



UNIVERSITÀ DEGLI STUDI DELLA TUSCIA DI VITERBO
DIPARTIMENTO DI SCIENZE ECOLOGICHE E BIOLOGICHE

Corso di Dottorato di Ricerca in
ECOLOGIA E GESTIONE DELLE RISORSE BIOLOGICHE - XXX Ciclo

Spatio-temporal variations of benthic communities associated with the *Posidonia oceanica* seagrass (meadow and *Sabellaria alveolata* bioconstrictions)

(s.s.d. BIO/07)

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A.A. 2017/18

Abstract

Posidonia oceanica (L) Delile (1813) is the endemic seagrass of Mediterranean Sea, subjected to a diffuse regression in last 50 years. *P. oceanica* meadow play a fundamental ecological role in coastal ecosystems and recognized worldwide such as a coastal hotspot for biodiversity and nursery area. The *P. oceanica* beds can be considered a unique substrata supporting a high variety of macro and micro-environments that create various ecological niches useful for the colonization and sustenance of several marine species. Sedimentary flux is one of the ecological factors of the seagrass ecosystems and makes an important theme for the conservation of coastal natural resources. The present work investigates the spatio-temporal variations of the benthic communities associated with the *P. oceanica* bed and their linkage with the sedimentary processes and the plant biological cycle. The experimental investigations about sedimentation of organic and inorganic matter were monthly conducted on a meadow placed at 7 m depth in Civitavecchia (Italy), throughout the year 2015-2016, by the use of sediment traps. Fauna assemblage were analysed seasonally on three macro-habitat (sand pool, rhizome and leaves) of *P. oceanica*. The experimental investigations conducted on *P. oceanica* meadow have demonstrated the role of seagrass on particles sedimentary process and how this interaction has a direct implication on the structure of fauna assemblage. Proceeding from the bottom toward the leaves a vertical gradient of stability is clearly recognized. The leaf stratum fauna is the most variable and strongly dependent to the growth of leaves; the population of rhizomes is more susceptible to sedimentary dynamic regime of particles, that causes a shift of trophic categories while populations of sand pool are quite stable during the year. The capacity of a *P. oceanica* meadow in particles retention, especially during the maximum growth of leaves, favours the accumulation of organic matter and sediment that contribute to 'matte' accretion and provide habitat and feed for benthic species that live in the rhizome-matte stratum. During the taxonomic identification phase, four alien organisms associated with *P. oceanica* were reported (*Mesanthura* sp., *Caprella scaura* Templeton, 1836, *Paracerceis sculpta* (Holmes, 1904) and *Parantura japonica* Richardson, 1909). Among these, the Isopod *Mesanthura* sp. was recorded for the first time in the northern Tyrrhenian Sea. The rare Polychaeta Sabellid *Acromegalomma messapicum* was observed for the first time in the Tyrrhenian Sea, making this the second report of this species ever. This find added some useful morphological and biological information to the original description of this species. Moreover, the effects of *P. oceanica* foliar renewal have been observed in association with a small *Sabellaria alveolata* reef located in the study area. Our results demonstrate that the presence of supra and meso-littoral deposits of *P. oceanica* leaf litter (banquettes and resuspended fragments) alter the *S. alveolata* population structure, causing a significant decrease in the quality of the bioconstructions and increasing the population of epibionts. The seagrass litter affects both the species assemblage associated with the *S. alveolata* bioconstructions and the communities associated with the sediments surrounding these structures.

INDEX

1. Introduction	1
1.1 Introduction to the thesis structure	4
2. Objectives and Scope	5
3. Seasonal structure of communities associated to <i>Posidonia oceanica</i> and their interactions with the sedimentary processes	6
3.1 Introduction	6
3.2 Materials and methods	7
3.2.1 Characteristics of the study site	7
3.2.2 Benthos	9
3.2.3 Analysis of physical factors	10
3.2.4 Characteristics of <i>Posidonia oceanica</i> meadow	11
3.3 Results	12
3.3.1 Characteristics of seagrass	12
3.3.2 Analysis of physical processes	13
3.3.3 Description of taxonomy and trophism	15
3.3.3.1 Total sampling	15
3.3.3.2 Sands pool (SP)	19
3.3.3.3 Rhizomes (RH)	21
3.3.3.4 Leaves (LE)	24
3.3.3.5 Analysis of benthic fauna	26
3.4 Discussion	34
3.5 Conclusion	39
3.6 Analysis of the ecological quality (AMBI and M-AMBI indices)	41
4. Sedimentary process in a shallow water <i>Posidonia oceanica</i> meadow	43
4.1 Introduction	43
4.1.1 Sedimentary process	45
4.2 Study site	46
4.3 Methods	48

4.4 Results	52
4.4.1 Meteorological conditions	52
4.4.2 Seasonal changes of <i>Posidonia oceanica</i> meadow characteristics	52
4.4.3 Bed sediment composition	54
4.4.4 Particulate sedimentation flux	56
4.5 Discussion	64
4.6 Conclusion	68
5. Rare and alien species associated with <i>Posidonia oceanica</i>	69
5.1 Addition to the knowledge on <i>Acromegalomma messapicum</i>	69
5.1.1 Introduction	70
5.1.2 Materials and methods	72
5.1.3 Results	73
5.1.4 Conclusion	78
5.2 New Mediterranean Biodiversity Records (December 2017)	81
5.2.1 Introduction	82
5.2.1 First records of the genus <i>Mesanthura</i> (Isopoda: Anthuridae)	
in the northern Tyrrhenian Sea and notes about its ecology	84
5.2.1.1 Introduction	84
5.2.1.2 Materials and methods	85
5.2.1.3 Results	85
5.2.1.4 Discussion	87
5.3 New Mediterranean Biodiversity Records (July 2016)	88
5.3.1 Alien crustaceans associated to <i>Amathia verticillata</i> :	
new Mediterranean records in Italian waters of <i>Caprella scaura</i> ,	
<i>Paracerceis sculpta</i> and <i>Paranthura japonica</i> .	92
6. The effects of <i>Posidonia oceanica</i> leaf litter on the <i>Sabellaria alveolata</i>	
biocostructions	95
6.1 Introduction	95

6.2 Study area	96
6.3 Materials and methods	97
6.4 Results	99
6.4.1 Analysis of the seasonal variations of the blocks morphological features.	99
6.4.2 Analysis of <i>S. alveolata</i> reef associated fauna	105
6.4.2.1 Total faunal assemblages	105
6.4.2.2 Analysis of the seasonal variation in the three Areas of the reef.	111
6.4.2.3 Analysis of the benthic communities in the substrates associated at the <i>S. alveolata</i> reef.	117
6.4 Discussion	121
6.5 Conclusion	124
7. Photographic collection	125
8. Overall conclusions	143
9. Comprehensive literature references	145

1. Introduction

Posidonia oceanica (L) Delile (1813) is the dominant endemic seagrass in the Mediterranean Sea (Procaccini et al., 2003). This seagrass is a monocotyledon belonging to the Posidoniaceae family. Class Liliopsida, Order Alismatales, Family Posidoniaceae, Genus *Posidonia*, Species *P. oceanica*.

The ecological importance of seagrass meadows is known for all coastal systems, both in tropical and temperate seas. In the Mediterranean Sea, the *P. oceanica* meadows are one of the most valuable ecosystems of the environment.

The structure of the meadows provides substratum heterogeneity and creates a high variety of habitats and resources essential to the associated fauna and flora, (Gambi et al., 1992, 1995; Boero, 1981; Mazzella et al., 1989). The morphology of the meadow provides an effective barrier, defending the coast from erosion. The *P. oceanica* meadows play a fundamental role in coastal dynamics because they influence sedimentation rates, at least on a local scale, modifying the original implant sediment (Dauby et al., 1995). This phenomenon is due to the double action that the living leaves exert both on the fine particulate material that is captured and harnessed between the rhizomes, and the effect on waves and the currents whose intensity is greatly reduced. The meadow also represents a strong but elastic structure that can absorb part of the wave energy (Fonseca et al., 2007) that control the sedimentary processes, favouring the settlement of particles and preventing resuspension (Gacia & Duarte, 2001; Hendricks et al., 2008).

P. oceanica meadows represent a very complex and well-structured biocoenosis, characterized by a high biological variability of the associated plant and animal communities (Buia et al., 2000). This biocoenosis consists of the overlap of different populations: the photophile associated with the leaf layer, the sciaphile associated with rhizomes and matte (Mazzella et al., 1989; Gambi et al., 1992; Buia et al., 2003) and the most heterogeneous one, linked to the sediments on which the 'prairies' are established (Harrigue et al., 2006).

The *P. oceanica* ecosystem also constitutes a nursery area for fish and a refuge for a large number of organisms, including numerous species of considerable economic importance (Francour, 1997).

It is known that the *P. oceanica* meadows are one of the fundamental components for the equilibrium and the richness of the Mediterranean coastal areas. They are characterized by a high oxygen production, high vegetable biomass and their primary production results are among the highest for the marine environment (Pergent et al., 1994; Pergent-Martini et al., 1994).

A considerable part of this primary production (from 25% to 85%, Boudouresque et al., 2006) is exported in the form of dead leaves to other coastal substrates, where it represents a food resource of great importance. The organic substance produced is a direct and indirect source of food for many organisms as well as the basis of a complex trophic network (Mazzella et al., 1992).

After heavy autumn storms, coinciding with the main period of foliar renewal, a variable proportion of leaf litter (10–90 %, depending on the local hydrodynamics) is exported away from the meadows and stacked onshore forming structures known as “banquettes” in the Mediterranean Sea (Romero et al. 1994). The stranded biomass supplies important amounts of sediments and nutrients to beaches, especially in those locations where sediments are largely of biogenic origin. Additionally, this litter covers the sand of the beaches, keeping it from erosion during storms (Jeudy de Grissac, 1984a) and some of the detritus piled up on the shoreline remain in the water, increasing its viscosity, and thus, lessening the energy of the swell and the risk of coastline erosion (Marbà 2009). The *P. oceanica* seagrass is particularly affected by changes in environment quality and it has been observed that an increase in coastal pollution can lead to the disappearance of this phanerogam; for this reason *P. oceanica* is considered an excellent indicator of the quality of the environment (Pergent et al., 1995; Montefalcone, 2009).

Human development in coastal areas has caused a significant shift in ecosystem dynamics and scientific evidence of the adverse effects of anthropogenic fluxes are of concern due to the continuous decline in seagrasses (Orth et al., 2006; Montefalcone et al., 2015; Serrano et al., 2016). The development of land, often with the attendant erosion of soil, can cause a qualitative and quantitative change of substance and sediments entering into the sea, causing pollution, alteration of sedimentary balance and contamination of sediments. Untreated sewage outlets, fish-farm effluent or runoff from fertilized agricultural areas are serious threats to neighbouring *P. oceanica* meadows. Multiple human pressures and the degradation of coastal ecosystems can result in the progressive replacement of seagrasses by opportunistic macrophytes and algae and the impoverishment of ecosystem functioning and services (Costanza et al., 1997; Duarte, 2000; Montefalcone et al., 2015).

The synergic interactions among disturbances, together with their duration and magnitude, may lead to a shift in ecosystem dynamics and the loss of seagrass ecosystems (Duarte, 1995; Montefalcone et al., 2015). Another regression cause is due to the introduction of alien species that can compete with *P. oceanica* or with the organisms that constitute the associated communities (De Villele and Verlaque, 1995; Montefalcone et al., 2007, 2010).

The *P. oceanica* seagrass meadows are protected by the Habitats Directive 1992/43 / EEC (implemented in Italy with the D.P.R. 357/1997) as a priority habitat (whose conservation requires the designation of special areas). The presence of *P. oceanica* meadows involves the establishment of Sites of Community Importance (SCI) that constitute, together with the Special Protection Areas (SPAs) (Birds Directive), Natura 2000 Network sites, a network of protected natural areas, established by the European Community. In addition, the European Marine Strategy Directive (2008/56 / EC), implemented in Italy by Legislative Decree 190/2010, suggests this habitat is suitable for the ecological quality assessment. This assessment is carried out through the definition of the Good Environmental Status (G.E.S.) in order to perform a sustainable management of the marine environment.

