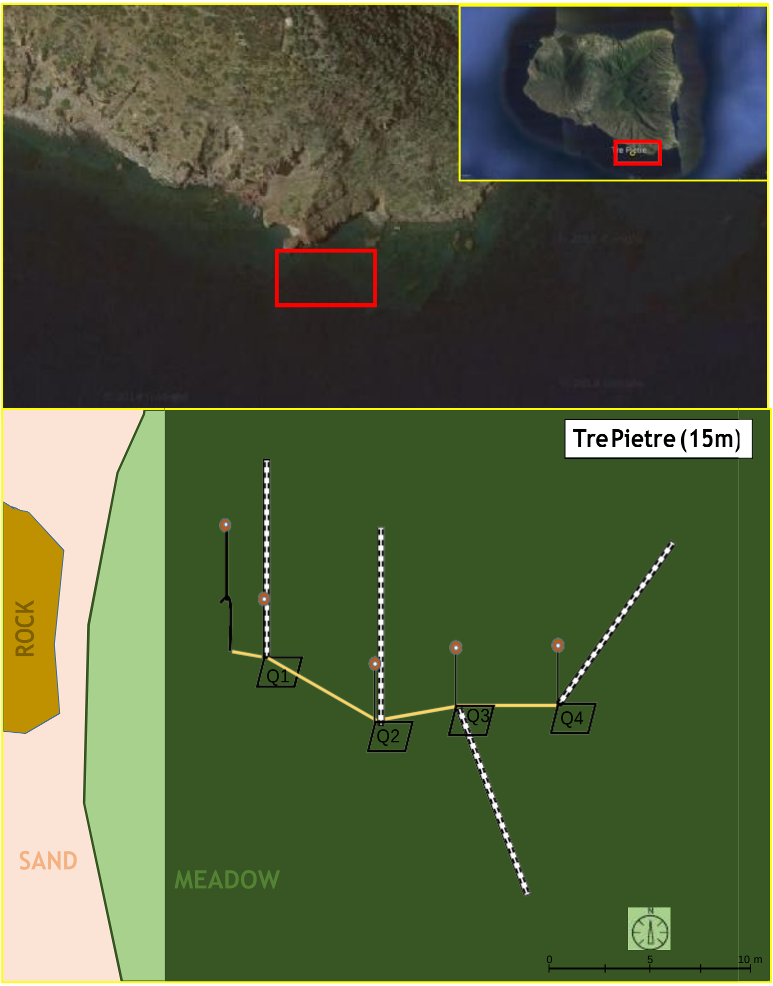

Figure 11. Geographic location of Tre Pietre station (upper panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (lower panel).

Station name	Tre Pietre
Depth	15m
Coordinates - Latitude	38° 32.135' N
Coordinates - Longitude	14° 50.904' E
Sampling date	12/06/2018

Table 1.Tre Pietre station, general information.

The average meadow density of the station was 736 ± 198 shoots m^{-2}, with minimum and maximum values of 519 and 988 shoots m^{-2}, respectively. The percentage of meadow cover varied between 48.5 and 74.9, with an average value of 64.4 ± 13.0 %.

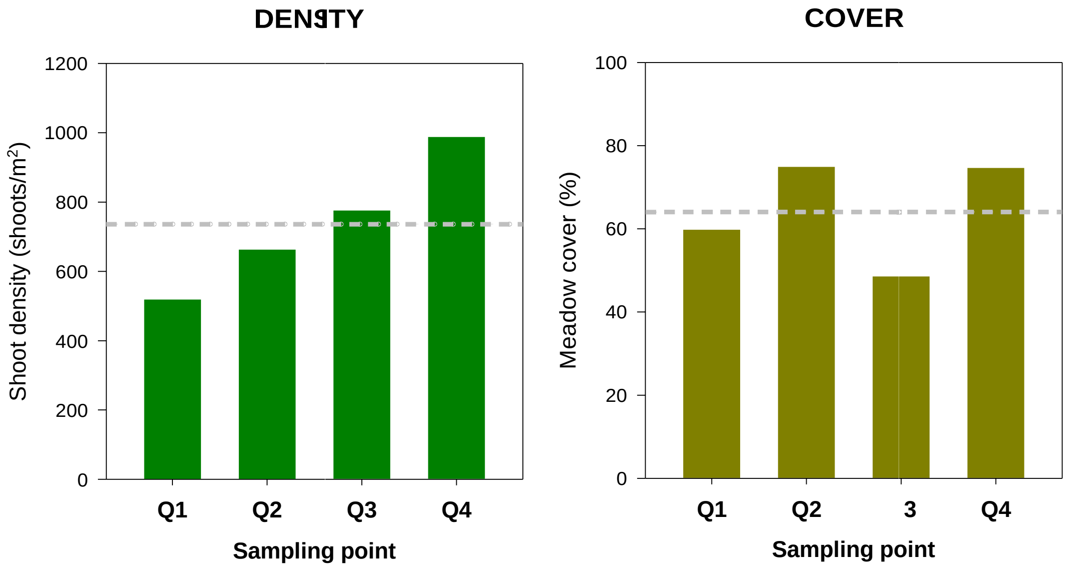

Figure 12. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Tre Pietre station. Grey dashed lines represent the average value for the station.

Shoot burial was fairly homogeneous and ranged between 5.4 and 6.4 cm, with an average value of 5.8 ± 0.4 cm. Although the site is frequented by sport divers no signs of regression or impacts were visually detected in the area, as supported by the positive and homogeneous values of shoot burial. Novel divers usually produce sediment resuspension with two potential negative effects on plants. One is the reduction in the amount of light available for plants to growth; and the other is plant burial, which can be lethal for the species when the frequency of divers is high in the area. The station, which is far from human settlements, did not show signs of regression or damage and no invasive algae were observed in the area. One fan worm was recorded inside the 40 x 40 cover quadrats.

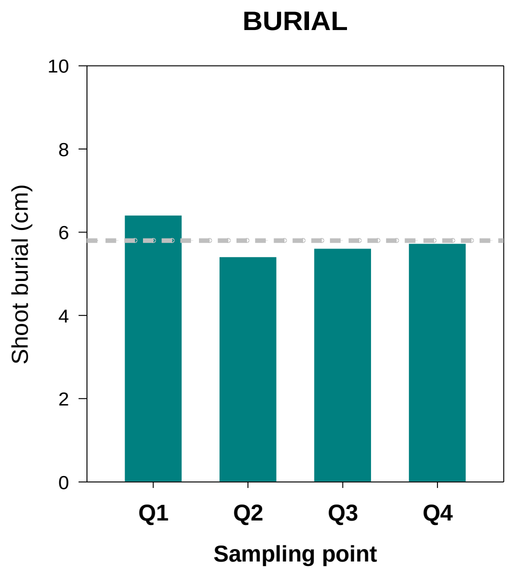

Figure 13. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Tre Pietre station. The grey dashed line represents the average value for the station.

Figure 14. A 10-meters long transect extended above the meadow for the characterization of meadow cover at the Tre Pietre station.

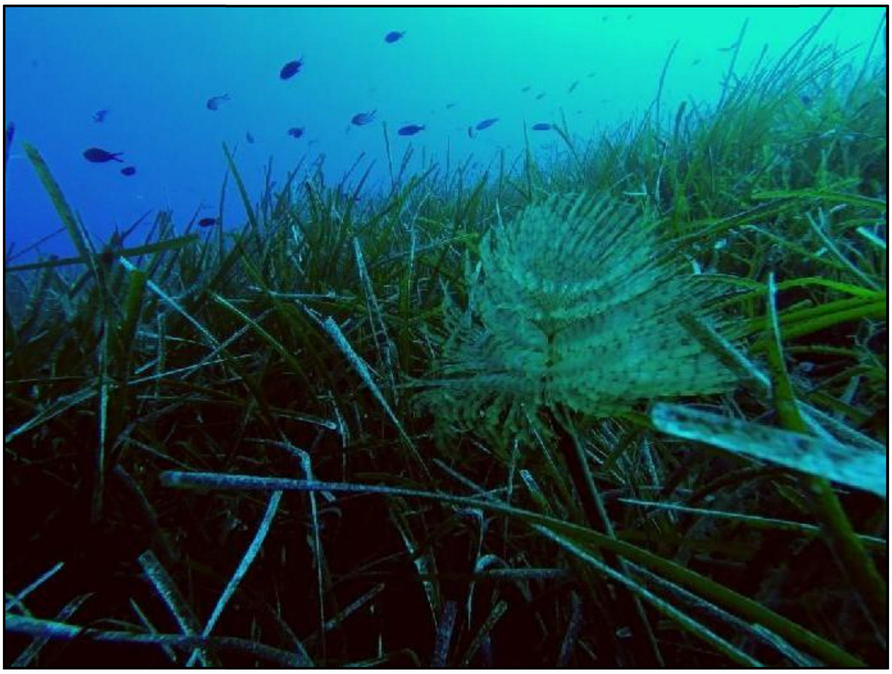

Figure 15. A fan worm growing within the Tre Pietre station.

STATION 2: MALFA TORRICELLA

The Malfa Torricella station is located in the north side of the Island of Salina at ca. 1.5 km to the east of the port of Malfa town. The name of the station is given by a tall tower-like rock located nearby, that is is actually the interior lava of a volcano. The outer cone crumbled a long time ago and the solidified magma was left giving the aspect of a tower (Torricella in Italian). The station was set up on the 13th June 2018 at 300 m from the shore line and at a depth of 17 m. The seascape of the site is mainly shaped by the presence of small and midium sized *P. oceanica* patches intermingled with sand patches and channels and with the presence of boulders of different shapes and sizes.

Figure 16. Geographic location of MalfaTorricella station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	MalfaTorricella
Depth	17m
Coordinates - Latitude	38° 35.066' N
Coordinates - Longitude	14° 51.348' E
Sampling date	13/06/2018

Table 2. Malfa Torricella station, general information.

The sampled meadow at Malfa Torricella station was characterized by an average shoot density of 609 ± 85 shoots m^{-2}, with values ranging from 531 to 722 shoots m^{-2}. The percentage of the sea bottom covered by living plants was in average 50.9 ± 13 %, with minimum and maximum meadow cover values of 36.5 and 61.1 respectively. Meadow cover values of the Q3 sampling point was not considered for the calculation of station average value, since they were recorded along a 10-meter transect almost completely extended on sandy bottoms outside meadow patches.

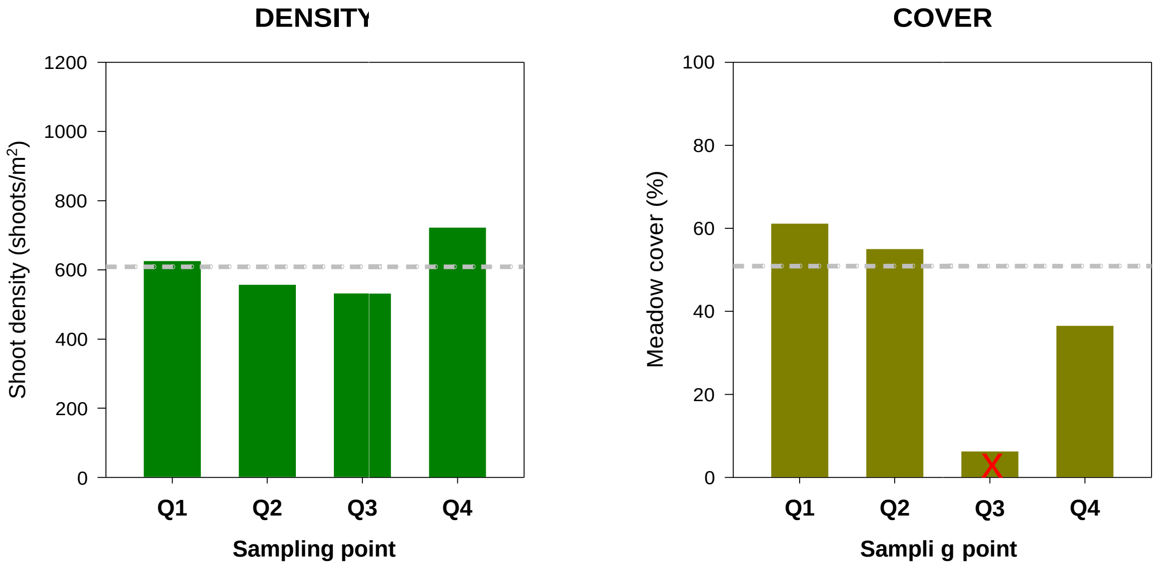

Figure 17. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Malfa Torricella station. Grey dashed lines represent the average value for the station.

Shoot burial in the site ranged between 2.8 and 7.2 cm, with an average value of 5.2 ± 1.8 cm. The station did not evidence sign of altered sediment dynamics, and the variability among sampling points reflected the distance of the fixed quadrats from the meadow edges. Higher burial values (lower positive or higher negative values) are usually found in the meadow borders, where sand waves are constrained and retained by the physical structure of the meadow.

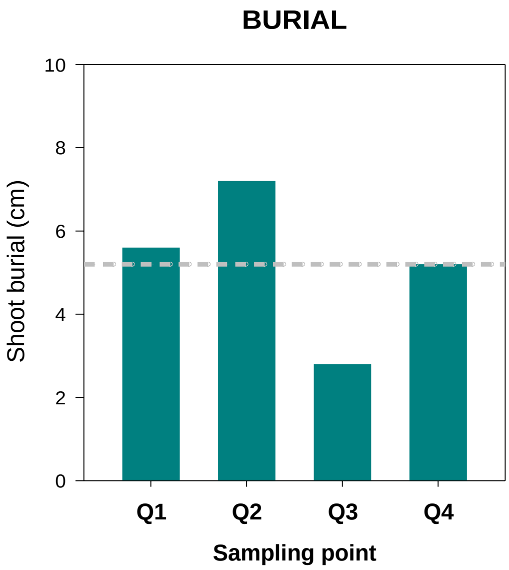

Figure 18. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Malfa Torricela station. The grey dashed line represents the average value for the station.

The presence of the alga *C. cylindracea* was recorded in the station. This invasive species was only observed outside the meadow, growing on sandy and rocky substrates where it formed low-density and low-biomass patches. The presence of dead *Pinna nobilis* individuals was also recorded in the station. No signs of damage were detected on the studied meadow, and the ecosystem as well as the associated community seems to be in a good ecological status.

Figure 19. Seascape at the Malfa Torricella station showing the presence of two divers working on two fixed sampling points marked with a small buoy.

Figure 20. A detailed view of the use of an underwater compass to roll out the 10 meters transect used for the characterization of the meadow cover.

STATION 3: PORTO SHALLOW

The Porto Shallow station is located about 300 meters south of Santa Marina's harbour and 100 meters off the eastern coast of the Island. The station was installed in the upper limit of the meadow on the 14th of June 2018. The four fixed sampling points were distributed from 6 to 10 meters depth, the higher depths corresponging to the sampling stations closest to the Port of Santa Marina (Q1 and Q2), where the upper meadow limit were more strongly regreessed most likely due to the influence of the harbour. A great number of vessels have been observed during the sampling campains in the area, which is one of the most frequented and important areas for anchoring and mooring in the Island.

Figure 21. Geographic location of Porto Shallow station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Porto shallow
Depth	6-10 m
Coordinates - Latitude	38° 33.137' N
Coordinates - Longitude	14° 52.184' E
Sampling date	14/06/2018

Table 3. Porto Shallow station, general information..

Shoot density was uniform between fixed sampling points with values ranging from 591 to 688 shoots m^{-2}, and an average value of 652 ± 43 shoots m^{-2}. Meadow cover was also homogenous and showed an averaged value of 42.0 ± 7.0 %. Density and cover values in this shallow station were lower than the values obtained in other stations at shallower depths (e.g. Station 1 and 2), contrary to what expected for an undisturbed meadow. Under undisturbed conditions, the natural structure of *P. oceanica* meadows is progressively reduced due to the strong attenuation that light experiences with depth. The fact that the

Porto Shallow meadow is less dense and sparser than nearby deeper meadows is likely reflecting the existence of perturbations in the area. In fact, the presence of scars produced by anchors and chains were observed inside the meadow as well as in the surrounding sandy bottoms.

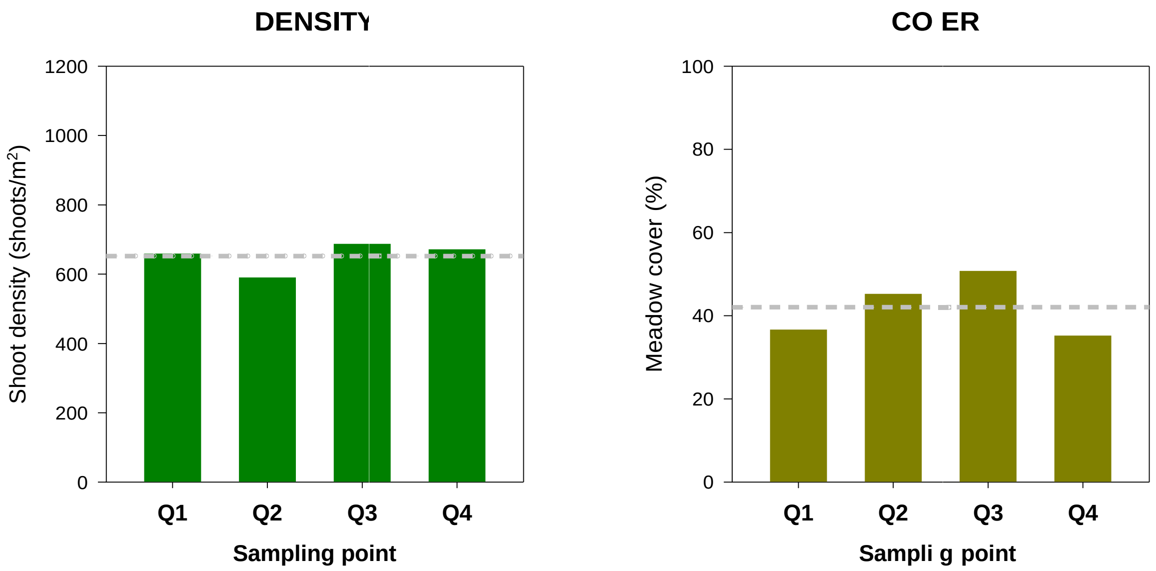

Figure 22. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Porto Shallow station. Grey dashed lines represent the average value for the station.

Shoot burial ranged between 1.6 and 8.2 cm, with an average value of 5.4 ± 2.9 cm. One sea cucumber was found inside one cover quadrats and the presence of *Caulerpa cylindracea* within the meadow margins was recorded. It is also important to note the presence of mixed meadows of the pioneer seagrass *Cymodocea nodosa* and the introduced *Halophila stipulacea* together with the invasive seaweed *C. cylindracea* in degraded areas adjacent to the monitoring station, were the meadow has totally disappeared. In fact, the proportion of muddy and silty sediments in the area, which is indicative of sediment resuspension by the mechanical action of anchors, was visually higher than in other stations from this side of the Island without apparent disturbance (e.g. Stations 5 and 9).

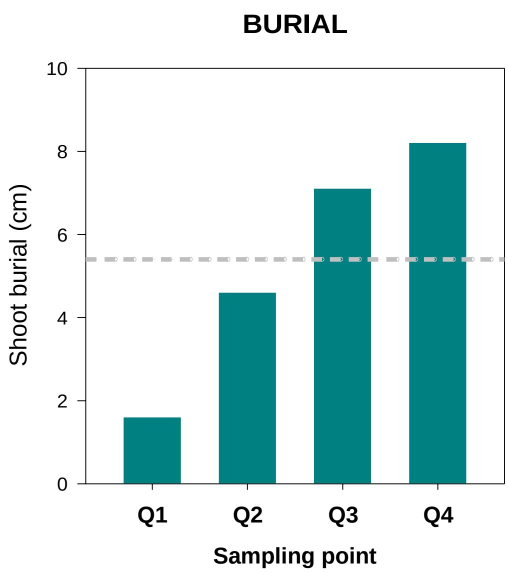

Figure 23. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Porto Shallow station. The grey dashed line represents the average value for the station.

In summary, the meadow to the south of Santa Marina's Port seems to be highly damaged by boat anchoring. Large meadow areas have already disappeared and in some cases they have been substituted by mixed beds of lower-sized and faster-growing pioneer seagrass species. This change in species composition has enormous consequences for the functions and services provided by seagrasses, since they are intimately linked to the physical structure of the meadows. Moreover, we have observed dispersed around the meadow a large number of abandoned mooring systems for boats and boats directly anchoring inside the meadow. Given the current situation, we suggest to activate urgent measures in order to protect the *P. oceanica* meadows in the area and to favour a sustainable use of this sheltered side of the Island for boat mooring.

Figure 24. General views of the Porto Shallow station. On the left: Detail of the upper meadow limit dead matte evidencing the regressive status of the meadow. On the right: Presence of a boat anchored inside the meadow very close to the monitoring station, where the presence of boats is high during the summer season.

Figure 25. Presence of mixed meadow patches formed by the pioneer seagrass *Cymodocea nodosa* and the introduced *Halophila stipulacea* together with the invasive seaweed *C. cylindracea* in degraded areas adjacent to the Porto Shallow station (left panel). Presence of abandoned mooring systems in the surroundings of the monitored meadow.

STATION 4: RINELLA

The station number 4, Rinella, is placed in front of the town of Rinella, about 300 m west of the port. The Rinella's Port is the second biggest harbour in the Island of Salina and has a large amount of the maritime traffic that conects the Island with other localities. The *P. oceanica* monitoring station was established on the 15th June 2018 on a seabed dominated by a very dense *P. oceanica* meadow mixed with sand channels and big boulders. The station was localed along a depth gradient between 9 and 11 m, following a sand channel surrounded by big boulders. Due to its orientation, the station is highly exposed to waves and currents.

Figure 26. Geographic location of Rinella station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Rinella
Depth	9-11 m
Coordinates - Latitude	38° 32.748' N
Coordinates - Longitude	14° 49.457' E
Sampling date	15/06/2018

Table 4. Rinella station, general information.

With an average density of 929 ± 183 shoots m^{-2}, the *P. oceanica* meadow at Rinella is the densest one of the 11 meadows characterized around the Island of Salina within the frame of the POMIS project. The higher density corresponded to the shallower sampling point (Q1, 9m) with 1181 shoots m^{-2}. The percentage of meadow cover was in average 36.3 ± 11%, with values comprised between 23.3 and 49.8%. The high variability in meadow cover among sampling points and the relatively low average value of the station reflects the high heterogeneity of the habitat in this locality, where small and medium meadow patches are intermingled with sand channels and boulders of different shape and size.

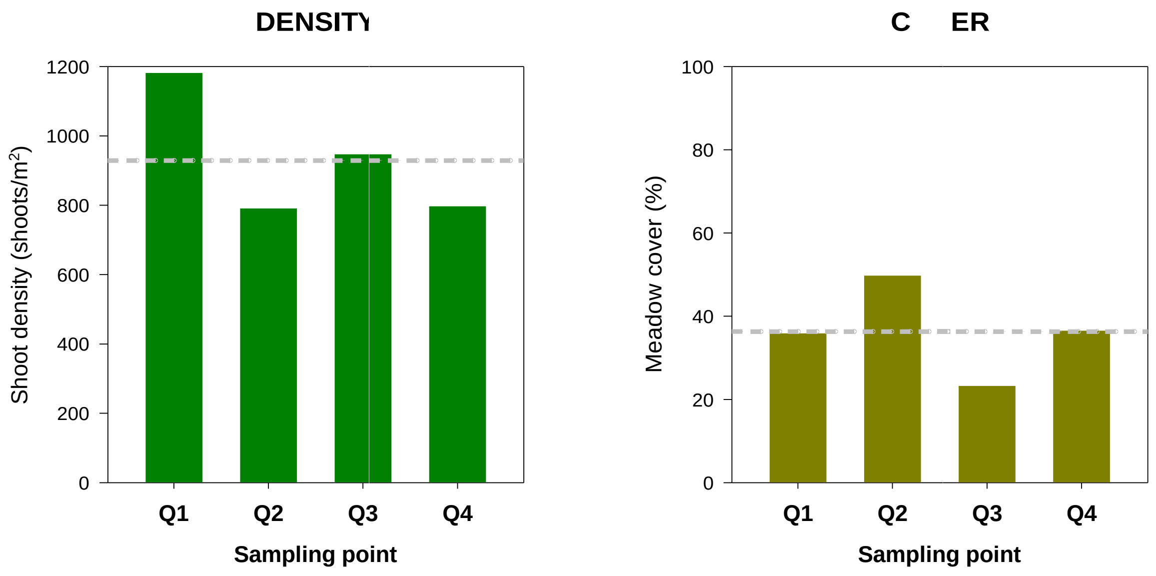

Figure 27. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Rinella station. Grey dashed lines represent the average value for the station.

Shoot burial was in average 3.3 ± 1.9 cm, being the lowest value 0.6 cm in Q2 and the highest 4.6 in Q3. This variability is again reflecting the heterogeneity of the habitat. Indeed, we did not observe visible signs of deterioration and the environmental status of meadow seems to be very good. Accordingly, the associated meadow community was also well represented and preserved. Many fish species were observed within and around the meadow and two sea stars were found inside cover quadrats. *Caulerpa cylindracea* was also observed sparse in the station, but without showing signs of an invasive character since the patches of this seaweed were quite small and not very dense.

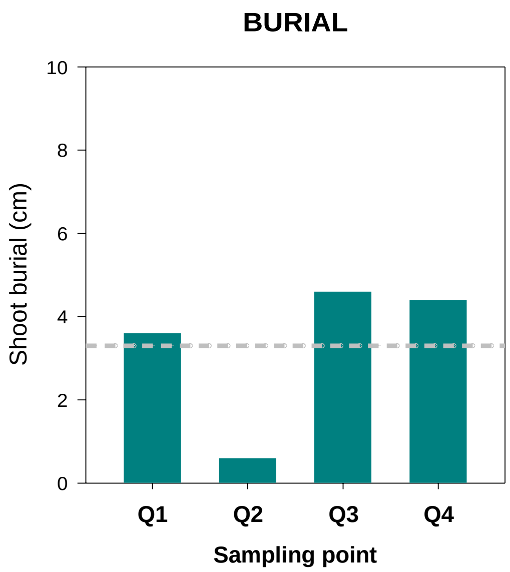

Figure 28. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Rinella station. The grey dashed line represents the average value for the station.

Currently, the construction of a new port adjacent to the one already existing at Rinella is being planned with the aim to increase the provision of controlled boat mooring in the Island, and in order to reduce the number of free anchoring boats that are actually damaging *P. oceanica* meadows on the western coast of the Island. The construction of this coastal infrastructure, however, could have direct and indirect negative consequences for the existing coastal habitats in the area. The direct effects include the physical occupation of the environment with the resultant destruction of the natural habitats present in the area. Indirect effects are mainly caused by the modification of coastal currents, which generally results on alterations of the sediment dynamic in the area, as well as the toxic effects of pollution derived from boats and port activities. Due to the high ecological value of the meadow growing in the vicinity of the area where the new harbour is planned to be constructed, it is critical to conduct a detailed environmental study that includes any potential direct and indirect effect that the construction of the port could have on this valuable ecosystem. The study should also include various alternatives to allow selecting the more environmental respectful option.

Figure 29. The seascape at the Rinella monitoring station is dominated by the presence of very dense *P. oceanica* patches intermingled with big boulders and sand patches and channels.

Figure 30. The *P. oceanica* meadow at Rinella is the densest meadow we found around the Island of Salina.

STATION 5: LINGUA SHALLOW

The station 5 Lingua Shallow is located in the southeast of the Island of Salina. In particular, the station is situated on the east coast of the Island at approximately 800 m to the south of Porto Shallow station (Station 3) and 100 m in front of the cementery of the locality. The instalation of sampling points and the characterization of the meadow were conduted on the 16th June 2018. The four fixed samping points of the station were distributed around a sand patch sorrounded by a wide *P. oceanica* meadowat 6 m depth. In the Lingua Shallow station *P. oceanica* grows on a flat slope bottom creating a dense and wide meadow from very shallow waters down to 9-10 meters depth, after which the bottom slope sharply changes down to the lower meadow limit at about 20-22 m depth. This meadow morphology contrast to other areas of the Island where the species grows on steep slopes forming narrow meadow bands instead of extensive meadows.

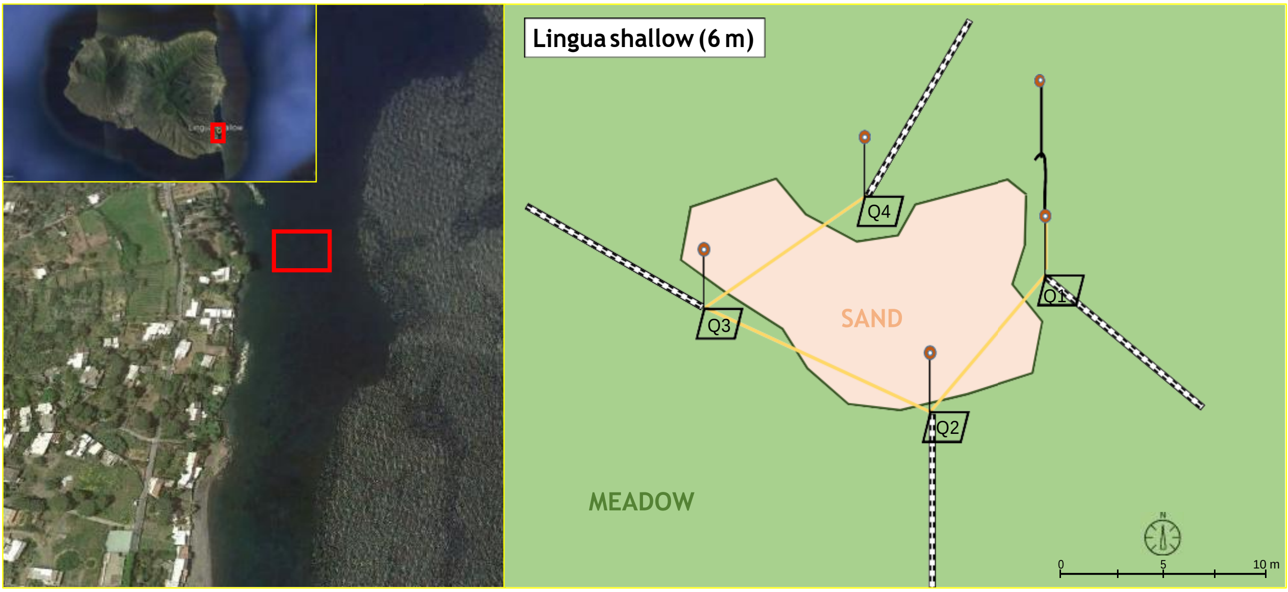

Figure 31. Geographic location of Lingua shallow station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Lingua shallow
Depth	6 m
Coordinates - Latitude	38° 32.683' N
Coordinates - Longitude	14° 52.237' E
Sampling date	16/06/2018

Table 5. Lingua Shallow station, general information.