Another important species for maintaining the quality of the coastal ecosystem is the honeycomb worm *Sabellaria alveolata*, a gregarious bioconstructor polychaete worm belonging to the family Sabellariidae. This worm is an ecosystem engineer species, being able to modify the coastal environments and so it is considered the most important building organism in temperate shallow environments (Naylor and Viles, 2000). *S. alveolata* increases the heterogeneity of pre-existing substrates by creating complex bioconstructions, resulting in three-dimensional structures that constitute new suitable hard substrates for the settlement of a great amount of characteristic and rare invertebrates, both sessile and vagile species and are also able to provide coastal protection (Dubois et al., 2002, 2006; La Porta and Nicoletti 2009; Schlund et al., 2016; Lisco et al., 2017).

The *S. alveolata* reefs are included in the European Red List of Habitats (Gubbay et al. 2016), because of their great vulnerability to anthropogenic disturbance (e.g. pollution, beach nourishment, trampling) (Dubois et al., 2002; Plicanti et al., 2016). For the aforementioned reasons, honeycomb worms bioconstructions are considered as valuable and vulnerable marine habitats that must be evaluated for protection by European Union (EU) legislation, including the Habitats Directive (Directive 92/43/EEC), the Water Framework Directive (Directive, 2000/60/EC) and the Marine Strategy Framework Directive (Directive, 151 2008/56/EC).

In the light of the scientific state of the art presented, this PhD thesis analyse and describe, through an integrated approach, the relationship between the dynamic processes and the spatio-temporal variations of the species distribution in the different macrohabitats of a *P. oceanica* meadows located in the northern Latium coast (Italy) of Central Tyrrhenian Sea. This should provide complete knowledge about the biotic interactions (e. g., feeding behaviour) in three different macro-habitats (leaves, rhizoma layer and sand pools) with the abiotic factors, to determine the actors influencing the seasonal variation of the structure of the communities. The dynamics of vertical sedimentation flux over *P. oceanica* meadow seabeds was monitored, during one year, using sediment traps, highlighting the role of *P. oceanica* growth in the sedimentation processes.

Furthermore, this work increases the knowledge of rare (e.g. *Acromegalomma messapicum* (Giangrande & Licciano, 2008) and alien species (*Mesanthura* sp., *Caprella scaura* Templeton, 1836, *Paracerceis sculpta* (Holmes, 1904) and *Paranthura japonica* Richardson, 1909) associated with this phanerogam also by reporting of two new species in this sector of the Tyrrhenian Sea.

The effects of *P. oceanica* foliar renewal have been observed in association with a small *S. alveolata* reef located in the study area. In this work, the effects of *P. oceanica* leaf litter (fragments and banquettes) on the bioconstructions were analyzed and described for the first time through the study of the seasonal change in the morphological feature of the reef and by the analysis of the spatio-temporal variation of the associated fauna.

1.1 Introduction to the thesis structure

The first part (chapter 3) has been organized to discuss the taxonomical and trophic structure of the fauna associated to the leaves, rhizomes and seabed of *P. oceanica* meadow in a seasonal context. These seasonal variations of the macrobenthic communities are placed in relation to the seasonal fluctuation of environmental parameters such as *P. oceanica* growth, sea-water temperature, mainland inputs and sedimentary processes of inorganic and organic matter. In this chapter the ecological quality of the study area was also analyzed through the use of the AMBI, the AZTI Marine Biotic Index.

In the fourth chapter, the results of a one year experiment, conducted with sediment traps inside a shallow-water *P. oceanica* meadow, are used to explain vertical sedimentation flux over a seabed dominated by this phanerogam.

Chapter 5 is focused on the rare and alien species sampled on the *P. oceanica* meadow described in the previous chapters: *Acromegalomma messapicum* (Giangrande & Licciano, 2008) samples were collected and reported for the first time on the Tyrrhenian coasts allowing us to examine additional fresh material and to add some useful morphological and biological information to the original description of this species. Concerning the four alien crustaceans collected from shoots and leaves of *P. oceanica*, our results represent the first record of the genus *Mesanthura* (Isopoda: Anthuridae) in the northern Tyrrhenian Sea and support the suspected introduced origin and the establishment of this exotic species in the area. Moreover the non-native species *Caprella scaura* Templeton, 1836, *Paranthura japonica* Richardson, 1909, and *Paracerceis sculpta* (Holmes, 1904) were also observed for the first time in association with *P. oceanica*. In this chapter our work of 2016 was also included, which reports this species also being associated with the allochthonous bryozoan *Amathia verticillata* (Della Chiaje, 1822) in the Adriatic Sea.

Finally in Chapter 6 the seasonal variation in morphological features of a small *S. alveolata* reef associated with a cyclic presence of *P. oceanica* banquettes has been investigated, analyzing the relationship between the temporal variation of the physical structure of the bioconstruction and the presence of *P. oceanica* leaf litter and describing the seasonal variation of the fauna assemblage associated at the reef and the its epibionts community.

A photographic collection of the most abundant species sampled on the different substrates analyzed is included in this work.

2. Objectives and scope

This PHD thesis aims to analyse the species distribution on three different macrohabitats associated with the *P. oceanica* and their relationship with dynamic processes. The seasonal foliar renewal of *P. oceanica* has also been analyzed in relation to the quality and conservation status of a small *S. alveolata* reef located in the study area. This study has increased the previous knowledge about the role of *P. oceanica* meadows located in shallow water on the structure of coastal communities through a multidisciplinary approach.

The community analysis was also useful to determine the ecological quality of the study area, a sector of coast bordering the commercial Port of Civitavecchia which also has touristic infrastructures, as suggested by the *Water Framework Directive 2000/60/EC* or *Marine Strategy Framework Directive 2008(56/EC)* of the European Community.

The Port of Civitavecchia is a major hub for national and international commercial traffic. The constant evolution of the port structure modify the sedimentary dynamic and the high number of ships that transit in these waters, increase the introduction of alien marine species. These factors are considered one of the main threats to coastal ecosystems biodiversity at different scales and variable extent. The constant monitoring of the communities associated with the port substrates and in neighboring areas, is essential for the control of the allochthonous and nonindigenous species and for the management of the coastal ecosystem.

3. Seasonal structure of communities associated to *Posidonia oceanica* and their interactions with the sedimentary processes.

3.1 Introduction

The Mediterranean coastal area is widely colonized by the seagrass *Posidonia oceanica*, which is a vascular marine plant that supports highly complex and productive ecological systems (Pergent and Pergent-Martini, 1991; Gambi et al., 1992; Gambi et al., 1995; Borg et al., 2010; Bedini et al., 2011). Much attention has been focused on the physical and biological role of the *P. oceanica* in the marine environment, assigning to this vascular plant a fundamental ecological role in coastal ecosystems (Hemmings and Duarte, 2000) and recognized worldwide such as a coastal hotspot for biodiversity (Myers et al., 2000) and nursery area. The *P. oceanica* beds can be considered unique substrata supporting a high variety of macro- and micro-environments (Stoner, 1980; Orth et al., 1984; Buia et al., 2000). The plants provide additional microhabitats and the structural and functional descriptors of seagrasses (shoot density, or leaf surface and biomass), strongly affect the composition and abundance of the fauna associated with them. Many relationships were found between the meadow structure and the associated organisms, more evident for epifauna associated with the leaf stratum, than for the infauna, which are more or less buried in the sediment (Howard et al., 1989). This habitat complexity provides a refuge from predators, and allows different species to occupy various ecological niches in the same habitat (Stoner, 1980; Orth et al., 1984). Previous studies analysed and described three different faunal assemblages associated with the leaves, rhizome stratum and soft bottom. These different macrohabitats can be colonized by a high number of species that can live, preferentially or exclusively, in one of these different spatial compartments (Gambi et al., 1995; Boero, 1981; Mazzella et al., 1989).

The ecology of the meadows is regulated by several environmental parameters. Some studies concern about the relationship to the structure and distribution of the communities with environmental parameters (Mazzella et al., 1989; 1992; Gambi et al., 1992, 1995; Scipione et al., 1996; Bedini et al., 1997; Borg et al., 2010; Bedini et al. 2011). The linkage of the health of seagrass meadows to several factors such as light, nutrient, trace metals, sediment accumulation rates and grain-size, organic carbon stocks and its accumulation rates was demonstrated (Serrano et al., 2016). In particular, several studies focus on the role of *P. oceanica* on hydrodynamic and sedimentary processes (Gacia & Duarte, 2001; Hendricks et al., 2008) observing its effect on turbidity filtering and trapping particles (Hendricks et al, 2008) and the capacity to promote the

deposition and reduce the resuspension process thus providing a bio-geomorphological role (Vacchi et al., 2016). In shallow underwater environments, the local geomorphology, currents and wave exposure play a very significant role in controlling habitat distribution, particularly for seagrass meadows (Short et al., 2002; Koch et al., 2006; Ryan et al., 2007). Furthermore, in shallow waters the meadow and the associated fauna quickly respond to the variations of environmental parameters (Bedini et al., 2015).

In this work we have seasonally analysed the taxonomical and trophic structure of the fauna associated with the leaves, rhizomes and soft-bottom seabed during one year in a coastal site of Civitavecchia (Italy), located on the eastern side of the Northern Tyrrhenian Sea. Coupled to the seasonal analysis of macrobenthic communities some environmental parameters were measured, such as *P. oceanica* growth, sea-water temperature, run-off and sedimentary processes of inorganic and organic matter. Sedimentary processes were studied during one year through the use of sediment traps and bed sediment sampling. *P. oceanica* growth was directly measured on the sampling station, while the variation of other parameters was retrieved by monitoring stations available in the study area. This integrated approach aims to analyse the relationship between the dynamic processes and species distribution on the different macrohabitats. This should provide more complete knowledge about the biotic interactions (e. g., feeding behaviour) in three different macro-habitats with abiotic factors, to determine the actors influencing the seasonal variation of the structure of the communities. The description of the structural and functional aspects of macrofauna assemblages within a *P. oceanica* meadow during a yearly cycle allow us to detect the preferentially and exclusively species association in the different macrohabitats.

3.2 Materials and methods

3.2.1 Characteristics of the study site

The study area is located at 7-meters depth in the northern Latium coast (Italy) of Northern Tyrrhenian Sea, which is characterized by a spring tidal range of 0.3 m and is exposed to waves mainly from the SW and to southerly and northerly winds. The wave intensity exhibits a seasonal fluctuation with a maximum during the winter and autumn and a minimum in the summer. On the basis of rainfall records of the last 12 years (2003-2016) retrieved from the Hydrographic Service of Latium Region (<http://www.idrografico.roma.it/>), the average annual precipitation in the study area is 481 ± 163 mm and is subjected to seasonality with a maximum intensity in the autumn (225 ± 45 mm) and a minimum intensity in the summer (59 ± 34 mm). The coastal morphology is characterized

by a dominance of terraces where the irregular seabed is composed by rocky outcrops and natural depression covered by sediments. Along the coast, there are only several minor streams that originate from the nearby Tolfa Mountains, while the largest river (i.e., the Mignone river) is located 11 km north of the study site. The sediment contribution from the Mignone river does not influence the study site because sediment transport along the shore is oriented northward (Anselmi et al. 1976, Berriolo and Sirito 1985, Noli et al. 1996). The seabeds of the coastal area are widespread colonized by *P. oceanica* that extend from approximately 10 m to 30 m in depth. In the experimental site the *P. oceanica* meadow appears from a depth of 3 m, and the architecture exhibits a nearly continuous cover with the presence inside the meadow of several sand patches of various dimensions. Moving from northwest to southeast parallel to the shore, the meadow is interrupted by a wide sandy channel, which is a transitional zone between the rocky outcrops and the meadow (Fig.1).