In the shallow stand of the meadow, shoot density showed in average 713 ± 225 shoots per m^2, being the maximum density value (Q4, 988 shoots m^{-2}) almost the double than the lower one (Q3, 531 shoots m^{-2}). This variability is mainly due to the formation of submarine terraces (called "mattes") in the area, although we cannot discard the existence of perturbations, due to the high number of boats mooring and frequenting the area. Indeed, although we have not visually identified clear signs of damage in the monitoring station, these signs were evident during a diving survey in adjacent areas. In this shallow site the meadow develops submarine terraces of high vertical thickness (up to 1.5-2 m) formed by the interwoven dead rhizomes and trapped sediment that remains below the living plants of the meadow. The creation of these organic structures that trap large amount of organic material and lower the energy of waves, protecting the coastline, is favoured by the flat slope of the seabed and the sheltered characteristics of the locality. Meadow cover was high in the station, with an average value of 65.1 ± 20%. This high percentage of meadow cover reflects the structural homogeneity of the meadow, favoured by the flat slope and the absence of big boulders due to the lack of abrupt cliffs in the surrounding coastline.

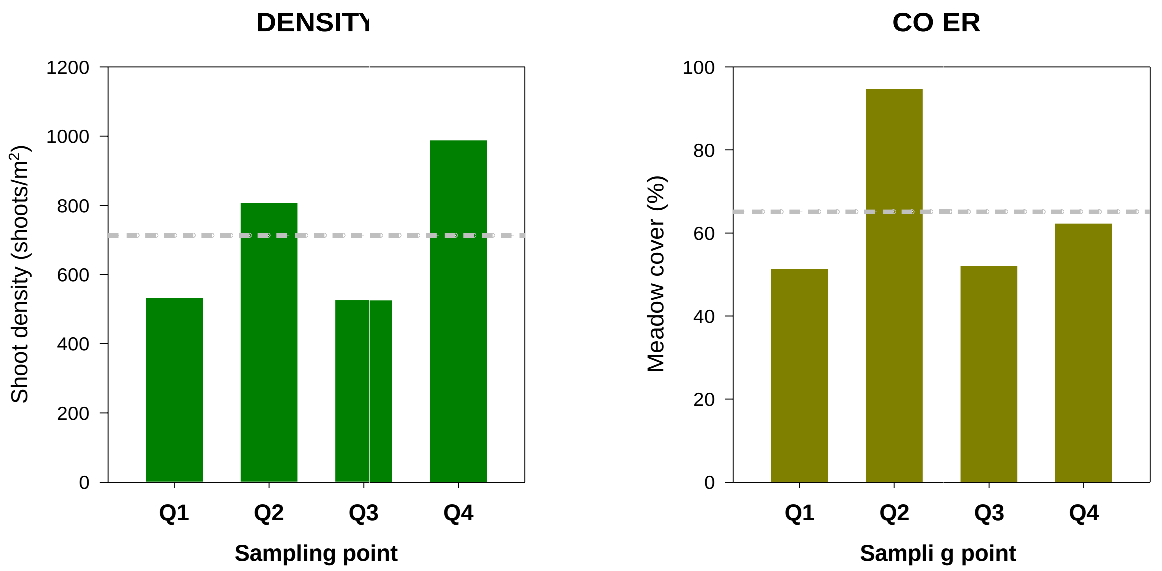

Figure 32. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Lingua Shallow station. Grey dashed lines represent the average value for the station.

Shoot burial in the station ranged between 3 and 7.5 cm, with an average value of 5.2 ± 1.8 cm. We have observed a high abundance of dead *Pinna nobilis* in the area, some of them damaged and broken most likely due to the use of anchors. It is worth to note that we have not found one single living *Pinna nobilis* all around the Island of Salina, which lead us to think that local populations have experienced a marked decline as recently described in other regions of the Mediterranean Sea where 100% of mortality have been recorded in the last two years. Curiously, we have found a Pencil sea urchin (*Cidaris sp*) in one of the fixed 40x40 cm density quadrats at 6 m depth, when the species is commonly found in deep waters (down to 1800 m depth) of the Mediterranean Sea.

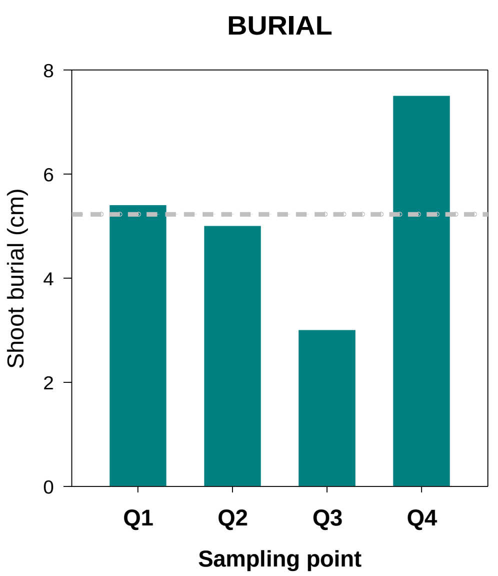

Figure 33. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Lingua Shallow station. The grey dashed line represents the average value for the station.

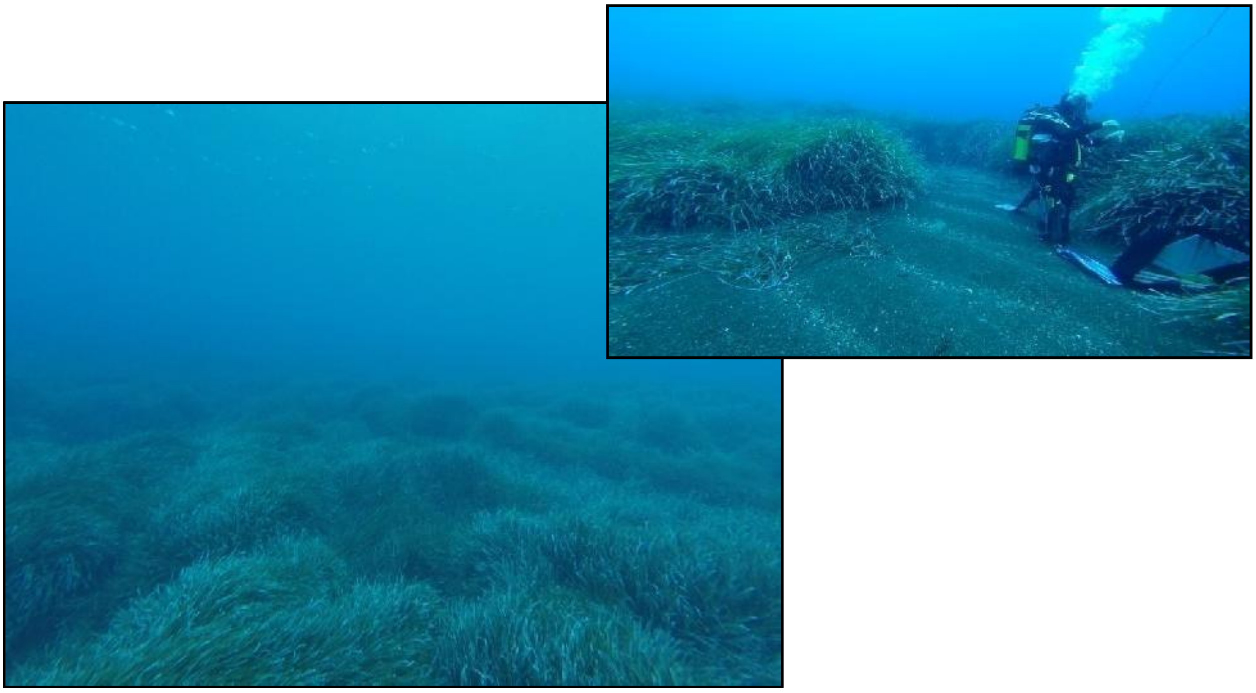

Figure 34. General view of the shallow wide meadow of Lingua Shallow station (left panel). The sand patch around which the monitoring station was installed (right panel).

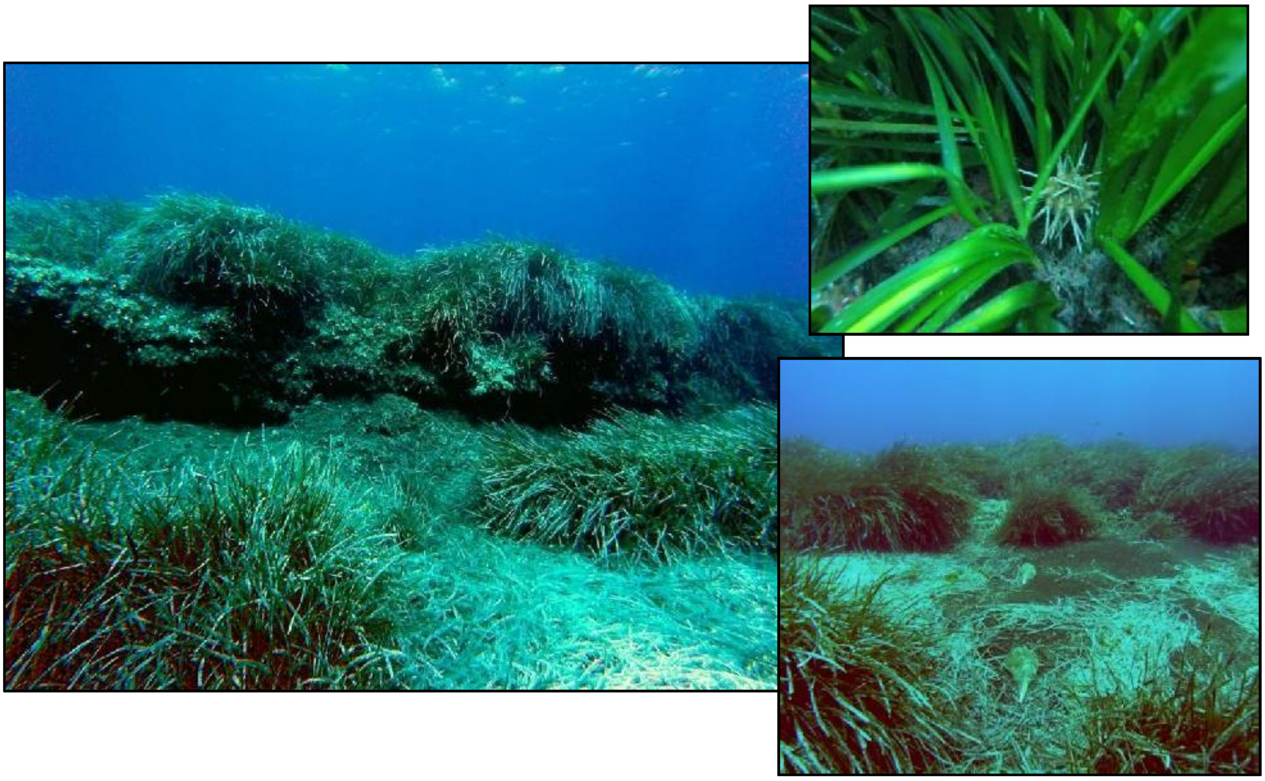

Figure 35. Matte of *Posidonia oceanica* (submarine terraces) in the vicinity of Lingua Shallow station (left panel). The Pencil sea urchin *Cidaris sp* found inside a fixed density sampling point (upper right panel). Presence of dead *Pinna nobilis* (fan shell) in the surroundings of the station (lower right panel).

STATION 6: SCOGLIO CACATO

The Scoglio Cacato station is located in the Northern side of the Eastern coasts of the Island of Salina, where it is possible to admire the volcanic aspect of the Island and the high cliffs formed by rocky layers of different colors and composition emerging from the crystalline sea waters. The name of the station is given by the accumulation of bird faeces on rocks emerging from the sea near the coastline. The station was established on the 16th June 2018, on the deep limit of a *P. oceanica* meadow. Covering a meadow portion between 25 and 28 m depth, the Scoglio Cacato station is the deepest of the 11 stations studied in the POMIS project. The area is highly frequented by recreational boats and the site is also of interest by sport divers.

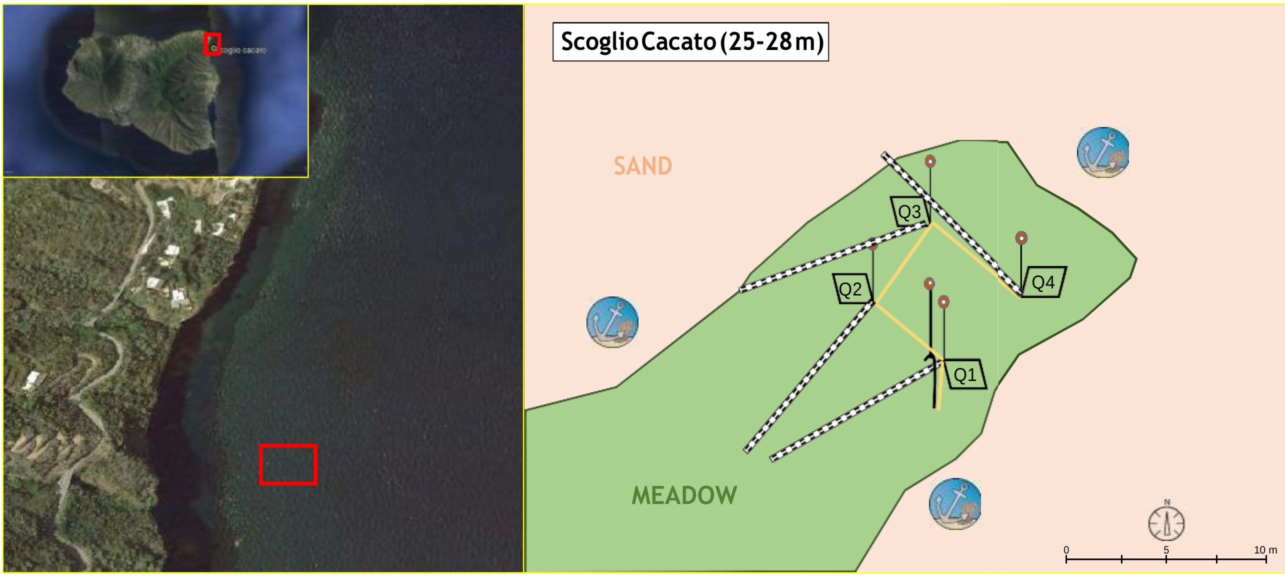

Figure 36. Geographic location of Scoglio Cacatostation (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	ScoglioCacato
Depth	25-28 m
Coordinates - Latitude	38° 34.548' N
Coordinates - Longitude	14° 52.403' E
Sampling date	16/06/2018

Table 6. Scoglio Cacato station, general information.

The monitoring station was positioned within a tongue-shaped meadow of several meters width that spreads from 14 m depth down to 30 m on a steep slope sea-bottom. Plant density in this site was the lower of all studied stations around the Island of Salina, which is in accordance with its highest depth. The average meadow density at the moment of sampling was 201 ± 59 shoots m^{-2} (range: 125-250 shoots m-2). However, plant density in one of the 40x40 cm fixed quadrats was very low, with only 20 living shoots. The cause of such a dramatic reduction in the number of shoots is probably due to the mechanical effect of anchors. Large, heavy anchors dig up plants from the seafloor creating clearings and channels without vegetation. Subsequently, these meadow bounds act as an erosive front progressively increasing the surface area of unvegetated seafloor, as a result of hydrodynamic forces. In fact, the erosion channels created by anchors were clearly visible during sampling not only in the deep meadow stand but also in shallow areas of the meadow. The percentage of seafloor covered by living plants was in average 39.6 ± 22%, being the lower and higher values of 18.9 and 70.1 respectively. This extremely wide range of values should in part be reflecting the presence of these erosive channels and clearances.