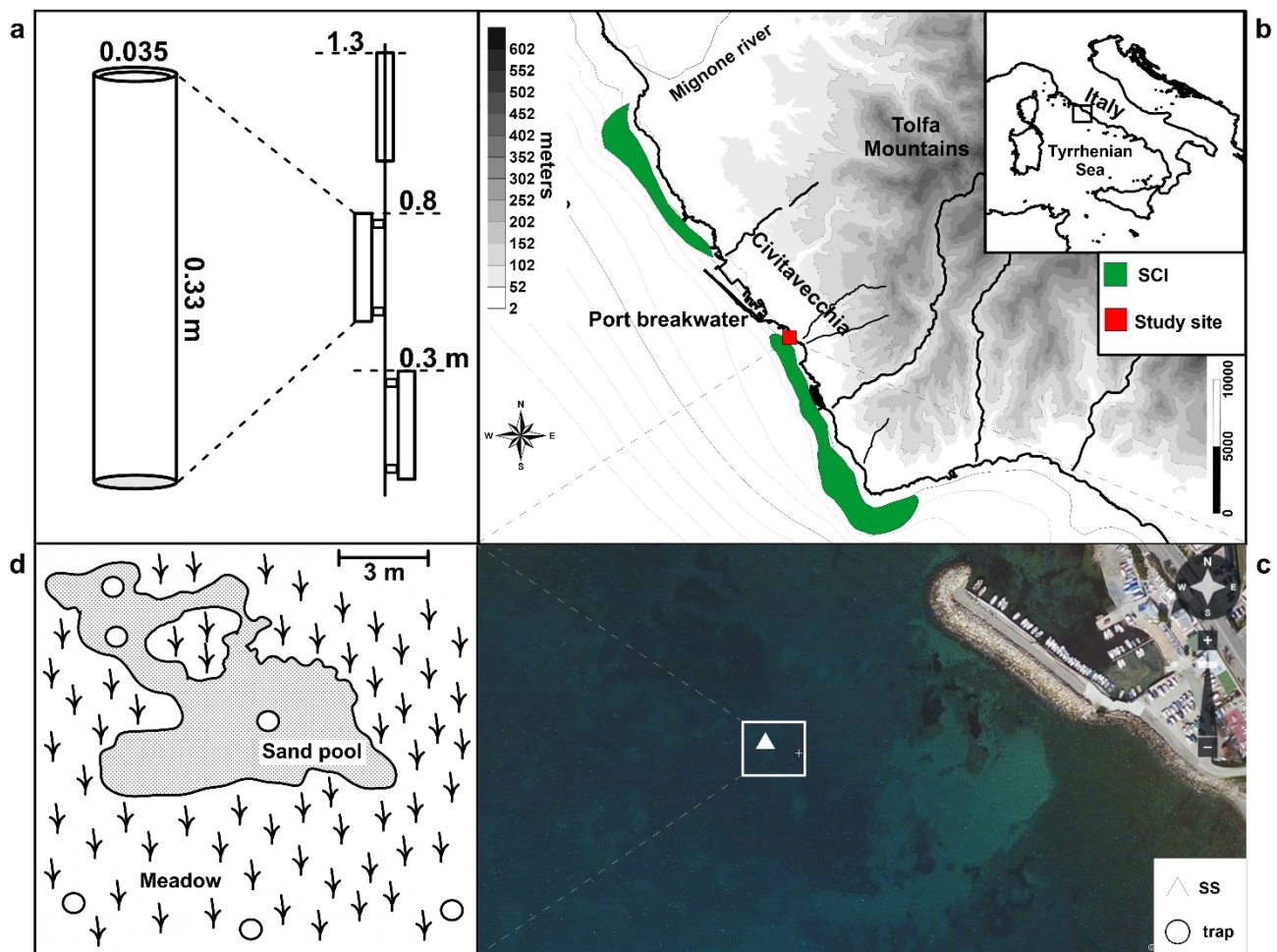


Figure.1 a) sketch of the structure of sediment traps station; b) regional view of the study area showing the location of Sites of Community Importance (SCI) and study site; c) aerial view of experimental site; d) configuration, position and distance of the steel rods where traps were mounted.

3.2.2 Benthos

Benthic organisms were sampled by SCUBA divers during the four seasons (October, March, May and August) considering the vertical gradient of the *Posidonia* meadow system. In detail, the sampling was made in sand pools that patch the meadow (SP), at rhizomes (RH) and leaves (LE). The different faunal assemblages of the different macrohabitats were sampled by three different sampling techniques. The fauna associated with the leaf stratum (LE) was sampled by a hand-towed net (40 Å~ 20 cm, 0.4-mm mesh size). Two samples tens of metres distant from each other were collected in each season. Each sample consisted of a series of 60 strokes over the seagrass canopy (Russo et al., 1985; Buia et al., 2003; Gambi et al., 1992, Gambi et al., 1995).

The air-lift is used to sampling the fauna living in the rhizoma layer (RH) and on the *Posidonia* matte. In each season, one air-lift sample (over a surface of 1m²) was taken inside the meadow (Russo et al., 1986; Gambi et al., 1995). Moreover, to analyse the fauna associated with the *Posidonia* scales, a number varying from 40 to 50 of orthotropic rhizomes were sampled in each season. Rhizomes were randomly selected in two sub-areas and were immediately inserted into PVC containers with a hermetic cap (Gambi et al., 2002).

The fauna living in the sand pools (SP) was collected by means of corers. Each corer consisted of a PVC tube 10 cm in diameter and 25 cm in height (surface = 78.5 cm²), with a 0.4 mm mesh net on top, that was inserted about 20 cm into the sediment. At each season, five core replicates were collected (Gambi et al., 1998, Buia et al., 2003) and each sample was sieved with a mesh size of 1 and 0.5 mm. Due to the fact that the corer technique and the air-lift method collects quantitative samples whereas the hand-net technique collects semi-quantitative samples, the number of individuals found using the three methods cannot be compared and they must be analysed separately.

Macrofauna samples were sorted and taxonomically classified. Polychaetae, Amphipoda, Isopoda, Tanaidacea, Decapoda, Bivalvia, Gastropoda and Echinodermata were identified to the species level, whereas the others were classified into the highest taxa. Species were assigned to different trophic guilds following Fauchald and Jumars (1979), Jangoux and Lawrence (1982), Grahame (1983), Russell-Hunter (1983), Gambi and Giangrande (1985), Macdonald, et al., 2010 and <http://marinespecies.org/>. Analysis of the benthic fauna defines the dominant taxa of the total sampling and for each macrohabitat. Classic biotic indexes (Number of species, Abundance, Diversity and Evenness) in the different macrohabitats are estimated to define the population structure. The ANOVA test highlights the presence of significant seasonal fluctuation of the

structure of population while the SIMPER test determines the contribution of such species to the total variance during the seasons. Canonical correspondence analysis was used to assess the relationship between species and feeding mode to dynamic processes of the environment.

3.2.3 Analysis of physical factors

During the year of benthic sampling, some environmental parameters that influence the coastal system were recorded. In particular, the evolution of the sedimentary flux of organic and inorganic matter, the organic matter concentration in the bed sediment, the temperature of water column and the rainfall was monitored. The first is the result of the interaction between the hydrodynamic energy, induced by wind and waves, and the seabed that causes stress and resuspension of the seabed sediments in shallow waters. From the total sedimentary flux, the inorganic and organic compounds were separated. Sea-water temperature is a fundamental ecological factor that influences the biological cycle of seagrass. Variations of sea-water temperature along the water column were determined by monthly measurements with a multiparametric CTD probe. The rainfall contributes to the runoff of sediments, nutrients and organic matter from the mainland especially the study site, due to the absence of rivers. The rainfall data was collected by the pluviometric station of the Hydrographic Service of the Latium Region, in Civitavecchia.

The measurements of sedimentary process were conducted on two measuring stations placed at 7-metre depth on the *Posidonia* meadow (PM) and on the sand patch inside a meadow (SP), respectively. The distance between the PM and SP stations was 15 meters. The total sedimentary flux was monitored in the PM and SP using sediment traps from October 2015 to December 2016. The traps were constructed using polyethylene cylindrical tubes with an opening diameter of 0.035 m and a length of 0.33 m; this provided an aspect ratio of 9.4, which is near the optimal aspect ratio suggested for minimizing the over- and under-trapping (Gardner 1980; Hargrave and Burns 1979). The traps were mounted on a steel rod at three elevations from the seabed (i.e., 0.3 m, 0.8 m and 1.3 m; Fig.1a) in three replicate units located within a radius of approximately 3-6 metres. Considering previous studies (Gacia and Duarte 2001), at the same distance from the bottom, the different frames could be considered as replicate units. Before the installation, the traps were filled with surface water; then they were covered with caps, which the scuba divers removed at the start of the survey.

The experiment involved 10 surveys extended over a year; the surveys were conducted almost monthly in order to detect the seasonality of the sedimentary dynamic processes. Each survey lasted

for a period ranging between 2 and 14 days. The contents of the sediment traps were collected in two ways, depending on the amount of the trapped material: for trapped content lower than 1g, the material was collected by filtration onto pre-combusted 47-mm GF/F filters; for trap content greater than 1g, the wet sediment was placed into a pre-weighed aluminium tray. In both cases, the collected materials were inspected for active swimmers, which were removed if present (Michaels et al. 1990), and dried in an oven for a minimum of 24 hours at 60 °C until a constant weight was obtained (precision of 1 mg). The load of the traps was converted into flux ($\text{g m}^{-2}\text{d}^{-1}$) considering the geometry of the traps and the duration of the survey.

According to Pejrup et al., (1996), the total sedimentary flux at the bottom (Dr) is the sum of resuspended material and the natural settling material (primary). Following the methodology of the same authors, the resuspension flux (Fr) can be fitted by an exponential function where the load declines exponentially with increasing height above the sediment source. Fr can be estimated as the intercepts at the sediment surface of the fitted exponential relationship between the downward depositional flux and the height of the sediment traps above the bottom. As a general rule, primary flux can be obtained by considering the vertical asymptotic value of the exponential function. Bed sediments were sampled seasonally at the PM and SP stations using a 0.20-m diameter corer during October and December 2015 and April and July 2016. Organic matter content was determined from the traps and bed-sediment samples using a mass-loss technique referred to as loss on ignition (LOI). The samples were ignited at 550 °C for 4 h, left to cool inside the furnace, then placed in the dessicator and weighed. The mass of the dried and ignited sediment was recorded with a precision of 1 mg using an analytical balance. The loss on ignition of the dry mass of the sample is expressed as a percentage calculated from the dry mass of sediment, the mass of crucible and the mass of the residue of ignition.

The data collected during monthly surveys are used to determine the seasonal variations of sedimentary processes. It was defined as the average vertical sedimentation flux, the contribution of the resuspended component within the flux and the average content of organic matter compounds within the flux.

3.2.4 Characteristics of *Posidonia oceanica* meadow

The *P. oceanica* meadow was analysed at the depth where the traps were placed by defining the seagrass density and biometry of the leaves. The biometry of leaving leaves (foliar shoots) was determined seasonally on 10 shoots according to Giraud (1977); the Leaf Area Index (LAI, leaf

surface area per shoot, m^2m^{-2}) was also calculated. The shoot density was evaluated in the meadow by counting the number of shoots using $0.4 \times 0.4 \text{ m}^2$ standard quadrates (10 runs). In addition several pictures were made during surveys to detect change of the *Posidonia* meadow environment during the year.

3.3 Results

The results are presented in different subsections where are detailed the descriptions of taxonomy and trophism, the dynamic of physical factors, the evolution of *P. oceanica* meadow and their mutual relationship.

3.3.1 Characteristic of seagrass

The sand patch at the SP station shows large changes between the seasons (Fig. 2a-d). In autumn, the sand patch presented, apparently, the maximum extension, while during the summer the growth of seagrass leaves reduced the bare surface by half. During strong autumn and winter storms, the currents winnow and may scour the seabed, producing ripple marks and the outcrop of bedrock (Fig. 2b). In the late summer, *P. oceanica* started to shed leaves, which progressively covered the seafloor with leaf litter (Fig. 2d). The *P. oceanica* meadow was sampled over the year and the length of leaves shows a significant variation over the seasons (ANOVA $p < 0.001$); the minimum is in the autumn (October), with an average value of $0.17 \pm 0.06 \text{ m}$, and the maximum is in the summer (July), with an average value of $0.47 \pm 0.20 \text{ m}$ (Fig. 2e). The growth of leaves also influences the LAI, which shows the same trend of leaf length reaching its maximum value in May ($6.6 \pm 1.99 \text{ m}^2\text{m}^{-2}$) and minimum value in October ($2.82 \pm 0.8 \text{ m}^2\text{m}^{-2}$). Density does not show a significant variation over the year (ANOVA $p = 0.9$); it remains quite constant in the range of 260-312 shoots m^{-2} (Fig. 2e).

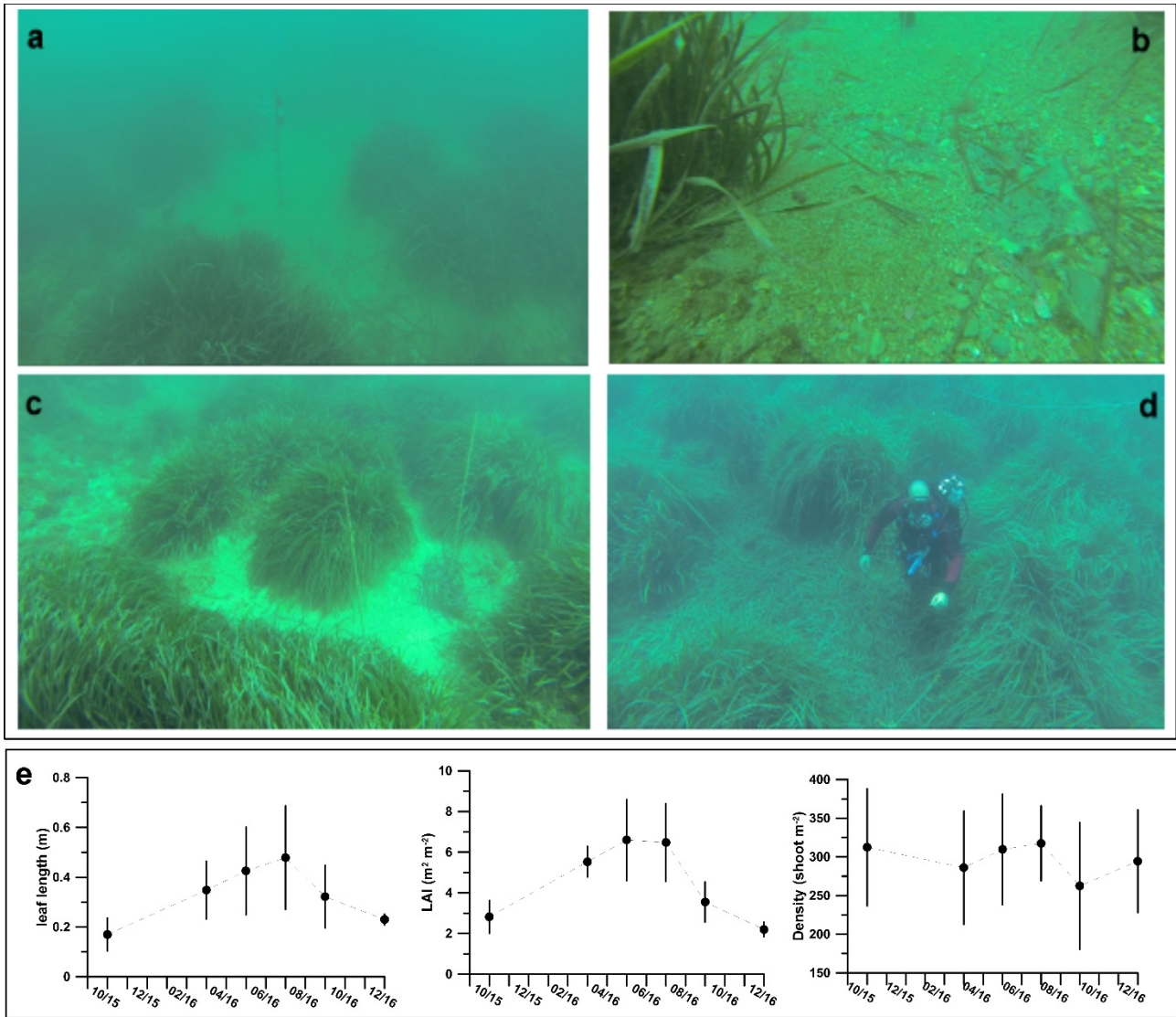


Fig.2 Annual variation of the *P. oceanica* meadow and sand patch. a) autumn phase; b) rocky outcrop produced by intense storm in sand patch; c) spring phase; d) late summer phase when leaf litter totally cover the seabed; e) seasonal trend of descriptors of *P. oceanica*, from left to right, leaf length, LAI and density.

3.3.2 Analysis of physical processes

The average seasonal sedimentation fluxes obtained by trap records in the two bed types (Fig. 3a) show the progressive decrease of sedimentation fluxes proceeding from autumn to summer. Inside the meadow the average seasonal sedimentation fluxes recorded by traps varied from $782 \pm 56 \text{ g m}^{-2} \text{d}^{-1}$ in autumn and $20 \pm 4 \text{ g m}^{-2} \text{d}^{-1}$ in summer. In the sand pool, great variability occurs among the runs and the average seasonal flux ranges between $807 \pm 133 \text{ g m}^{-2} \text{d}^{-1}$ in autumn and $44 \pm 13 \text{ g m}^{-2} \text{d}^{-1}$ in summer. The resuspended component (Fr) within the total flux fluctuates from 27%

and 57% inside the meadow, while in the sand pool there is a large contribution of the resuspended fraction on total vertical flux that fluctuates from 50% to 70%. On the contrary, the settling flux (Fp) component is twice that inside the meadow, except for the winter period when both settling and resuspended components are similar. In Fig. 3b it is possible to observe the vertical profiles of sedimentation flux obtained after two surveys in the two bed types during two different phase of vegetation growth during energetic conditions that better explain the dynamic of sedimentary processes.

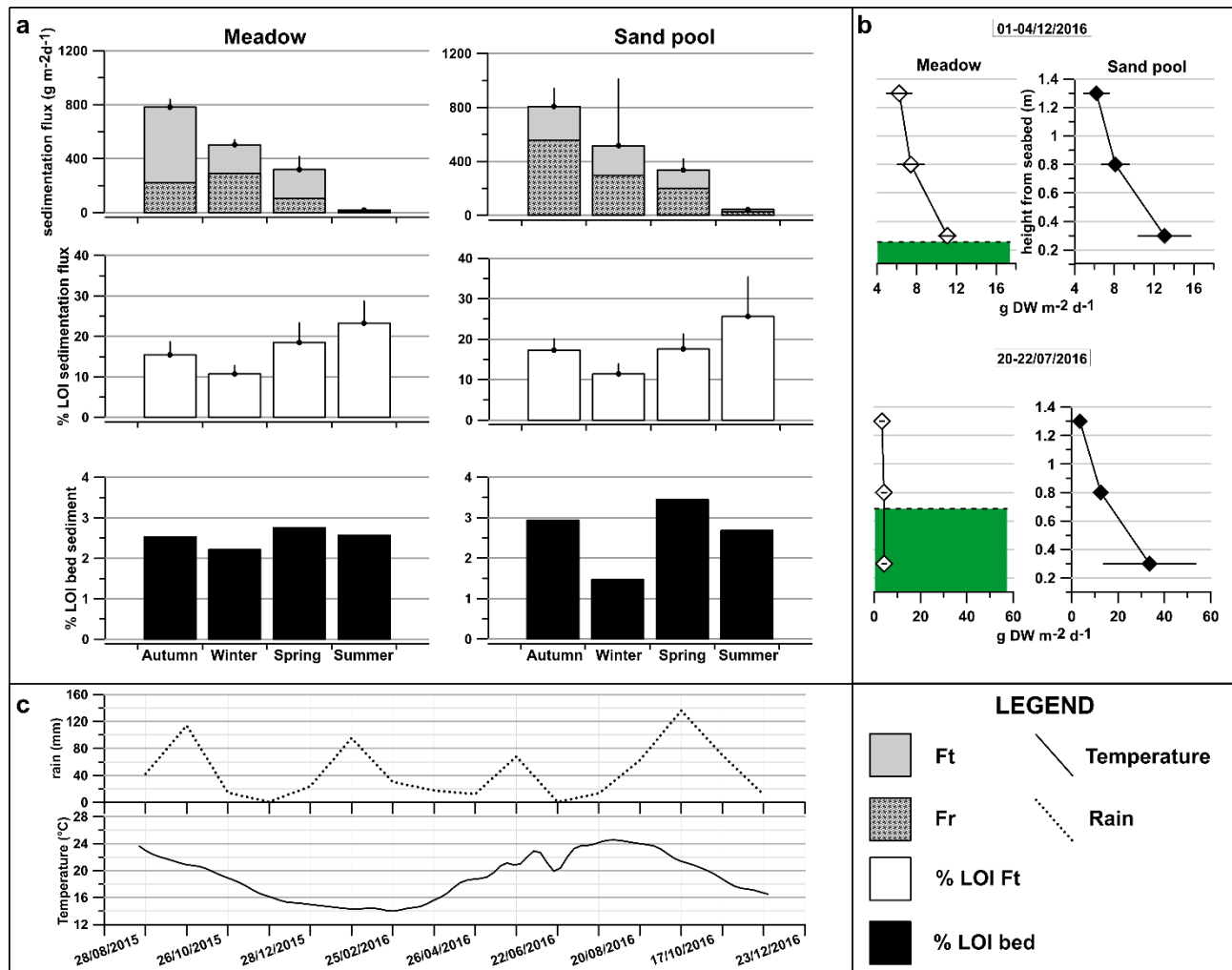


Fig.3. a) Sedimentary fluxes and organic matter compound within the flux and bed sediment; b) dynamic inside the meadow and sand patch during two phases of different growth of *P. oceanica*; c) variation of rainfall and seawater temperature.

During the winter survey the meadow is characterized by short leaves and both profiles are characterised by an exponential increase of flux toward the bottom due to resuspension processes. On the contrary during the summer, when leaves reach the maximum extension, the dynamic of sedimentation profiles is very different between the two bed types. In the sand pool the profile is

characterised by resuspension while inside the meadow station the vertical profile is characterised by a homogeneous trend. The organic matter content within the flux show the same trend on the two bed types with similar values that fluctuate from a maximum of 23-25% in summer to a minimum of 10-11% in winter. The organic content of the bed sediments of the two bed types show a greater variability of concentration into the sand pool than the meadow where the concentration is more stable during the year. The organic matter fraction of bed sediment fluctuates from 2.2% (winter) to 2.8% (spring) into the meadow while into the sand pool sediment the values ranged from 1.4% in winter and 3.4% in spring.

The precipitations recorded during the sampling period (Fig. 3c) are characterised by a total rain of 713 mm with seasonal fluctuation where larger value of rain is recorder during autumn (439 mm) and winter (131.6 mm) and minimum in spring (60 mm) and summer (82 mm).

The depth average temperature of water column recorded during the year in the sampling station (Fig. 3c) shows a seasonal fluctuation characterised by progressive decrease from September to March when reach the lowest values (13°C). From March the water temperature starts to rise progressively until August when they are highest (25°C).

3.3.3 Description of taxonomy and trophism

The benthic sampling results are presented giving a summary about abundance, biodiversity and trophism of total sampling and then detailing each macrohabitat separately.