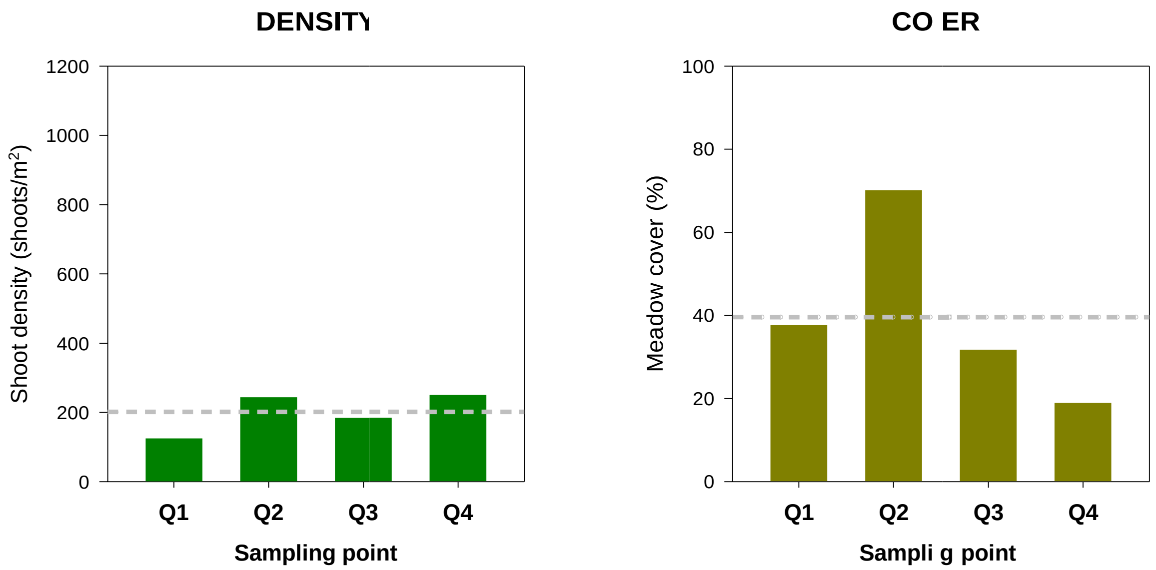

Figure 37. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Scoglio Cacato station. Grey dashed lines represent the average value for the station.

Plant burial was homogeneous between the four sampling points with an average value of 5.5 ± 0.8 cm. Although we did not find any of the targeted faunal species within the station, we have observed the presence of dead *Pinna nobilis* in shallower areas close to the station. Anchors and chains scars were also clearly visible in sandy bottoms of these shallow eroded areas, in which the meadow has disappeared and has been substituted by mixed beds of *Cymodocea nodosa*, *Halophila stipulacea* and *Caulerpa cylindracea*. The former two species are pioneer and fast-growing plants with a high ability to recover from impacts due to their higher plasticity, lower ecological requirements and faster growth rates, whereas the latter is an invasive seaweed species with high colonization potential mainly above dead *P. oceanica* matte substrate.

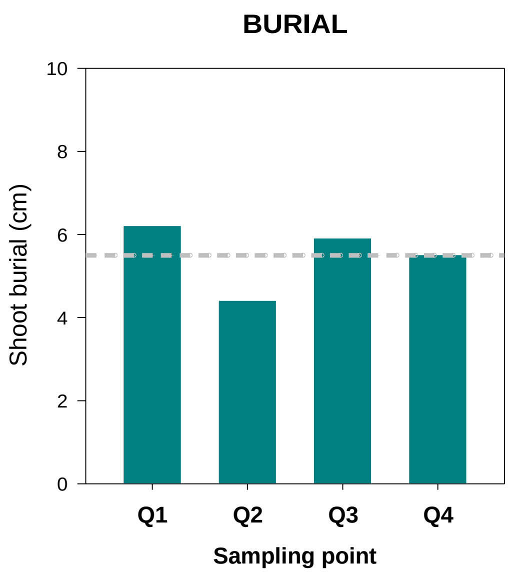

Figure 38. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Scoglio Cacato station. The grey dashed line represents the average value for the station.

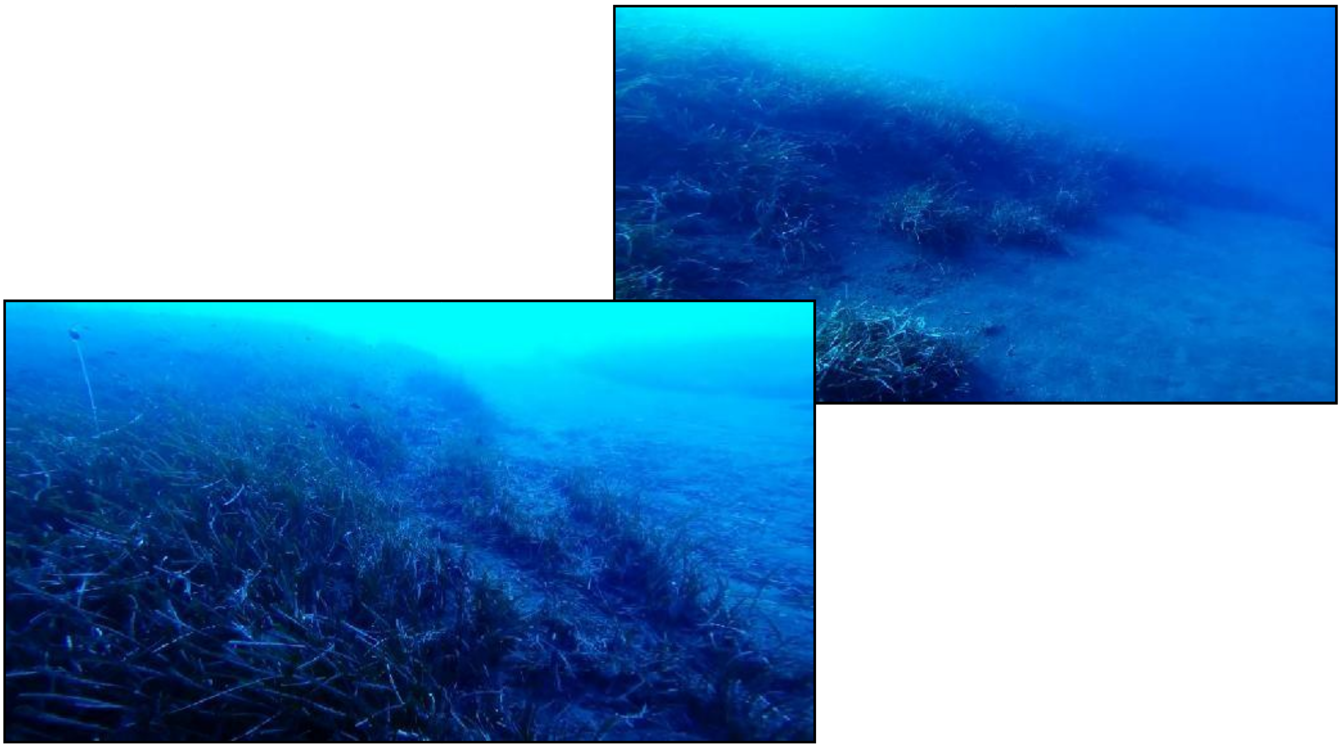

Figure 39. Overall views of the degraded and fragmented lower meadow edge of the *P. oceanica* meadow at the Scoglio Cacato station. Anchor scars, clearly visible as unvegetated channels, facilitate erosion processes in the meadow.

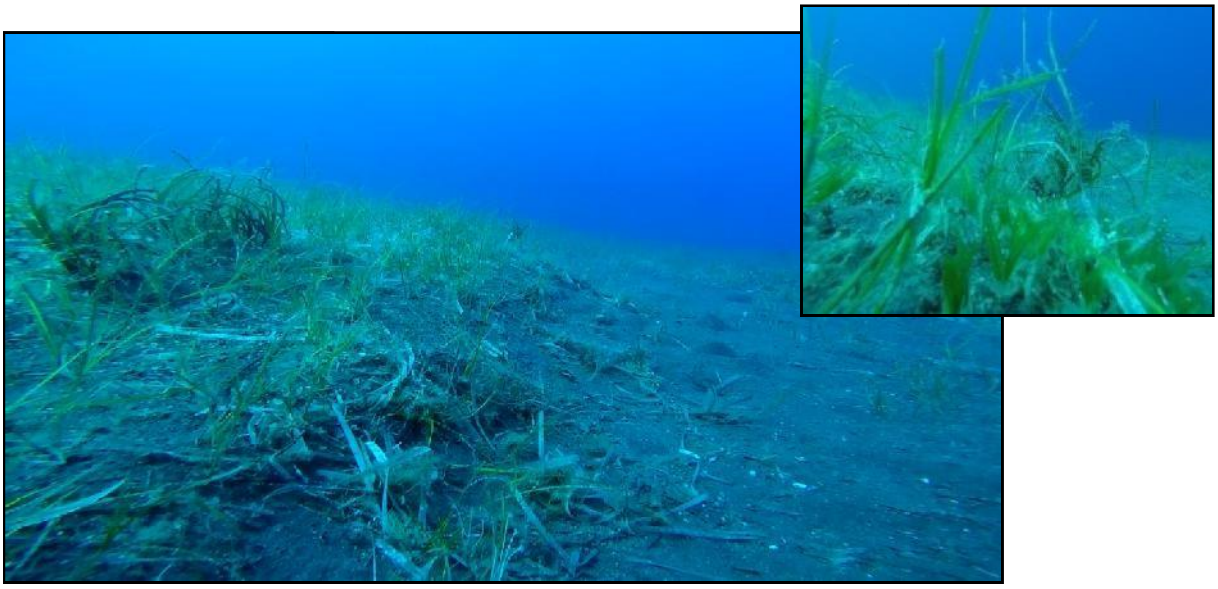

Figure 40. In shallow meadow areas at the Scoglio Cacato station, the eroded meadow has been colonized by pioneer species. This species substitution has important consequences for the functioning of the ecosystem since the much lower complexity of the habitat precludes the provision of important human services such as coastal protection, carbon sequestration or fisheries maintenance. Note the presence of some relict *P. oceanica* plants within the newly formed patches of the low-sized species *Cymodocea nodosa* and *Halophila stipulacea*.

STATION 7: MALFA SPIAGGIA

The Malfa Spiaggia station is located west of Malfa at approximately 200 m of the town's beach, on the Island's northern coast. The four fixed sampling points were distributed along a sand channel at 17 m depth, on the 17th June 2018. The dense and wide *P. oceanica* meadow is crossed by sand channels and riddled with boulders covered by a well developed photophilic community of canopy-forming algae. The meadow was visually healthy without signs of deterioration despite its close prossimity to the town of Malfa of less than a thousand residents. Here the coast is higher, with a steep cliff and very suggestive sea.

Figure 41. Geographic location of Malfa Spiaggia station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	MalfaSpiaggia
Depth	17 m
Coordinates - Latitude	38° 35.043' N
Coordinates - Longitude	14° 50.014' E
Sampling date	17/06/2018

Table 7. Malfa Spiaggia station, general information.

Plant density varied between 481 and 697 shoots m^{-2}, with an average value of 606 ± 90 shoots m^{-2} for the station. Meadow cover was also high with a mean percentage of 66.9 ± 11, and with a maximum and minimum value of 57.6 and 80.7% respectively. Shoot burial ranged between 3 and 4.9 cm, with an average value of 3.6 ± 0.8 cm.

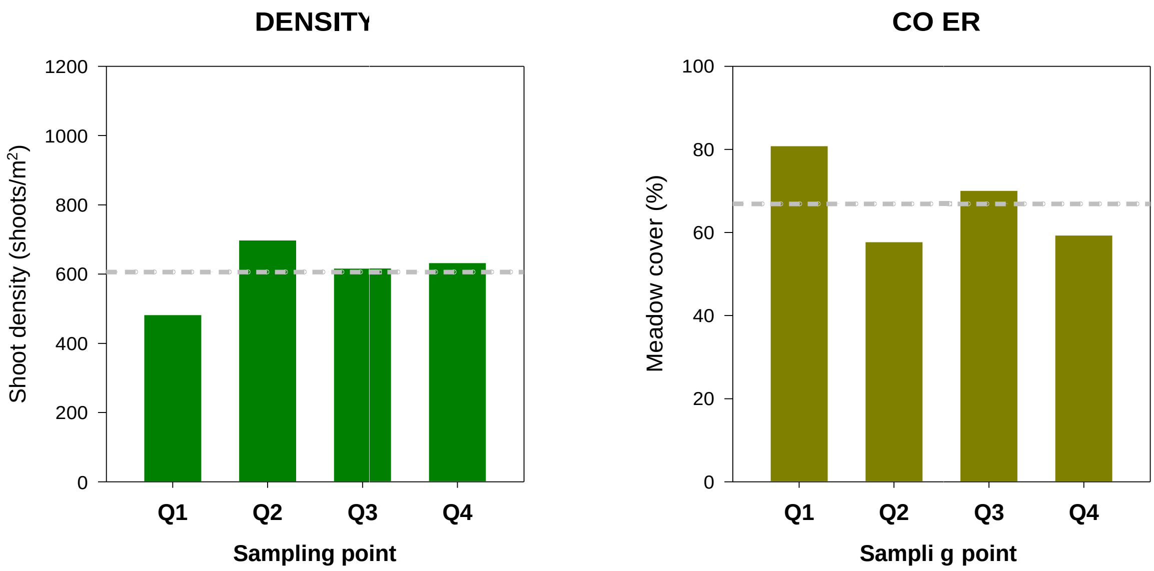

Figure 42. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Malfa Spiaggia station. Grey dashed lines represent the average value for the station.

During our dives in the station we have observed the presence of dense fish shoals of the species *Chromis chromis*, *Sarpa salpa* and *Oblada melanura* swimming around the meadow. Well represented in the station were also some common fish species of the Labridae and Sparidae family, swiming inside the meadow in search of protection and food.

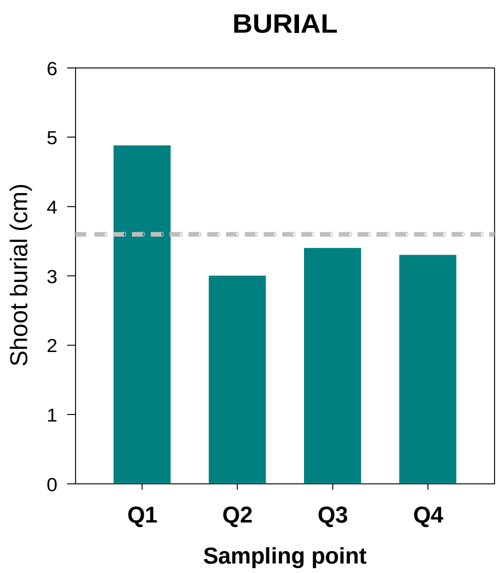

Figure 43. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Malfa Spiaggia station. The grey dashed line represents the average value for the station.

Figure 44. Plant counting inside a fixed 40 x 40 cm quadrat for the determination of plant density.

Figure 45. Dense fish shoals of the species *Oblada melanura* swimming around the monitoring station.