3.3.3.1 Total Sampling

A total of 1905 organisms in 246 taxa were determined in the total sampling. These comprised: Polychaeta 773 (107 species), Amphipoda 496 (45 species), Isopoda 73 (11 species), Tanaidacea 51 (3 species), Decapoda 98 (16 species), Echinodermata 57 (11 species), Gastropoda 100 (20 species), Bivalvia 62 (22 species) and Mysida are represented only by *Siriella clausi*. At the seasonal scale the total assemblage shows the maximum abundance and diversity in spring and summer. In particular, the greatest abundance occurs in May (754 individual), followed by August (575), October (340) and March (228) (Fig. 4a).

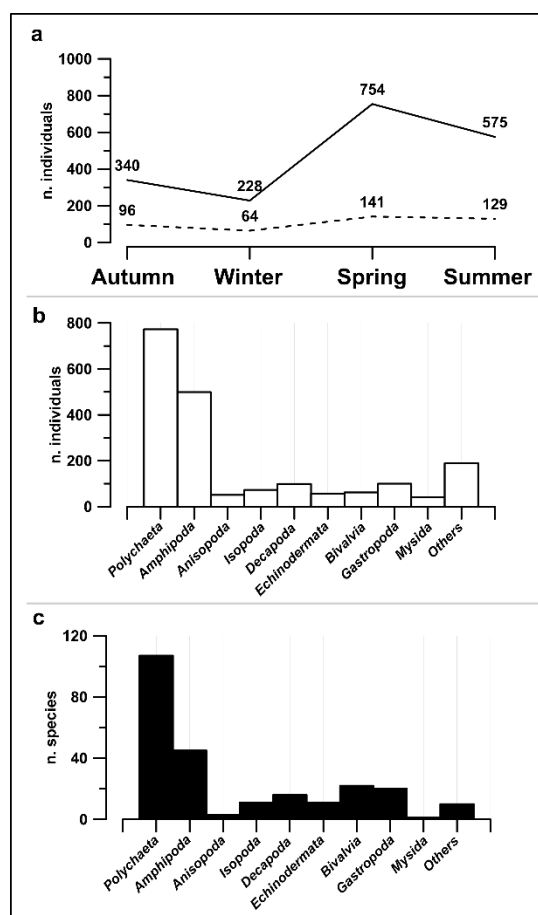


Fig.4. a) variation of total abundance and biodiversity; b) abundance of the most important taxa; c) biodiversity of the most important taxa

The taxonomic analysis has shown two most abundant taxa are represented by the Polychaeta group, which reach 40.6% and the Amphipoda, which amount to 26.1% (Fig. 4b). The Polychaeta are always dominant throughout the year whereas the crustacean Amphipoda show a rapid increase in spring.

The trophic analysis of the total benthic fauna reveals that the dominant feeding categories of the community are: Predators (30%), Deposit feeders (25%) and Suspension feeders (21.3%), followed by Detritus feeders (17%), Grazers (3%), Herbivores (3%) and Parasites (0.4%) (Table 1). In particular, some trophic behaviour of organisms is sub-divided into several feeding guilds, which are the combination of the feeding mode and diet (Macdonald et al., 2010) and the results are shown in Table 1 and Fig.5a. Total Herbivores (T-He), obtained by the summing of Pre-Herb, Det-Herb, Dep-Herb and Herb, amount to 20.5% of the total community.

Feeding mode	Feeding guilds	Percentage (%)
Predators (Pre)	Pre-car	14.22
	Pre-omn	13.35
	Pre-herb	3.40
Deposit feeders (Dep)	Dep-omn	9.53
	Dep-herb	11.85
	Dep-susp	3.2
Detritus feeders (Det)	Det-omn	14.11
	Det-herb	3.14

Tab.1. Total percentage of feeding categories

The Predators (Pre-Omn and Pre-car) dominate the SP in all seasons, reaching their highest values in winter when they represent 74.3% of the community (Fig. 5b). Suspension feeders are the most abundant in the RH stratum, showing a marked seasonal variation with the maximum values in spring when they represent the 58% of total population of this macrohabitat (Fig. 5c). The Det-Omn are most common in both the RH stratum and SP; and this trophic category, most closely associated with the Amphipoda group, shows the highest values in winter in RH (29.1%) and in August in SP (30.2%). Dep-herb are mostly represented by Gasteropoda and the shrimp *Hyppolite inermis*; this feeding group is retrieved only in LE (Fig.5d) with the highest value in autumn (100%) and summer (81.8%) and lowest in spring (48.8%) and winter (42.8%). The T-He are scarce in SP throughout the year (maximum value < 3%) but are more frequent in RH and LE: in RH the maximum is obtained in summer (36.3%) while the minimum occurs in winter (12.2%). In LE samples, the T-He represents the total fauna in autumn and during the other seasons the abundance is always above the 50% level.

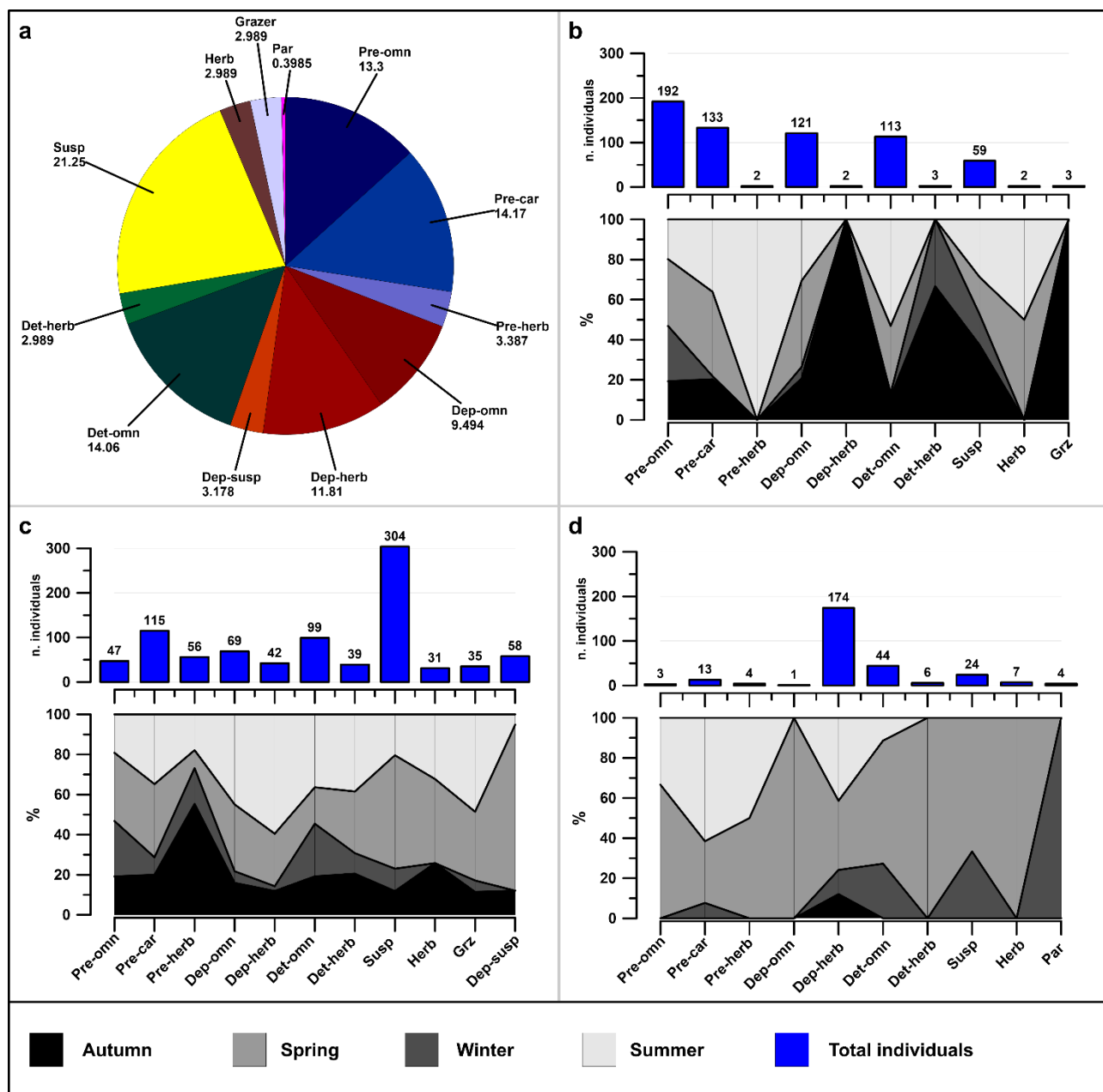


Fig.5. Spatio-temporal variation of feeding guild in the three macrohabitat a) total sampling; b) SP; c) RH; d) LE

The three macrohabitats of sampling (Sand Pool, SP; Rhizome, RH and Leaves, LE) were analysed in detail separately. In general, 663 organisms in 97 taxa were sampled on the SP, 956 organisms in 153 taxa were sampled on the RH stratum and 284 organisms in 44 taxa were sampled on the LE.

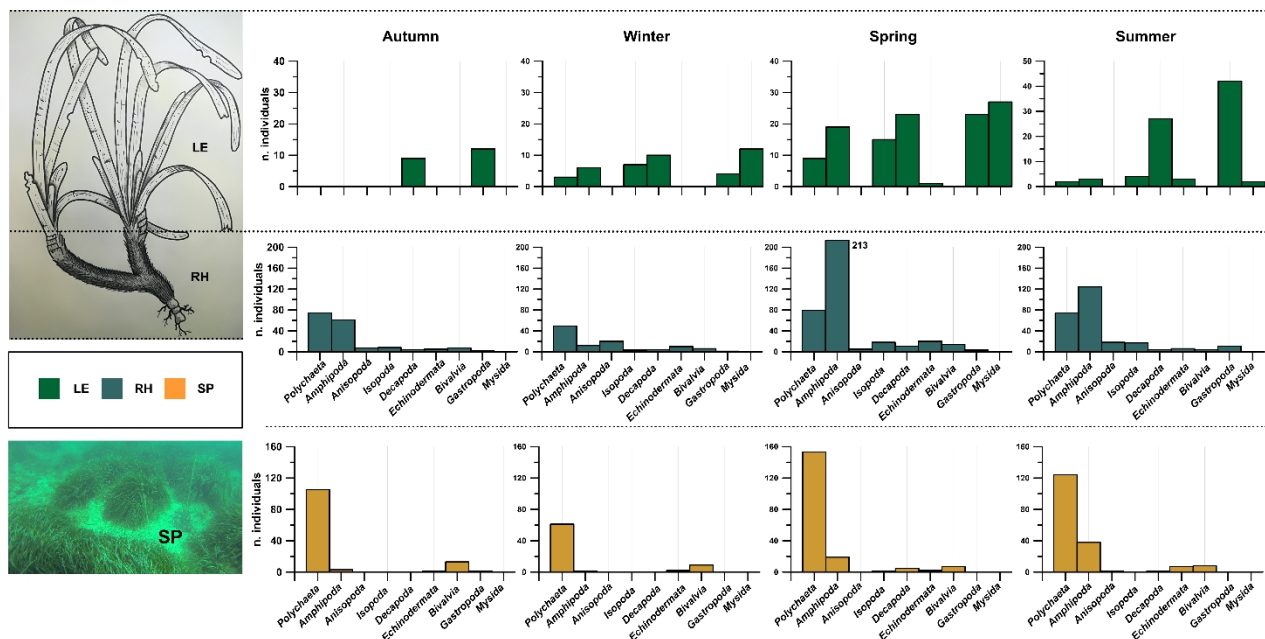


Fig.6 Abundance of main taxa in the three macrohabitats over the seasons

In Fig. 6 the abundance of the main taxa is shown for three different macrohabitats over the seasons. The figure shows the constant dominance of Polychaeta in the SP, reaching 66.9% of the community. The most representative groups in the RH are Amphipoda (45%) and Polychaeta (30%); Amphipoda show the maximum in spring and summer when this group reach the 59% and 49%, respectively, of the total fauna. In LE three taxa account the 68% of the total fauna and these taxa are represented by Gasteropoda (29%), Decapoda (24%) and Mysida (15%).

3.3.3.2 Sands Pool (SP)

The **Polychaeta** group dominate the sampling of SP with 443 individuals in 56 species. This group is dominant during the whole year and their frequency fluctuates from 69.2% in summer to 83.6% in autumn. The most common families are: Onuphidae, Dorvilleidae, Phyllodocidae, Hesionidae, Glyceridae and Cirratulidae. The dominant species in all samples is the Pre-omn Onuphidae *Aponuphis brementi* (Fauvel, 1916), which represents 26.3% of the community. In autumn, the opportunistic Pre-car species *Protodorvillaea kefersteini* (McIntosh, 1869) and *Pseudomystides limbata* (Saint-Joseph, 1888), increase markedly, having a frequency of 10% and 12%, respectively. The Pre-car species *Kefersteinia cirrhata* (Keferstein, 1862), generally associated with the leaf and rhizome stratum (Gambi et al., 1995), shows an increase in spring,

reaching 14.5%. The family Cirratulidae is represented by the species *Monticellina dorsobranchialis* (Kirkegaard, 1959), *Aphelochaeta filiformis* (Keferstein, 1862) and *Caulleriella alata* (Southern, 1914). All these Dep polychaetes are relatively frequent in this macrohabitat (7.54%) and do not show a seasonal variation.

The **Amphipoda** is the second most representative taxa (10.9%) with 61 individuals in 14 species. This taxonomic group shows a gradient during the year: in autumn and winter the Amphipoda are almost absent (< 2.5%), in spring they increase slightly (10.2%) and reach 21.2% of the population in summer. This particular temporal pattern is given by the increase of three Det species: The Nuuanidae *Gammarella fucicola* (Leach, 1814) and two Maeridae *Melita palmata* (Montagu, 1804) and *Maera grossimana* (Montagu, 1808). Moreover, the alien Caprellidae *Caprella scaura* Tempton, 1836 was found in this substrate.

The Molluscan **Bivalvia** represent 6.6 % of the community with 37 individuals in 11 species. Bivalves represent the most abundant Susp organisms in this macrohabitat. The bivalvia population is stable throughout the year. The most representative families are the Tellinidae, Veneridae and Cardidae. The three most abundant species are *Moerella donacina* (Linnaeus, 1758), *Gouldia minima* (Montagu, 1803) and *Venus verrucosa* (Linnaeus, 1758), which together represent 63% of the mollusca population.

The **Echinodermata** (2.1%) are dominated by the family Amphiuridae where the Susp species *Amphipolis squamata* (Della Chiajei, 1828) shows the maximum abundance in summer with a frequency of 4% of the total fauna.

The **Decapoda** (1%) are poorly represented in this macrohabitat and show a slight increase in spring when the species *Anapagurus sp.* and *Ebalia deshayesi* (Lucas, 1846) reach 3.7% of the community.

The other Taxonomic groups: Isopoda, Tanaidacea and Gasteropoda amount together to only 0.5% of the benthic population of SP and can be considered not representative of this macrohabitat.

The analysis of feeding mode on SP shows that Pre species dominate (53.4%) in all of the seasons. The Det species represent 19% of the community with a minimum in winter (4%) and maximum in summer (29.9%). Deposit feeders represent the 17.6% of the community with a seasonal fluctuation between 9.5% and 20.6% with a maximum in autumn. The Susp species are less representative of this macrohabitat and show a constant decrease during the year starting from autumn (16.8%) to summer (2.4%). The Total Omnivorous (T-O) species (computed as the sum of Pre-omn, Det-omn and Dep-omn) represent the 66.7% of the community. The abundance of this feeding group is always above 50% with the highest value in winter when they reach 84%. The Pre-

car species, represented only by Polychaeta, are quite stable during autumn (20.6%), spring (25.2%) and summer (23.7%), whereas in winter they show a dramatic decrease (2.70%). The T-He always comprise less than 1.5% and can be considered not representative of this macrohabitat.

3.3.3.3 Rhizomes (RH)

Amphipoda is the most abundant taxonomic group. It includes 410 individuals and 36 species grouped into seven main families: Ischyroceridae, Corophidae, Aoridae, Maeridae, Liljeborgiidae, Hyalidae and Dexaminidae. This taxon shows a seasonal variation characterised by a great population increase from winter to spring of about 44% (11.21% in winter, 54% in spring). These populations decrease during the summer (45%) and then decline further in the autumn (35%). This temporal pattern is linked to the seasonal population dynamics of three species: the Susp *Erichthonius punctatus* (Spence Bate, 1857), the Susp *Leptocheirus guttatus* (Grube, 1864) and the Dep-susp *Microdeutopus chelifer* (Spence Bate, 1862). These three species together amount to 50% of the Amphipoda community during the autumn, winter and summer. During spring, they reach 70% (15.4% of the total fauna). Within this taxon, two Det species, *Quadrimaera inaequipes* (A. Costa, 1857) and *Liljeborgia dellavallei* (Stebbing, 1906), display different temporal fluctuations with respect to the trends observed for the other species in this group. In particular, these Det species reach maximal abundance in the summer (22%). The Herbivorous (He) species *Hyale schmidtii* (Heller, 1866) and *Ampithoe helleri* (Karaman, 1975) are representative of 10.2% of the Amphipoda community and they do not show any particular population changes during the year.

The **Polychaeta** is the second most abundant taxonomic group. It is composed of 276 individuals and it is first in terms of species diversity, including 60 total species. The most abundant species are the Nereididae *Platynereis dumerilii* (Audouin & Milne Edwards, 1834) and *Nereis rava* Ehlers, 1868. These Pre-herb organisms do not show a particular temporal pattern in terms of population and they are equally distributed during the year. Another He polychaeta sampled in this macrohabitat is the Opheliidae *Polyophthalmus pictus* (Dujardin, 1839). This species is found only during the winter. It is the second most abundant Polychaeta species (21.7%). The largest family of Polychaeta fauna in RH is the Syllidae (25%). Among the Syllidae, the main species are the Pre-car Syllinae (*Syllis spongicola* Grube, 1855, *Syllis gracilis* Grube, 1840, *Syllis prolifera* Krohn, 1852 and *Eurysyllis tuberculata* Ehlers, 1864) and the He Exogoninae (*Exogone spp*, *Sphaerosyllis pirifera* Claparède, 1863 and *Sphaerosyllis hystrix* Claparède, 1868). While the Syllinae population does not fluctuate during the year, the Exogoninae are found only during the spring and summer

when individuals of the genus *Exogone* and *Sphaerosyllis* become the most abundant organisms in the rhizome stratum.

The Pre-car species *Kefersteina cirrhata*, *Harmothoe reticulata* (Claparède, 1870), *Eunice vittata* (Della Chiaje, 1828) and *Syllis spp.*, in addition to the family Phyllodocidae, are constant in population numbers during the autumn (9%) and winter (10%). Meanwhile, during the spring, their abundance increases by 22% and then reaches a peak of 42% in the summer.

The Susp Polychaetes are exclusively found in this macrohabitat and they are most populous during the winter and spring (30%). This group is represented by the Sabellidae *Acromegalomma messapicum* (Giangrande & Licciano, 2008), *Dyalychone collaris* (Langerhans, 1881), *Parasabella langerhansi* (Knight-jones, 1983) and *Branchiomma bombyx* (Dalyell, 1853). They also include the Serpulidae *Hydroides helmata* (Iroso, 1921), *Hydroides nigra* Zibrowius, 1971, *Serpula concharum* Langerhans, 1880 and *Serpula vermicularis* Linnaeus, 1767. Three Eunicidae “boores” were found in rhizome scales: *Lysidice collaris* Grube, 1870 (10 individuals), *Lysidice ninetta* Audouin & H Minle Edwards, 1833 (4 individuals) and *Nematonereis unicornis* Grube, 1840 (1 individual). These small polychaetes do not show a clear seasonal variation. However, they do achieve their maximal abundance during the spring with six total individuals.

The crustaceans **Tanaidacea** are exclusively found in this macrohabitat and they contribute 5.3% of the RH assemblage. They include 51 individuals that are mostly represented by the Dep Leptocheliidae *Chondrochelia savignyi* (Kroyer, 1842) (86%). This species reaches its greatest abundance during the winter, representing 19% of total RH fauna.

The **Isopoda** include eight species and a total of 46 individuals (4.8% of the total fauna). The three most abundant species are the Dep-herb *Cymodoce hansenii* (Dumay, 1972) (26.1%) and three Pre-car enclosed in the Italian alien fauna, which include the Anthuridae *Mesanthura* sp. (28.3%), the Paranthuridae *Paranthura japonica* (Richardson, 1909) (11%) and the Sphaeromatidae *Paracerceis sculpta* (Holmes, 1904) (1%). The largest abundance of Isopoda was observed during the spring and summer, which may be related to the increase of He species *Cymodoce hansenii* and *Dynamene edwardsi* (Lucas, 1849). Moreover, the Isopoda include the parasite (Par) *Gnathia vorax* (Lucas, 1849) and the “borer” *Limnoria* cf. *mazzellae* (Cookson & Lorenti, 2001).

Crustaceans, which are part of the **Decapoda**, contributed to 2.5% of the total fauna and are represented by 10 species of Pre-omn. This includes the Brachyura *Sirpus zariquieyi* (Gordon, 1953), *Pilumnus hirtellus* (Linnaeus, 1761), *Achaeus cranchii* (Leach, 1817) and *Macropodia* sp. It also includes the Anomura *Cestopagurus timidus* (Roux, 1830), *Paguristes syrtensis* (De Saint Laurent, 1971), *Pagurus anachoretus* (Risso 1827) and *Pisidia blutellii* (Risso, 1816), in addition to

the Caridea *Processa edulis edulis* (Risso, 1826) and *Alpheus* sp. The Decapoda achieve their greatest amount of population diversity and abundance in this macrohabitat during the spring.

The **Mollusca** include a total of 81 individuals belonging to 23 species, which represent 8.5% of the assemblage. The most abundant class is Polyplacofora (41%), which is dominated by Grazer (Grz) *Callochiton septemvalvis* (Montagu, 1803). These organisms undergo a gradual increase in population from winter to summer. A similar trend is observed in the class Gastropoda (20.7%). This pattern is in agreement with the observed increase of Dep-herb species *Rissoa violacea* (Desmarest, 1814) and *Alvania discors* (Allan, 1818). Instead, the Patellogastropoda *Tectura virginea* (O. F. Müller, 1776), the most abundant species (35.3%), is equally distributed in population during the year. The Bivalvia group (38.3%) has a maximum abundance in the spring and it is mostly represented by the Susp species *Musculus costulatus* (Risso, 1826), *Glans trapezia* (Linnaeus, 1767), *Striarca lactea* (Linnaeus, 1758) and *Hiatella arctica* (Linnaeus, 1767).

The Phylum **Echinodermata** represents only 4.3% of the total RH population. The seasonal fluctuation in their populations is linked to the oscillation of the most abundant species, Amphiuroida *Amphipholis squamata* (Delle Chiaje, 1828). This Susp species increases in numbers in the spring and decreases in the summer. In addition to this species, we sampled the Asteroidea *Asterina pancerii* (Gasco, 1876) and the two Holothuroidea, *Holothuria helleri* (Marenzeller von, 1877) and *Pseudocnella syracusana* (Grube, 1840).

In the RH macrohabitat, the Susp feeding guild is the most representative trophism, displaying a frequency of 32%. These dominate the overall populations during the winter to summer. The Susp species show a marked increase in numbers in the transition from winter to spring, during which they reach 46% of the total population, constituting an increase of about 140 individuals. This trend is directly linked to the increase in populations of Susp Amphipoda *Erichthonius punctatus* (Spence Bate, 1857) and *Leptocheirus guttatus* (Grube, 1864). A similar increase is also observed among the Dep-susp guild, which is represented by the Amphipoda *Microdeutopus chelifer* (Spence Bate, 1862).