STATION 8: PORTO DEEP

The Porto Deep station is located on the east coast of the Island, 400 m south of the Port of Santa Marina. The station was selected to monitor the influence of the port and the effects of anchoring in a deep meadow stand. Fixed sampling points were installed on the 18th July 2018 at a distance of 200 m from Porto Shallow station (Station 3), following the deep meadow margin. As said for the Porto shallow station, the area is highly frequented by recreational boats that anchor is this side of the Island due to is sheltered orientation. In this site the meadow grows forming a narrow and homogenoeus band with the upper and lower meadow limits separated by an horizontal distance of ca. 150 m, due to the steep slope of the bottom and the strong regression that the meadow edges experienced most likely as a consequence of intensive anchoring. In fact, the deep limit of the meadow were highly fragmented and anchor scars were clearly visible in deep areas of the meadow.

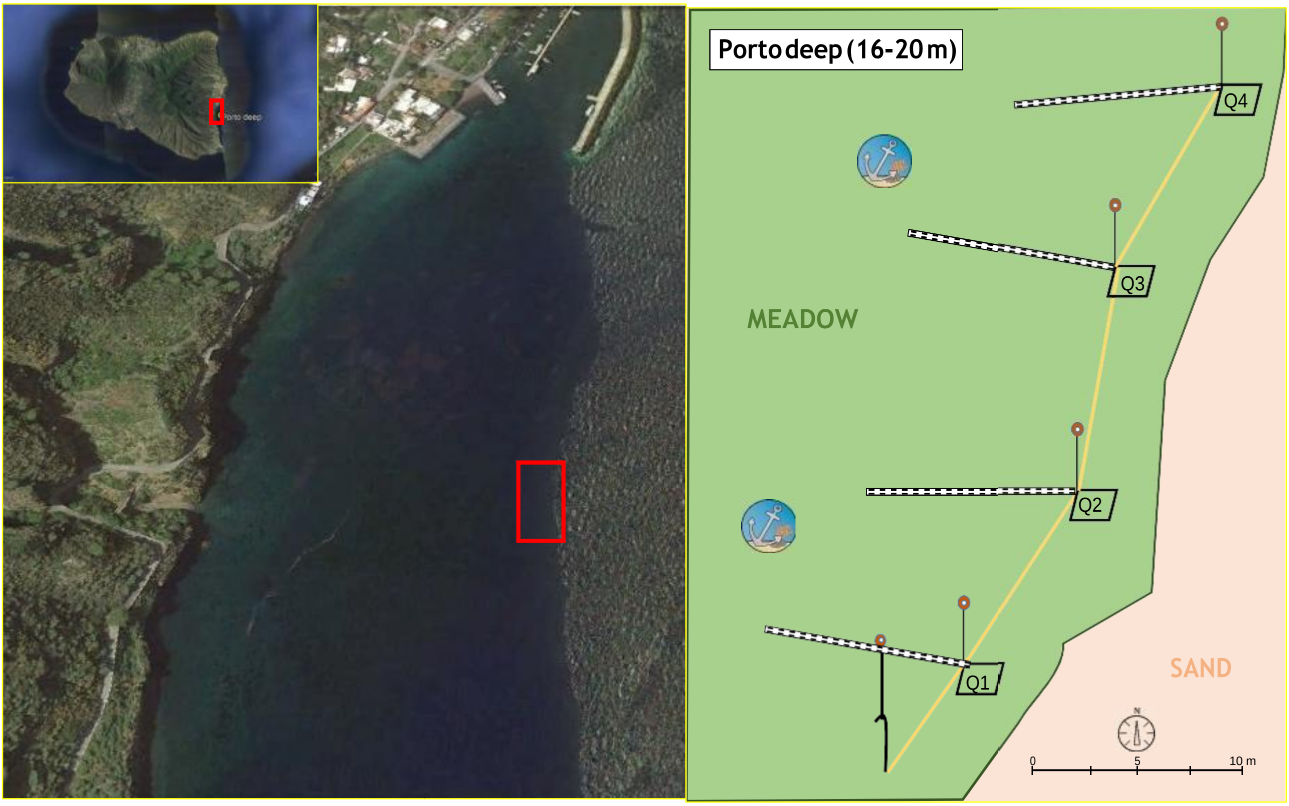

Figure 46. Geographic location of Porto Deep station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Porto Deep
Depth	16-20 m
Coordinates - Latitude	38° 33.050' N
Coordinates - Longitude	14° 52.271' E
Sampling date	18/07/2018

Table 8. Porto Deep station, general information.

Plant density was 355 ± 78 shoots m^{-2} in average for the station, with values ranging between 247 and 413 shoots m^{-2}. The estimated meadow cover in the station was 48.3 ± 15% with minimum and maximum values of 28.8% to 61.4% respectively. The great variation in meadow cover should in part be reflecting the fragmented condition of this meadow stand. Clearances and sand channels created by the mechanical effect of big anchors are intermingled and dispersed within the meadow area included in the monitoring station. In fact, a great number of recently uprooted plant fragments was observed inside and outside the meadow.

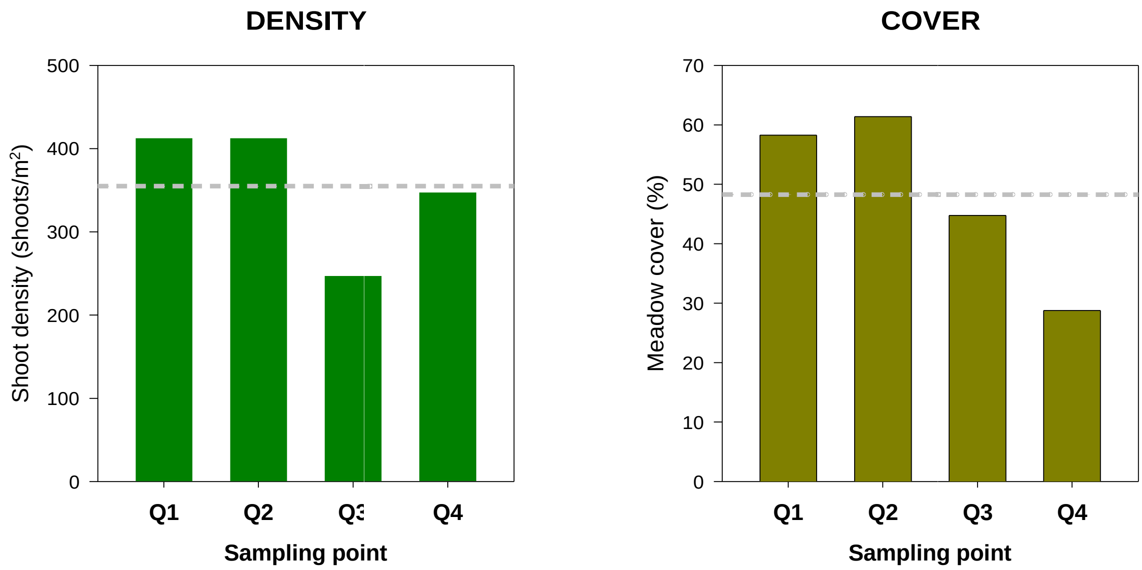

Figure 47. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Porto Deep station. Grey dashed lines represent the average value for the station.

The mechanical effects of anchors are also visible in the level of plant burial, which also showed high variability among sampling stations. These values ranged between 0.6 and 6.34 cm, with an average of 3.8 ± 2.4 cm. Anchors move and rework a great quantity of marine sediments in the sea bottom, giving rise to an irregular plant burial. This mechanical effect also produces sediment resuspension that finally resulted in sediment siltation in the area. Sediments in the station were, indeed, muddy and they were easily re-suspended during our sampling work. This has a potential negative effect, since deep meadow margins are quite sensitive to burial and to the light reduction produced by the resuspension of fine sediments.

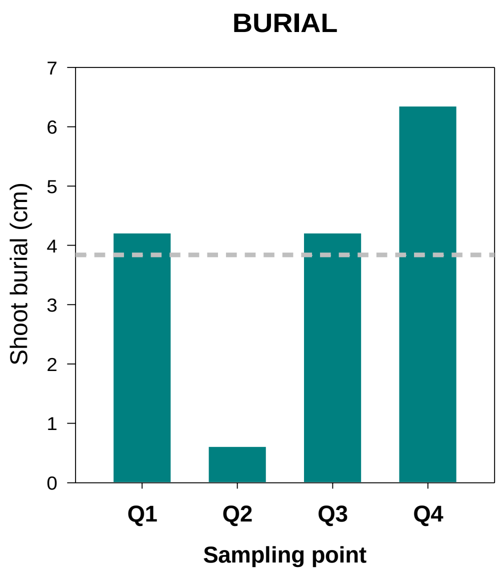

Figure 48. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Porto Deep station. The grey dashed line represents the average value for the station.

Therefore, the strong regression experienced by the deep meadow margin in this site should be favoured by a combination of burial, shading and the mechanical pulling up of plants, all them produced by anchors.

Figure 49. View of the fragmented meadow margin at Porto Deep station. The current lower limit of the meadow is at 18-22 m due to the strong regression experienced by the meadow. Rooted and unrooted plant fragments observed below the meadow edges provide strong evidences of this regression. The accumulation of muddy sediments and the increased water turbidity produced during sampling activities are also visible in the photo.

Figure 50. Detailed view of clearances and channels produced by boat anchoring in the Porto Deep station.

STATION 9: PUNTA BARONE

The Punta Barone station is located in the eastern side of the Island of Salina at approximately one kilometer to the north of Santa Marina's Harbour. In contrast to other sites of the Island, here the *P. oceanica* meadow was extensive, thanks to the flat slope of the seabottom that allows the meadow to grow over a large area before reaching the lower depth limit. On the 19th July 2018, the station was instaled around a patch of coarse sand at 7 m depth. The meadow was apparently healthy and visually appealing due to the presence of *P. oceanica* terraces (i.e. matte). The seawater of turquoise and cobalt-blue color and the abundance of fish are other attractive aspects of the site. The proximity of the Punta Barone beach seems to reduce the presence of anchored boats, which prefer the rocky coast or the vicinity of ports, they find in other sites of this sheltered side of the Island.

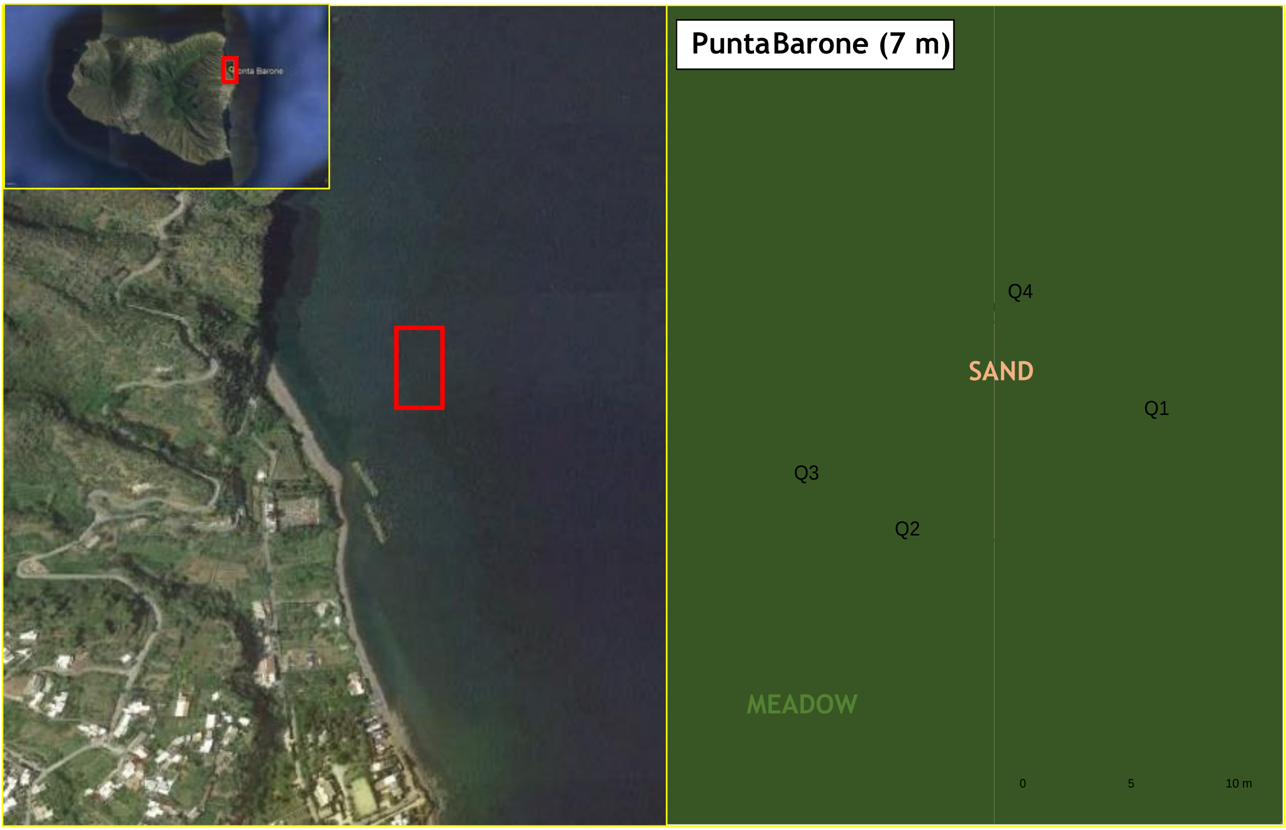

Figure 51. Geographic location of Punta Barone station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Punta Barone
Depth	7 m
Coordinates - Latitude	38° 34.149' N
Coordinates - Longitude	14° 52.457' E
Sampling date	19/07/2018

Table 9. Punta Barone station,general information.

Plant density in this station was high with 709 ± 60 shoots m^{-2} in average, values ranging from 644 to 788 shoots m^{-2}. Meadow cover was also high as reflected by the elevated percentage of sea bottom covered by living plants, which in average was 73.3 ± 6 %. Meadow cover along the four 10-m cover transects was quite homogenous from a minimum of 68% to a maximum of 80.6%. Plant burial was in average 4.0 ± 1.3

cm. Although the meadow around the monitoring station looked healthy and well conserved, we have observed large pieces of meadow uprooted by the effect of anchors in a visual survey conducted in the surroundings.

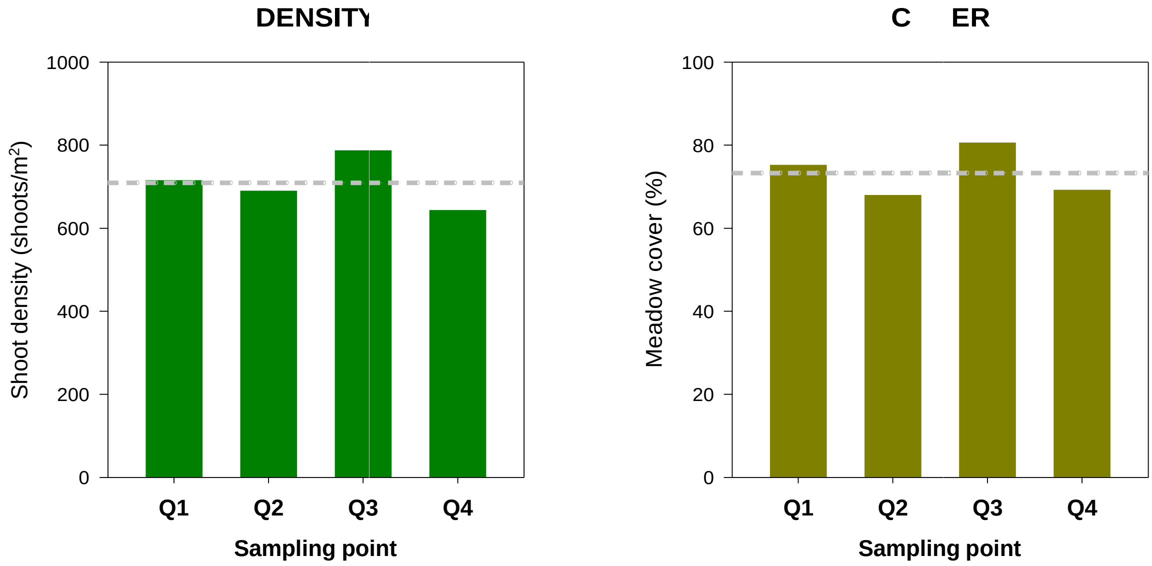

Figure 52. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Punta Barone station. Grey dashed lines represent the average value for the station.