The Pre-species populations do not fluctuate during the year and they represent the second guild in terms of abundance (23%). For this feeding mode, half of the organisms are Pre-car (12.3%) and quite constant during the year of sampling. The Pre-omn (5%) and Pre-herb (5.7%) show different population trends during the year. The omnivorous species reach a population maximum in the winter (12.5%), while the He species reach a maximum in the autumn (19.2%). This behaviour is strongly linked with increases in the abundance of the macro-herbivorous polychaete *Polyophthalmus pictus* (Dujardin, 1839).

The Dep mode (17.8%) gradually increase in numbers from winter to summer. Initially, it is scarce during the winter (4.8%), but increases in the spring (9.2%). It reaches its maximum abundance in the summer (21.5%). This temporal pattern is observed both for the Dep-omn (11%) and Dep-herb (6.8%).

The Det species do not show seasonal variations with a frequency of 14.5%. For this feeding mode, the Det-omn (10.4%) and Det-herb (4.1%) show a maximum density in the summer, but the Det-omn is most abundant during the winter (representing 30% of the total fauna). In RH, a minor role was played by other feeding modes, such as Grz (3.78%), Scavengers (Sca, 0.56%) and Parasites (Par, 0.44%).

In RH, the T-O group is the most abundant of the total assemblage (64%) and it dominates all of the seasons with a percentage that is always above 50%. The maximum value is observed in the spring when the individuals in this group number 277, which represents 74% of the total fauna.

The T-He group is second in terms of abundance (22.5%) and is shows a gradual incremental passing from winter to summer. Their contribution to the total benthic assemblage is greatest in the summer when they represent 32% of the total fauna. In RH, the Total Carnivorous (T-C), which is determined by the total number of Pre-car, Sca and Par organisms, has a frequency of 13.5%. Furthermore, no changes in population trends for the T-C are observed during the year.

3.3.3.4 Leaves (LE)

In this macrohabitat, the assemblage shows the most marked seasonal variations both in abundance and diversity. These variations are mainly related to the seasonal trend for the two most abundant species, *Hippolyte inermis* (Leach, 1816) and *Siriella clausii* (G.O. Sars, 1877), but also by the constant increase in the number of Gastropods during the year.

The Crustacea **Decapoda** are represented solely by the Caridea *Hippolyte inermis*. This Dep-herb shrimp contributes to 24% of the total fauna, which increases in abundance from the winter to the summer. The smallest abundance of this species has been observed in the winter (9 individuals), which represents 50% of total assemblage. The most significant population increase was observed during the transition between autumn and spring when the number of individuals doubled from 10 to 23. In the summer, the population remains quite constant at 26 individuals.

The *Siriella clausii* is the only **Mysida** collected in this study and it is found exclusively on the leaves stratum (LE). This Det-omn species represents 15% of the total annual assemblage and

appears only during two seasons. In the winter, the population frequency reaches 26%, and during the summer, it is 21%.

In LE, the **Gastropoda** is the most representative class both in terms of abundance (with 81 individuals representing 28.5% of the total fauna) and diversity (with 16 species). This taxon is dominated by the Dep-herb species and shows a constant increase in abundance from winter (4 individuals) to summer (42 individuals). They are most abundant in the autumn and summer when they constitute 57% and 47.7% of the total population, respectively. The families in this class are Rissoidae (78%), which is most represented by the species *Rissoa ventricosa* (34.5%) (Dasmarest, 1814), *Rissoa violacea* (9.8%) (Dasmarest, 1814), *Alvania discors* (9.8%) (Allan, 1818) and *Pusillina* sp. (3.7%). It also includes Phasinellidae (11.2%), which is composed of the species *Tricolia speciosa* (9.8%) (Megerle von Mühlfeld, 1824) and the Trochidae *Jujubinus striatus* (5%) (Linnaeus, 1758).

The Crustacea **Amphipoda** include 28 individuals and 9 species, representing 9.8% of the total LE assemblage. This order is most abundant in the spring. It includes 19 individuals, which increase in number as a result of the increase in the Susp *Photis longicaudata* (Spence Bate & Westwood, 1862) that represent 40% of the Amphipoda assemblage. Within these species, the Dep-herb *Apherusa chiereghinii* (Giordani-Soika, 1949), the Det *Aora spinicornis* (Afonso, 1976) and the two Herbs *Hyale schmidtii* (Heller, 1866) and *Ampithoe helleri* (Karaman, 1975) make only a small contribution to the overall population.

The order **Isopoda** are present and they include four species consisting of a total of 26 individuals (9.2% of the total fauna). The two species that are the most representative in the LE macrohabitat are the Dep-herb *Stenosoma appendiculatum* (Risso, 1816) (4.6%) and the Par *Gnathia vorax* (Lucas, 1849) (3.5%). The Isopoda order is not present during the autumn and reaches maximum abundance in the spring with a population of 15 individuals.

Polychaetes are not abundant in this macrohabitat (4.9%) and they are only represented by various He species, including the Sillidae *Sphaerosyllis hystrix*, the Opheliidae *Polyophthalmus pictus* and the Nereididae *Platynereis dumerilii*.

Only two species of **Echinodermata** are found in the LE: the Pre-car asteroidea *Asterina gibbosa* (Pennant, 1777) and *Asterina pancerii* (Gasco, 1876), which together constitute 1.4% of the total assemblage.

Samples from the leaves reveal the presence of organisms from two other taxa, which are retrieved only from this macrohabitat. They include members of the Order Cumacea (4.2%) and the phylum Chaetognata (2.5%).

The trophic analysis reveals the dominance of two feeding guilds that represent 77% of the total community: the Dep-herb (61%) and the Det-omn (16%). The seasonal variation of this feeding guild is closely linked to the population oscillations of the two taxa. The seasonal Dep-herb variation is linked with the class Gasteropoda and the shrimp *Hyppolite Inermis*, which represent the total fauna present in the autumn and summer (at 82%). The Det-omn are mostly represented by the Mysida *Siriella clausii*. The Susp (8.5%) and the Pre (7.5%) are not abundant on the leaves assemblage.

3.3.3.5 Analysis of benthic fauna

The seasonal analysis of benthic fauna in the different macrohabitats (Fig. 7) shows the maximum abundance and diversity of the RH assemblage followed by SP and LE. The seasonal fluctuation is evident in all macrohabitats, and the populations are at their minimum during the winter and at their maximum in the spring. The diversity index shows a large fluctuation in SP with a minimum value during the winter, while for the RH, the diversity index is constant throughout the year. On LE, there is an increasing trend from autumn to spring, which then remains constant during the summer.

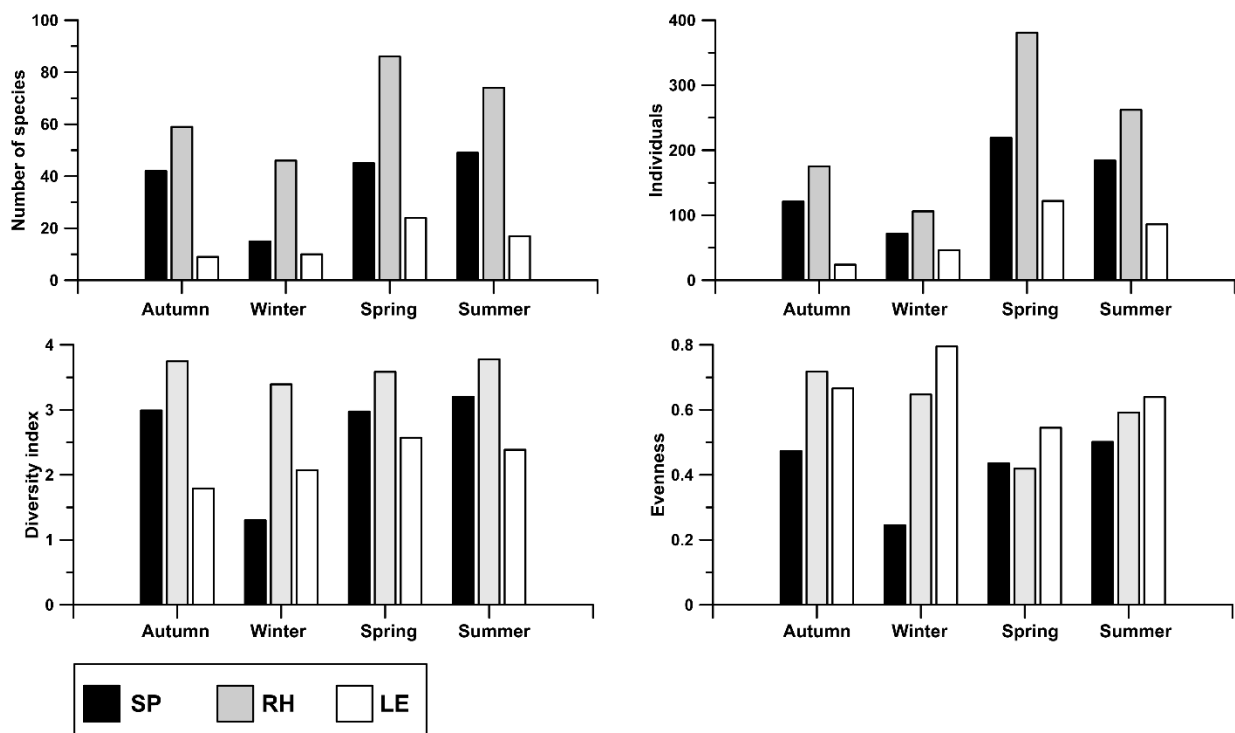


Fig.7 Classic biotic indexes of assemblages in the different macrohabitats

The Evenness index (Fig. 7) suggests that the presence of dominant species in SP is extremely significant during the winter. For RH, the values are always above 0.5 except for the spring samples, which is probably due to the increase in the numbers of Amphipoda *Erichthonius punctatus* (74 individuals). For LE, the index suggests the presence of multiple species that contribute to the total abundance, but no one species displays significant dominance.

An ANOVA test is applied to evaluate differences in the structure of the population (mean organism per species) among the seasons. The results show a significant difference among the seasons for the RH ($p = 0.003$) and LE ($p = 0.03$) assemblages. Meanwhile, for SP, the difference is not significant ($p = 0.18$).

The SIMPER test is applied for each macrohabitat coupling, which consists of autumn-winter, winter-spring and spring-summer pairs in order to understand which taxa contribute most significantly to differences between the seasons.

SP		
TAXA	autumn-winter	
	Av. dissimilarity	Contribute %
<i>Aponuphis brementi</i>		10.53
<i>Pseudomystides limbata</i>		6.31
<i>Protodorvillea kefersteini</i>		6.31
<i>Sabellaria spinulosa</i>		2.63
<i>Moerella donacina</i>		2.1
<i>Aphelochaeta filiformis</i>		2.1
<i>Gouldia minima</i>		1.57
<i>Ophelia limacina</i>		1.57
<i>Monticellina dorsobranchialis</i>		1.57
<i>Kefersteina cirrhata</i>		1.05
TAXA	winter-spring	
	Av. dissimilarity	Contribute %
<i>Kefersteina cirrhata</i>		10.42
<i>Monticellina dorsobranchialis</i>		3.47
<i>Aphelochaeta filiformis</i>		3.08
<i>Pseudomystides limbata</i>		3.08

<i>Anapagurus sp.</i>		1.93
<i>Maera grossimana</i>		1.54
<i>Syllis spp.</i>		1.54
<i>Gammarella fucicola</i>		1.54
<i>Protodorvillea kefersteini</i>		1.54
<i>Eriopisa coeca</i>		1.54
TAXA	spring-summer	
	Av. dissimilarity	Contribute %
<i>Kefersteina cirrhata</i>		6.33
<i>Gammarella fucicola</i>		4.95
<i>Aponuphis brementi</i>		4.95
<i>Melita palmata</i>		1.95
<i>Protodorvillea kefersteini</i>		1.65
<i>Ophelia limacina</i>		1.37
<i>Glycera alba</i>		1.37
<i>Anapagurus sp.</i>		1.37
<i>Gouldia minima</i>		1.10
<i>Amphipholis squamata</i>		1.10

Table.2 Simper test analysis for macrohabitat SP

The results of the SIMPER test in SP (Table 2) show that three species primarily contribute to the differences observed between each pair of seasons. The Polychaeta *Aponuphis brementi*, *Pseudomystides limbata* and *Protodorvillea kefersteini* account for 38.6% of the differences observed between autumn and winter. For the winter-spring pairing, one species (*Kefersteina cirrhata*) accounts for the largest contribution to the difference (18.88%). For the third pair of seasons (spring-summer), two Polychaetes (*Kefersteina cirrhata* and *Aponuphis brementi*) and one Amphipoda (*Gammarella fucicola*) are responsible for the differences observed (35.33%) between the seasons.