We have also observed in the vicinity of the station high number of dead *Pinna nobilis* lying above the sea bottom. In some cases, the valves of dead individuals were occupied by other organisms as for instance *Octopus sp*. We have also observed in the area many *P. oceanica* seedlings growing attached to different substrates including dead *P. oceanica* matte, sediments and even, the valves of dead *P. nobilis*. Curiously, we found two *P. oceanica* seedlings growing inside of the meadow, in particular inside one of the fixed 40x40 cm quadrats. Large shoals of fishes (*Boops boops*, *Chromis chromis*, *Diplodus spp*) were also observed around the station attracting predatory fishes such as groups of *Seriola dumerili*. A fire worm was observed in one of the sampling points as well as the introduced seagrass *Halophila stipulacea* recently growing in some meadow margins.

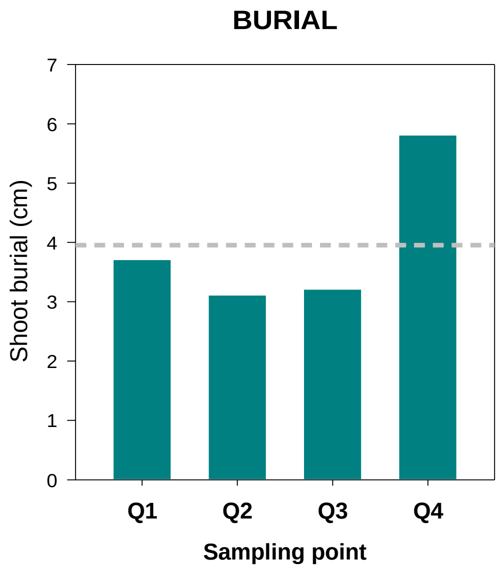

Figure 53. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Punta Barone station. The grey dashed line represents the average value for the station.

Figure 54. Scuba diver showing one detached piece of meadow formed by healthy long-lived *P. oceanica* plants (estimated to be more than 30 years old) in the surroundings of the monitoring station (left panel). The presence of a *P. oceanica* seedling growing inside the meadow, in particular inside one of the fixed quadrats used to monitor meadow density (right panel).

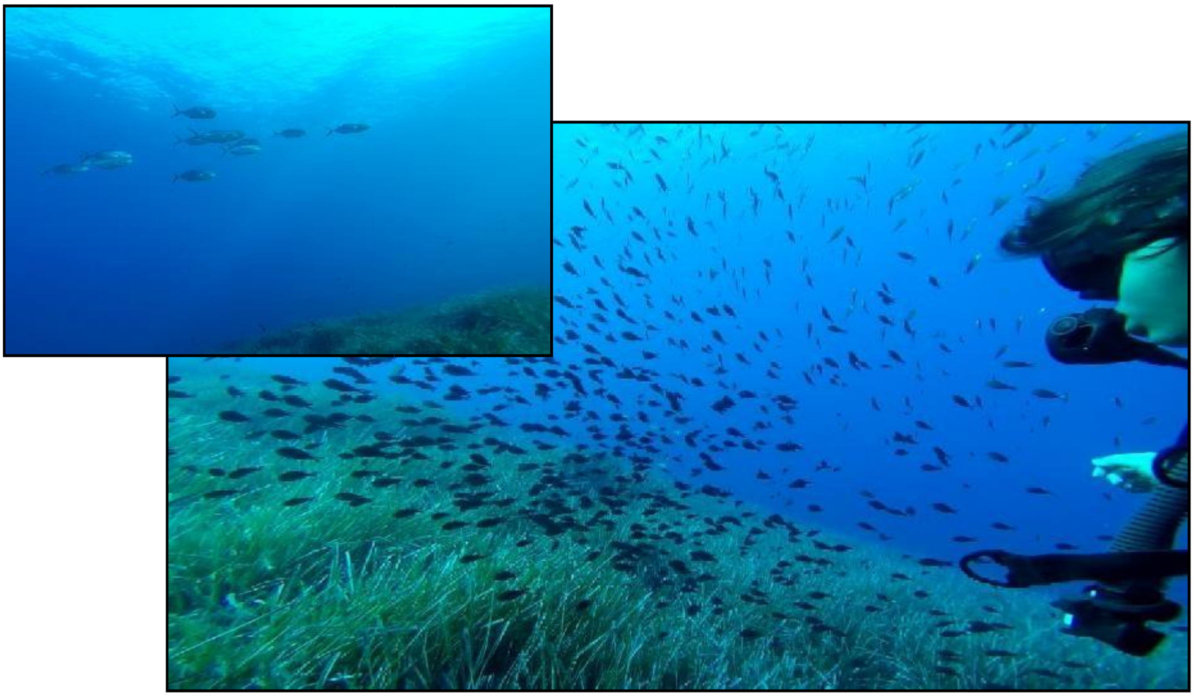

Figure 55. Large shoals of fish around the Punta Barone monitoring station (right panel). A group of predatory fishes of the genus *Seriola* patrolling the area in search of preys (upper right panel).

STATION 10: LINGUA FARO

The Lingua Faro station is located in the southeastern part of the Island of Salina, 300 m to the south of the Lingua's Lighthouse. The four sampling points of the station were distributed along the meadow margins of two different sand patches at 13 m depth. *P. oceanica* terraces of one to two meters in height were observed at that depth. The sea bottom showed a flat slope in shallow meadow areas, while after 14 m depth the slope sharply increases down to the lower meadow limit at 25-28 m depth. In the lower meadow limit we have observed a large amount of broken shoots totally unburied possibly due to the strong slope, the presence of unconsolidated sediments and the existence of strong currents favoured by the bottom geomorphology of the Lingua Cape (Punta Lingua). Evidences of damage by anchors or fishing nets were also observed between 15 and 25 m depth but not in shallower areas.

Figure 56. Geographic location of Lingua Faro station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Lingua Faro
Depth	13 m
Coordinates - Latitude	38° 32.066' N
Coordinates - Longitude	14° 52.233' E
Sampling date	20/07/2018

Table 10. Lingua Faro station, general information.

Shoot density at the Lingua Faro station was in average 511 ± 139 shoots m^{-2}, with values distributed within the range 384 – 700 shoots m^{-2}. The mean value of meadow cover was 61 ± 18 %, being the lowest and highest percentages of 41.8 and 85.3 respectively.

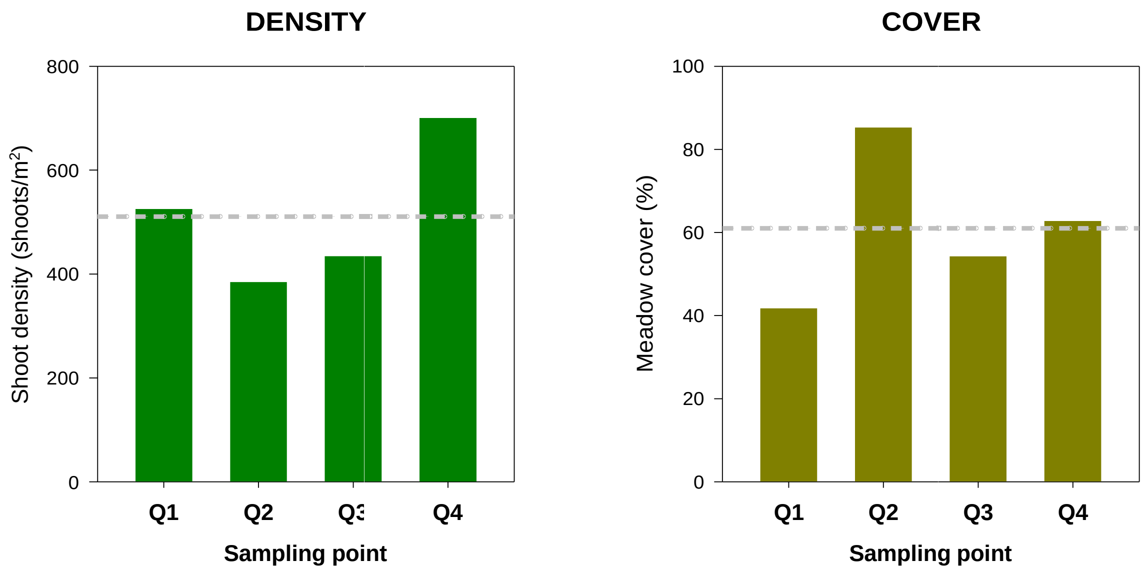

Figure 57. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Lingua Faro station. Grey dashed lines represent the average value for the station

Regarding shoot burial, the averaged value for the station was 8.1 ± 1.3 cm, with values as high as 15 cm in some sampling points. Although we have detected the presence of damage on deeper areas of the meadow, there was no evidence of mechanical damage in the station at 13 m. However, shoots were highly unburied, highly exposed above the sediments and fragile. In some cases, they presented a crispy texture and break easily when handling. We do not know the reason that could be underlying such shoot fragility, but possible domestic waste-water discharges in the proximities of the station could be the cause.

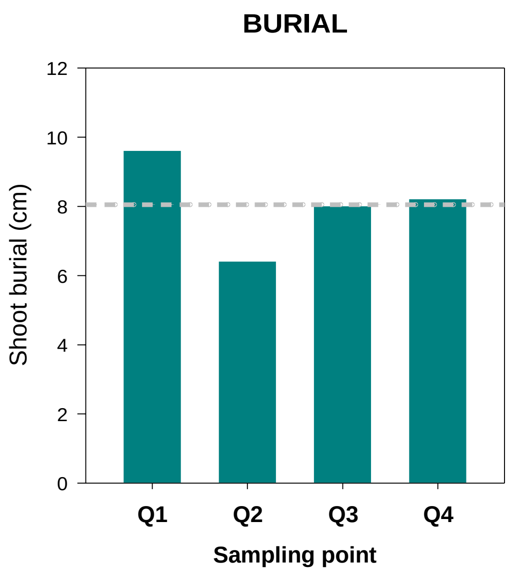

Figure 58. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Lingua Faro station. The grey dashed line represents the average value for the station.

Big fire worms were observed. A marine eagle visited us flying from the blue, while we were at few meters depth ermerging to the surface after sampling.

Figure 59. Overview of the Lingua Faro monitoring station.

Figure 60. Big bearded fire worm (*Hermodicecarunculata*) seeking refuge within the *P. oceanica* matte (upper left panel). Sea eagle (*Myliobatisaquila*) swimming above the Lingua Faro station during the sampling campaign (upper right panel). Accumulation of uprooted *P. oceanica* fragments in the lower meadow limit at Lingua Faro station (lower left panel). General view of the fragmented deep meadow margin and the accumulation of detached plant fragments at 25 m depth in the Lingua Faro station (lower right panel).

STATION 11: LINGUA DEEP

On the 21st July 2018 the Lingua Deep station was installed in the southeastern part of the Island of Salina. The station was located 150 m to the southeast of the Lingua Shallow station (station 5) with the aim to monitor the deep area of this important and extensive meadow. The four sampling stations (Q1-Q4) were distributed along the deep meadow margin at 22 m depth. The characteristics of this meadow area are quite similar to those of the Porto Deep station, located about 700 m to the north. In fact, both stations takes part of the same extensive meadow whose deep stands grow in a steep slope bottom and are highly impacted by the intensive use of this side of the Island for boats anchoring. The abrupt slope in this side of the island favours and intensifies the impact produced by anchors, as it concentrates recreational boats along a small band parallel to the coast coinciding with the presence of the meadow. The marked slope also favours anchors dragging from shallower to deeper bottoms affecting the deep meadow limits, that would be more distant form the coast if the slope were lower.

Figure 61. Geographic location of Lingua deep station (red square, left panel) and schematic representation of the sampling station with the four fixed 40x40 cm density quadrats (Q1-Q4) and 10-m length cover transects (right panel).

Station name	Lingua deep
Depth	22 m
Coordinates - Latitude	38° 32.621' N
Coordinates - Longitude	14° 52.307' E
Sampling date	21/07/2018

Table 11. Lingua Deep station, general information.

Meadow density was 246 ± 75 shoots m^{-2} in average for the station, with values comprised within a wide range from 150 to 331 shoots m^{-2}. Meadow cover also showed a great variation form 25 to 4 2%, being the mean coverage for the station of 34 ± 9 %. Plant burial varied between 3.6 and 8.1 cm with an average value of 6.0 ± 2.2 cm for the station. Anchor scars were visible all along the meadow margin, which was highly fragmented and in a clear regressive state. Due to the intense mechanical perturbation of the sea bottom, sediments showed high clay and lime content, being therefore easily resuspended during our work in the station.

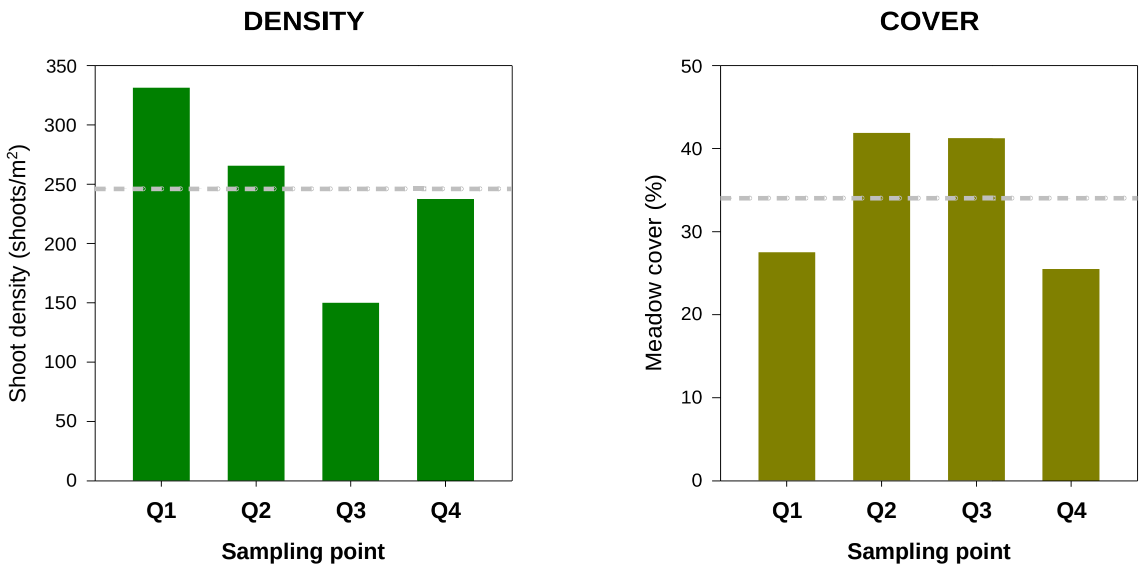

Figure 62. Values of meadow density (left panel) and cover (right panel) of the four fixed sampling points (Q1-Q4) of the Lingua Deep station. Grey dashed lines represent the average value for the station

The presence of fan worms (*Sabella spallanzanii*) was observed within the monitoring station. We have also observed dense groups of the hatpin urchin (*Centrostephanus longispinus)* growing at the basis of *P. oceanica* plants in this deep meadow portion. The species is probably attracted by the accumulation of leaf debris and the red and brown algae usually growing at the basis of the plants and above the leaves (epiphytes).

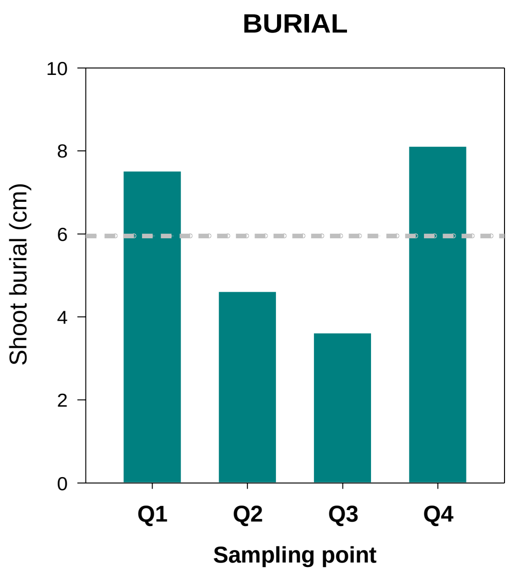

Figure 63. Values of shoot burial in the four fixed sampling points (Q1-Q4) of the Lingua Deep station. The grey dashed line represents the average value for the station.

Figure 64. Overall view of the deep meadow limit at the Lingua Deep station.

Figure 65. Detailed view of the deep meadow stand at Lingua where the presence of bounds (clearances and channels) produced by anchoring can be easily appreciated.

Figure 66. The hatpin urchin *Centrostephanus longispinus* formed aggregates of many individuals in the Lingua Deep station.

4.-RESULTS SUMMARY

Posidonia oceanica meadow density in the 11 monitoring stations studied in the POMIS project during the summer of 2018 varied between the minimum value of 201 ± 59 shoots m^{-2} in the Scoglio Cacato station (Station 6) and a maximum value of 929 ± 183shoots m^{-2} in the Rinella station (Station 4).

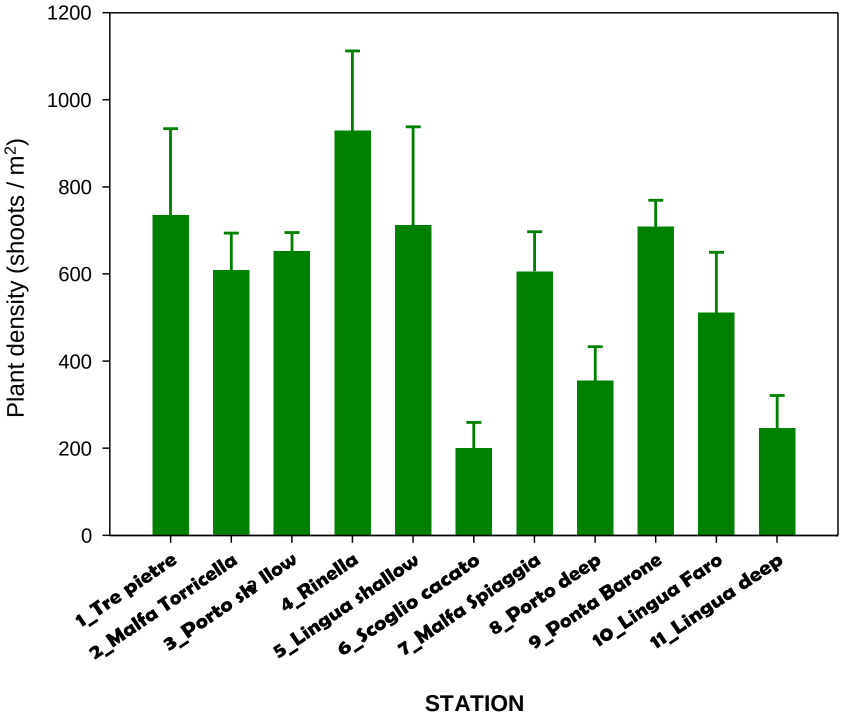

Figure 67. Plant density of the eleven *P. oceanica* monitoring stations distributed around the Island of Salina.

Under natural conditions, and in the absence of anthropogenic impacts, *P. oceanica* meadows naturally show a reduction in plant density with the increase in depth. This reduction in the number of plants growing per surface area of meadow reflects the strong reduction that light experiences in its path along the water column, which finally determines meadow productivity. The higher light availability in shallower areas promotes greater meadow productivity and therefore, the existence of more densely populated meadows in comparison to deeper areas. Accordingly, meadow density in the studied stations around the Island of Salina was significantly and negatively correlated with depth (N=11; r=0.810; p<0.01). Nevertheless, three shallow stations growing on flat slope sandy bottoms (Lingua Shallow 6 m, Porto Shallow 8 m and Punta Barone 7 m) showed similar meadow density values in respect to three deep stations growing on rocky substrate (Malfa Spiaggia 17 m, Malfa Torricella 17 m and Tre Pietre 15 m). It is known that meadow density is also affected, although to a lesser extent, by the type of substrate where the meadow grows, but the reduction in density can be more likely due to the unhealthy status of the meadows. It is possible, in fact, that the shallow meadows from the East side of the Island have already undergone a reduction in plant density due to the high frequency of vessels, impacting shallow sea-bottom through mooring and anchoring. The shallow Rinella station (10 m), extending in an area not subjected to anchoring, showed much higher plant densities than this other group of shallow stations. It is therefore critical to monitor the evolution of the meadows in this side of the Island that is suffering the pressure and impacts associated to a high influx of tourist vessels. We wish also to sound the alarm about importance of controlling and regulating boats anchoring around the Island of Salina by the competent authorities and to carefully estimate the possible impact of the new port in Rinella.

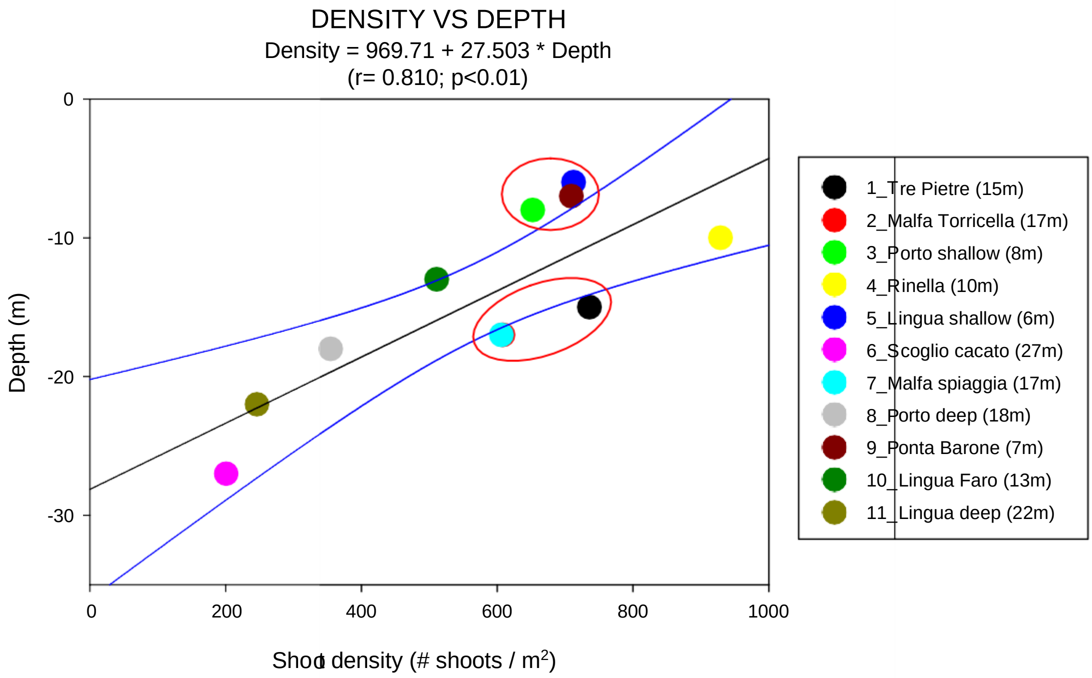

Figure 68. Linear regression of meadow density against meadow depth. Red circles indicate the two groups of meadows (shallower and deeper) with similar densities but contrasting depths (see the text).

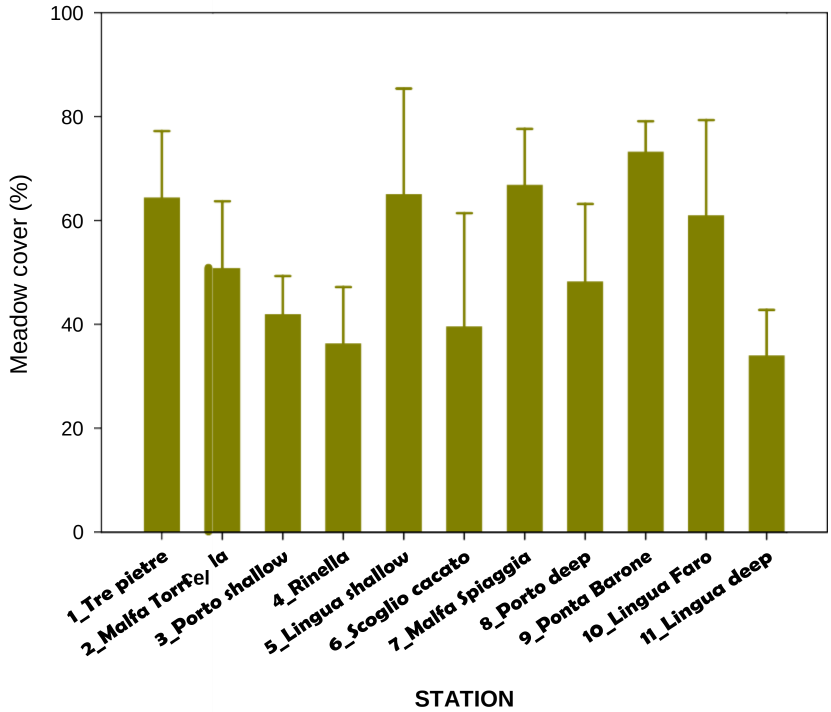

Figure 69. Meadow cover of the eleven *P. oceanica* monitoring stations distributed around the Island of Salina.

Meadow cover in the eleven studied sites ranged between 34 ± 9 % in the Lingua Deep station (22 m depth) and 73 ± 6 % in Punta Barone station (7 m). Contrary to plant density, this structural parameter meadow has not such a close relationship with depth, and no significant correlation was found between both parameters. The percentage of meadow cover, in the absence of a perturbation, mainly varies depending on the heterogeneity of the seabed, among other factors. In accordance, one of the highest and the lowest percentages of meadow cover corresponded to two shallow stations. The meadow at Rinella station (10 m) grows on bottoms of high structural heterogeneity, where sand channels are intermingled with big and medium sized boulders, and showed one of the lowest meadow cover recorded in this study, even if the meadow has the higher plant density. On the contrary, the meadow at Punta Barone (7 m) spreads on a flat slope sandy bottom and showed the highest percentages of meadow cover. Besides the natural variability in meadow cover as a function of natural factors, this structural parameter also varies depending on the degree of perturbation since it reflects meadow fragmentation and its thinning out. Indeed, human disturbances should be the cause for the great differences in meadow cover between two stations at similar depths: Porto Shallow (8 m) and Lingua Shallow (6 m) stations, both on the East coast of the Island. The former station with high boat density and visible anchor scars showed 42 % of meadow cover; whereas the later station located further from the Santa Marinas' Port and without clear signs of anchor damage had a 65 % of meadow cover.

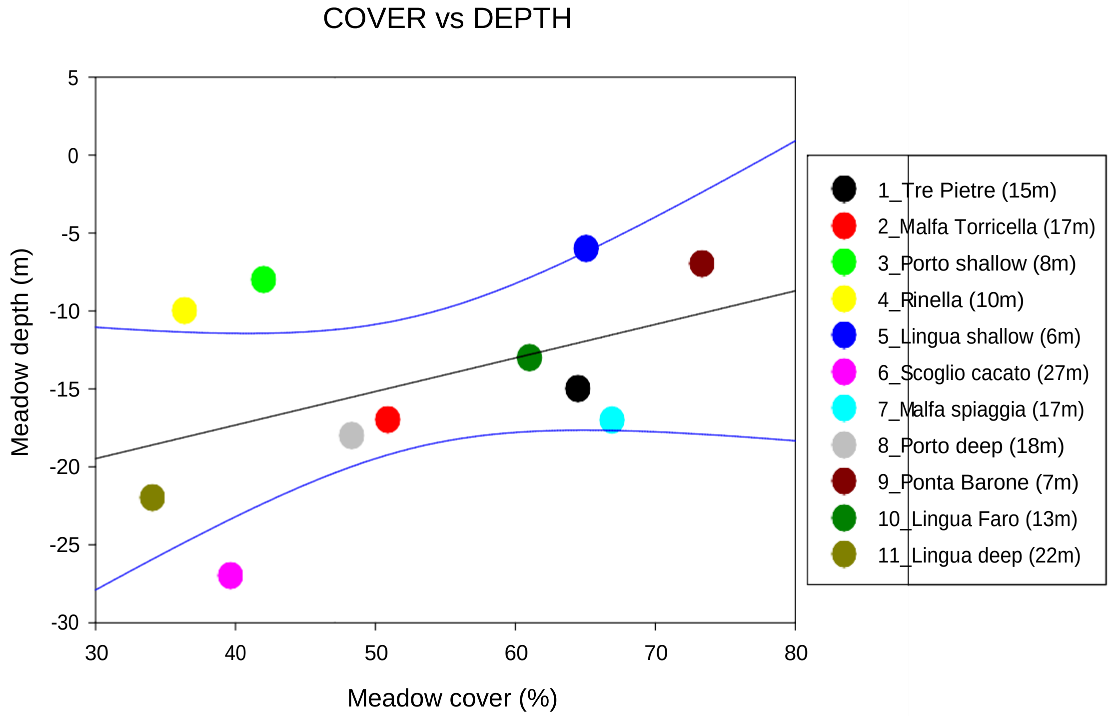

Figure 70. Linear regression of meadow cover against meadow depth.

The level of shoot burial in all studied sites varied between 3.3 ± 1.9 cm in the Rinella station and 8.1 ± 1.3 cm in the Lingua Faro station. Although we cannot draw conclusions from the values obtained for this parameter, the high unburial level of shoots in the latter station together with the fragility and crispy characteristics of the shoots warn that the station could be experiencing some kind of perturbation that can be of natural (e.g. changes in current pattern) or human (e.g. inflow of nutrients) origin. It is therefore important to focus the attention on the evolution of this meadow and to identify any possible human activity that could be affecting the environmental quality of this locality.

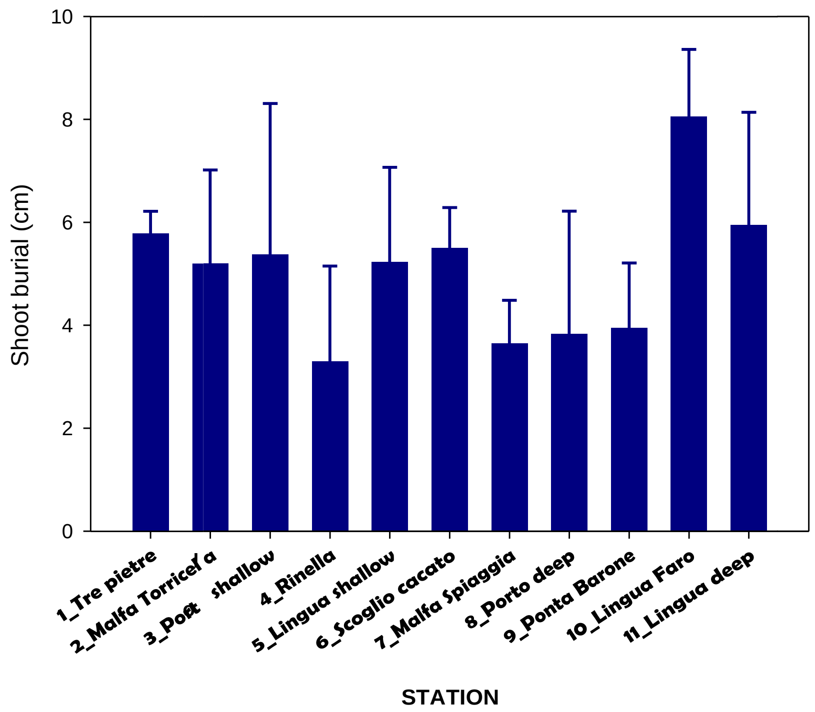

Figure 71. Shoot burial of the eleven *P. oceanica* monitoring stations distributed around the Island of Salina.

5.-CONCLUSIONS AND RECOMMENDATIONS

Within the frame of the POMIS project we have installed a series of long-term monitoring stations and characterized the structure of *P. oceanica* meadows at 11 different sites around the Island of Salina. Data derived from such characterization are presented in the present report with the aim to establish base values for each of the studied meadows that will be used as a benchmark to determine the future evolution of the *P. oceanica* meadows in the Island. The data set here presented is not, in itself, useful for determining with certainty the current ecological status of the meadows, for which other measurements at the physiological, biochemical and molecular levels are needed. The underlying value of this first characterization is based on their utility in the coming years as the initial state against which future changes of the meadows can be compared. It is, therefore, of great importance to continue characterizing, in the long term and on an annual basis, the structure of these meadows. Long-term data series will make it possible to discriminate natural cyclic changes of the meadows from the changes induced by human activities and by the human-induced climate change. This information will be precious for the proper conservation and adequate management of these valuable coastal ecosystems in the Aeolian Islands. One way to guarantee the provision of future data and to make the project more sustainable over the long term could be the involvement of diving centres from the Island and voluntary recreational scuba divers. This model is currently in use in many other places of the Mediterranean with great success; and would add a new social objective to the project, to promote education and environmental awareness among citizens. Voluntary divers need to be initially trained by marine biologist to gain knowledge about *P. oceanica* ecosystem and to produce accurate data, which is key for the correct characterization of meadows evolution.

Although the data here presented is not diagnostic of the conservation status of the studied meadows, as commented above, together with visual field observations they can be useful to warn about the possible existence of threats to the studied meadows. In this sense, the work conducted within the frame of the POMIS project is useful for raising awareness on the significant impact and regression that *P. oceanica* meadows from the Eastern coast of the Island are currently experiencing. All studied deep meadows in this side of the island are in regression and continue to suffer anchor damage, as we have noticed during our sampling surveys. Shallow meadow stands in the area are also highly impacted by boats anchoring, and the impact continues as testified by the presence of detached living fragments of the meadows. Meadows at any depth also show numerous wide scars and clearances produced by the boats mooring in the area; the existing wounds represent active erosion edges that can continue eroding the meadows, even if boat anchoring is prevented. Due to the extensive impact of anchoring, it is of key importance to lay down rules governing mooring and anchoring along the east coast of the Island in order to ensure the sustainable development of the Island, which is highly dependent on tourism. Nowadays there are environmental friendly alternatives to reconcile mooring of recreational vessels with *P. oceanica* meadow preservation. Furthermore, we have observed the presence of many abandoned mooring systems all along the east coast of the Island. The rehabilitation and servicing of these systems that are not currently in use, could be a first action intended to protect the valuable *P. oceanica* meadows from Salina. During the writing of the present project we have heard about the existence of a proposal for the construction of two new Piers about 200 m to the west of the Port of Rinella aimed to increase the number of anchorage points and to reduce the current anchoring pressure on the East side of the Island. We would therefore like to bring to the attention of the relevant public agencies about the importance of conducting comprehensive environmental impact analysis that include the main coastal habitats in the area and various possible alternatives, in order to avoid irreversible damage to valuable ecosystems such as the *P. oceanica* meadows. It is worth to note that in the area in which the new Piers are planned to be constructed exists a healthy and wide *P. oceanica* meadow with the larger shoot density values of all characterized meadows around the Island.

Dozens of dead fun mussels (*Pinna nobilis*), a species strictly protected at European level (Annex IV of EEC Habitat Directive, 1992), were observed around the Island, many of them lying on the seabed while others still attached to the seafloor in their upright position. The valves of dead individuals provide a hard substrate and were colonized by organisms such as sponges, algae and bryozoans. In other cases, they were occupied by octopuses that use the shells as a refuge. Strangely enough, we have found no one *P. nobilis* alive in any of the monitoring stations in which we have conducted our diving surveys, which allows us to suspect about the mass mortality of the species and the possible extinction of local populations around the Island. Mass mortality events of this endemic bivalve have been documented in several regions of the Western Mediterranean over the last two years. They first one occurred in the south-east of the Iberian Peninsula and Balearic Islands in late 2016 and has been rapidly spreading over since, causing the mortality of around 100% of individuals in all infected populations. To date, the mortality has been confirmed also in several locations in Italy (Naples and Sicily). To our knowledge, this is the first observation of high mortality of the species in the Island of Salina and possibly in the whole Aeolian archipelago, and should be understood as an urgent call for action. The first conservation measures to be implemented are those recently recommended by the UICN, and includes among others: i) the visual monitoring of the status of *P. nobilis* and *P. rudis* populations on a monthly basis (mainly during the summer) and, ii) the reporting of any unusual change in the populations. The *P. oceanica* monitoring network established in the present project represents a powerful opportunity to monitor and control the populations of these iconic mollusc species around the Island of Salina.

Several invasive and introduced species have been observed around the Island of Salina. The alien species *Caulerpa cylindracea var. racemosa* grows in several places in which the monitoring stations have been installed. The species was often growing in areas where the existing meadows showed evidence of damage by boats anchoring. In the sandy bottoms surrounding these impacted meadows (e.g. Porto Shallow and Scoglio Cacato stations) the seaweed forms extensive patches together with other pioneer and fast growing seagrass species (*C. nodosa* and *H. stipulacea*). Degraded meadow borders were also colonized by the alien species but the inner parts of the meadows were not invaded, most likely due to the strong light limitation imposed by the dense canopies developed by the species. It is expected that the alien seaweed progressively penetrates the meadows if anchoring continues to degrade them, lessening their structural complexity by reducing plant density and meadow cover. The continuity of the monitoring programme initiated by the POMIS project will be therefore key to determine not only the evolution of *P. oceanica* meadows around the Island but also that of the invasive seaweed populations, and how the interaction between both species determine the valuable functions and services provided by *P. oceanica* meadows in Salina. It is also noteworthy to mention the first record in the Island of Salina of the introduced seagrass species *Halophila stipulacea* in these impacted sites. Although the species is not showing an invasive behaviour in the Mediterranean, contrary to what described in the Caribbean, the consequences of its interaction with native seagrasses are unknown so far. Therefore, data derived from the monitoring programme in the long-term could be useful to recognize the future trend of the species in the Mediterranean and associated effects on native coastal communities. Furthermore, since its introduction in the eastern Mediterranean through the Suez channel, the species is progressively spreading westward likely due to the progressive seawater warming induced by the global climate change. In this sense, the installation of temperature sensors in several localities of the Island, as planned within the POMIS project, will produce seawater temperature time series of great value to ascertain the future trend of both seagrass species in the Island of Salina and the western Mediterranean basin.

6.- PHOTO GALLERY

Figure 72. Big meadow portions detached by the mechanical effect of anchors are present in *P. oceanica* meadows on the East coast of the Island of Salina.

Figure 73. High presence of recreational boats anchoring inside *P. oceanica* meadows from the eastern coast of the Island of Salina

Figure 74. Many abandoned mooring systems have been observed to the south of the Port of Santa Marina and other areas on the east side of the Island of Salina.

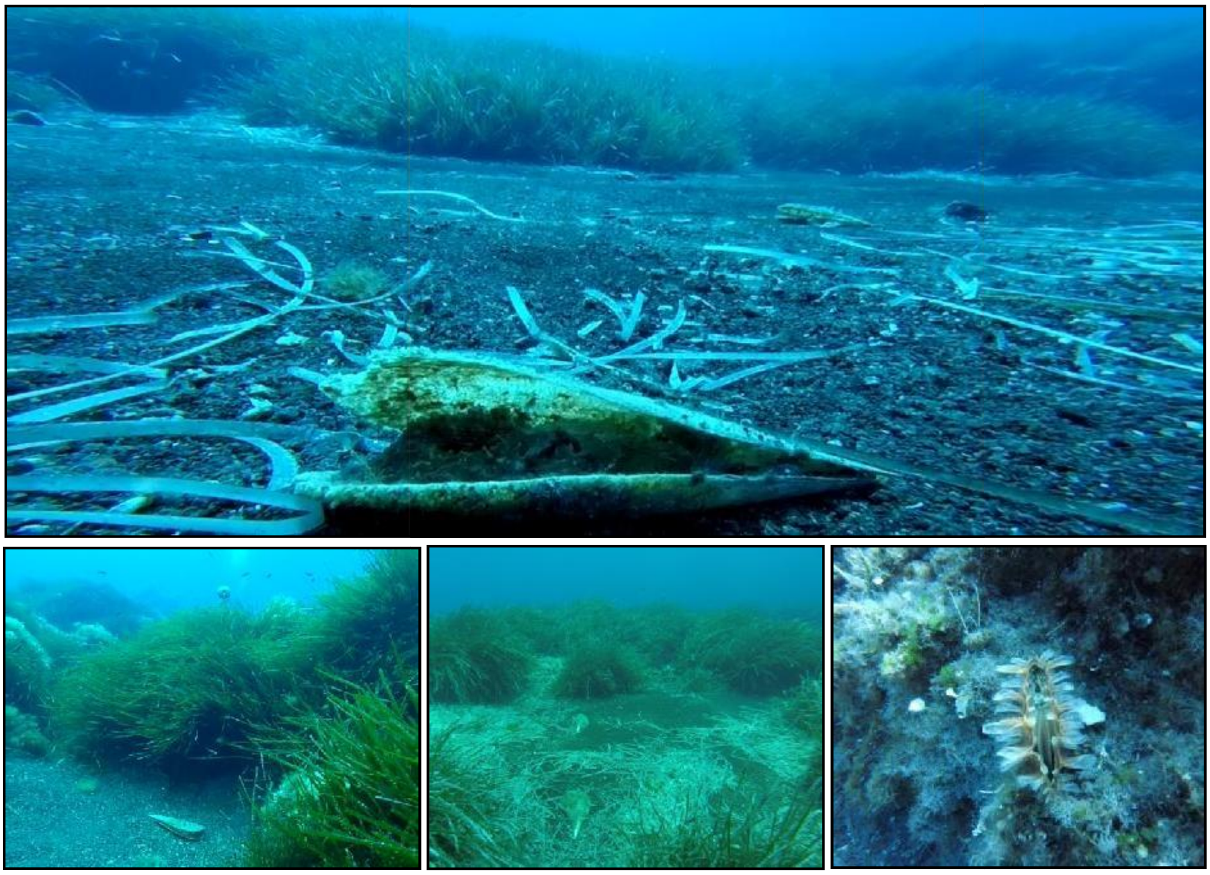

Figure 75. Dozens of dead pen shell (*Pinna nobilis*) individuals were observed around the Island of Salina. One single living individual of *Pinna rudis* was observed on the eastern coast of the Island (Right-bottom corner).

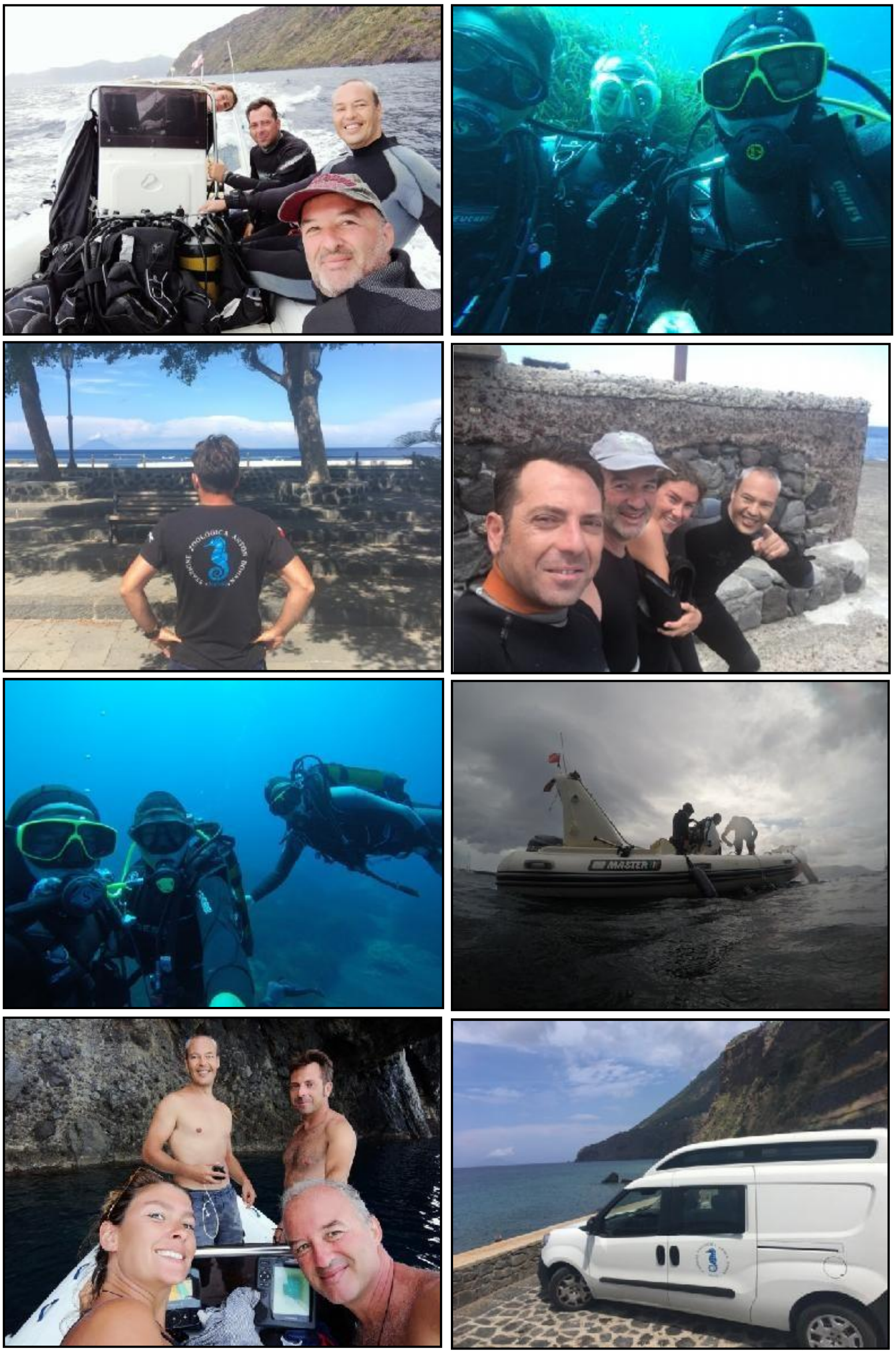

Figure 76. Some pictures of the POMIS working team during the field campaigns around the Island of Salina.