RH		
TAXA	autumn-winter	
	Av. dissimilarity	Contribute %
<i>Polyoptalmus pictus</i>		5.94
<i>Chondrochelia savignii</i>		5.20

<i>Acromegalomma messapicum</i>		2.60
<i>Microdeutopus chelifer</i>		2.23
<i>Leptocheirus guttatus</i>		2.23
<i>Nereis rava</i>		2.23
<i>Harmothoe reticulata</i>		1.85
<i>Hyale schmidtii</i>		1.85
<i>Branchiomma bombyx</i>		1.48
<i>Erichthonius punctatus</i>		1.48
TAXA	winter-spring	
	Av. dissimilarity	Contribute %
<i>Erichthonius punctatus</i>		15.40
<i>Microdeutopus chelifer</i>		9.70
<i>Leptocheirus guttatus</i>		4.85
<i>Chondrochelia savignii</i>		3.58
<i>Amphipolis squamata</i>		2.11
<i>Amphitoe helleri</i>		1.68
<i>Gammaropsis maculata</i>		1.68
<i>Callochiton septemvalvis</i>		1.68
<i>Sphaerosyllis hystrix</i>		1.26
<i>Golfingia vulgaris</i>		1.26
TAXA	spring-summer	
	Av. dissimilarity	Contribute %
<i>Erichthonius punctatus</i>		8.07
<i>Microdeutopus chelifer</i>		6.80
<i>Quadrinemaera inequipes</i>		3
<i>Amphipolis squamata</i>		1.89
<i>Chondrochelia savignii</i>		1.74
<i>Callochiton septemvalvis</i>		1.10
<i>Leptocheirus guttatus</i>		1.10
<i>Gammaropsis maculata</i>		1.10
<i>Apherusa chireghinii</i>		0.94
<i>Nereis rava</i>		0.94

Table.3 Simper test analysis for macrohabitat RH

The results of the SIMPER test for RH (Table 3) show that the autumn-winter pair displays an absence of a clearly dominant species contributing to the differences. The Polychaetes

Polyoptalmus pictus and *Acromegalomma messapicum*, along with the Tanaidacea *Chondrochelia savignii*, contribute to about 22.66% of the fauna population. For the winter-spring pair, two species (*Erichthonius punctatus* and *Microdeutopus chelifer*) greatly contribute to the differences (31.48%). This is the same for the spring-summer pair, which shows that these two species account for 27.98% of the differences in the populations.

LE		
TAXA	autumn-winter	
	Av. dissimilarity	Contribute %
<i>Syriella clausii</i>		17.14
<i>Alvania discors</i>		8.57
<i>Photis longicauda</i>		5.71
<i>Gnathia vorax</i>		5.71
<i>Cumacea spp.</i>		5.71
<i>Sphaerosyllis hystrix</i>		4.28
<i>Stenosoma appendiculatum</i>		4.28
<i>Apherusa chireghinii</i>		2.85
<i>Rissoa violacea</i>		2.85
<i>Polyoptalmus pictus</i>		2.85
TAXA	winter-spring	
	Av. dissimilarity	Contribute %
<i>Syriella clausii</i>		8.92
<i>Hyppolyte inermis</i>		7.73
<i>Rissoa ventricosa</i>		7.73
<i>Ampithoe helleri</i>		2.38
<i>Cumacea spp.</i>		2.38
<i>Stenosoma appendiculatum</i>		1.78
<i>Photis longicauda</i>		1.78
<i>Chetognata sp.</i>		1.78
<i>Gnathia vorax</i>		1.19
<i>Sphaerosyllis hystrix</i>		1.19
TAXA	spring-summer	
	Av. dissimilarity	Contribute %

<i>Syriella clausii</i>	12.02
<i>Rissoa ventricosa</i>	4.32
<i>Cumacea</i> spp.	3.84
<i>Photis longicauda</i>	3.36
<i>Gnathia vorax</i>	2.88
<i>Rissoa violacea</i>	2.88
<i>Sphaerosyllis hystrix</i>	2.88
<i>Tricolia speciosa</i>	2.4
<i>Jujubinus striatus</i>	2.4
<i>Amphitoe helleri</i>	1.92

Table.4 Simper test analysis for macrohabitat LE

The results of the SIMPER test for LE (Table 4) show the consistent dominance of *Syriella clausii* for all seasonal pairs, including a variance that is always greater than 19%. For the autumn-winter pair, *Alvania discors* is the second most important organism. Meanwhile, for the winter-spring pair, *Hyppolite inermis* and *Rissoa ventricosa* together account for 33.34% of the population differences. In the spring-summer pair, species other than *Syriella clausii* show similar results, which are always less than 8%.

A canonical correspondence analysis (CCA) shows a relationship among the seasonal variations of species abundance (Fig. 8) and feeding guilds (Fig. 9) for each macrohabitat (SP, RH, LE) with the physical processes and the characteristics of *P. oceanica*. In particular, the CCA was performed on 102 species, which were redistributed as follows: 24 species in SP, 62 species in RH and 16 species in LE. The species used for the analysis were selected on the basis of their abundance and the results of the SIMPER test. The two axes for macrohabitat SP account for 38.8% and 35.66% of the total variance. Autumn and winter are related to precipitation and resuspension flux on the positive pole of the first axis associated with the species *Aponuphis brementii*, *Notomastus latericeus* Sars, 1851 and *Pseudomistides limbata*. The percentage of organic matter in flux is related to the summer period and it is ordered along the negative pole of the first axis, showing a correlation among *Amphipolis squamata*, *Gammarella fucicola* and *Aphelocheta filiformis*. The percentage of organic matter in the bed sediments shows a correlation among *Maera grossimana*, *Syllis* spp. and *Monticellina dorsobranchialis*. Seasonal oscillations in the average sea water depth temperature is associated with *Glycera alba* (O.F. Müller, 1776). On the negative pole of the second axis, the leaf length are ordered, revealing correlations with *Kefersteina cirrhata* and *Eriopisa coeca* S. Karaman, 1955.

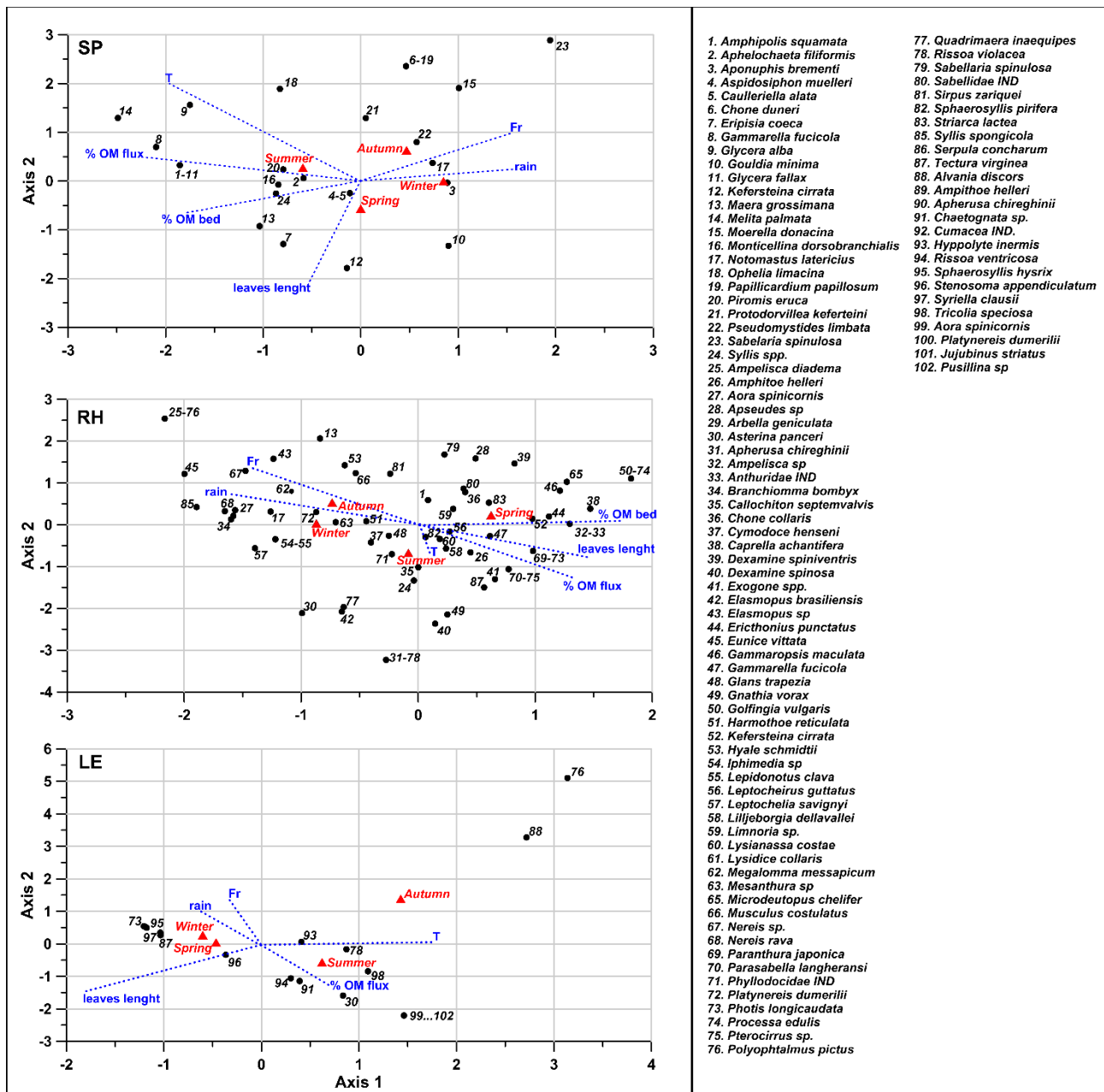


Fig.8. CCA analysis of species abundance of different macrohabitat

The axes for the macrohabitat RH account for 45.8% and 29% of the total variance. Along the negative pole of the first axis, the resuspension flux and the rain are correlated with autumn and winter. They are also correlated with the presence of several species, including *Acromegalomma messapicum*, *Platynereis dumerilii* and *Nereis rava*. The percentage of organic matter in the seabed sediment is ordered along the positive pole of the first axis and it is related to the spring season. A correlation with *Kefersteina cirrata* and *Erichthonius punctatus* is observed. The percentage of organic matter in flux and leaf lengths are always ordered along the positive pole of the first axis. This reveals a correlation with *Gammarella fucicola*, *Paranthura japonica*, *Photis longicauda*,

Ampithoe helleri and *Exogone sp.* The summer season is related to sea water temperature, which correlates with *Callochiton septemvalvis*.

The axes on the macrohabitat LE account for 58.6% and 34.6% of the total variance. Temperature is ordered along the positive pole of the first axis, revealing a correlation with *Rissoa violacea* and *Hyppolite inermis*. The percentage of organic matter in flux correlates with *Asterina panceri* and *Rissoa ventricosa*. Along the negative pole of the first axis, the leaf lengths correlate with *Stenosoma appendiculatum*, which is related to the spring season. The species *Photis longicauda*, *Sphaerosyllis hysrix* and *Syriella clausii* are related to the winter season.

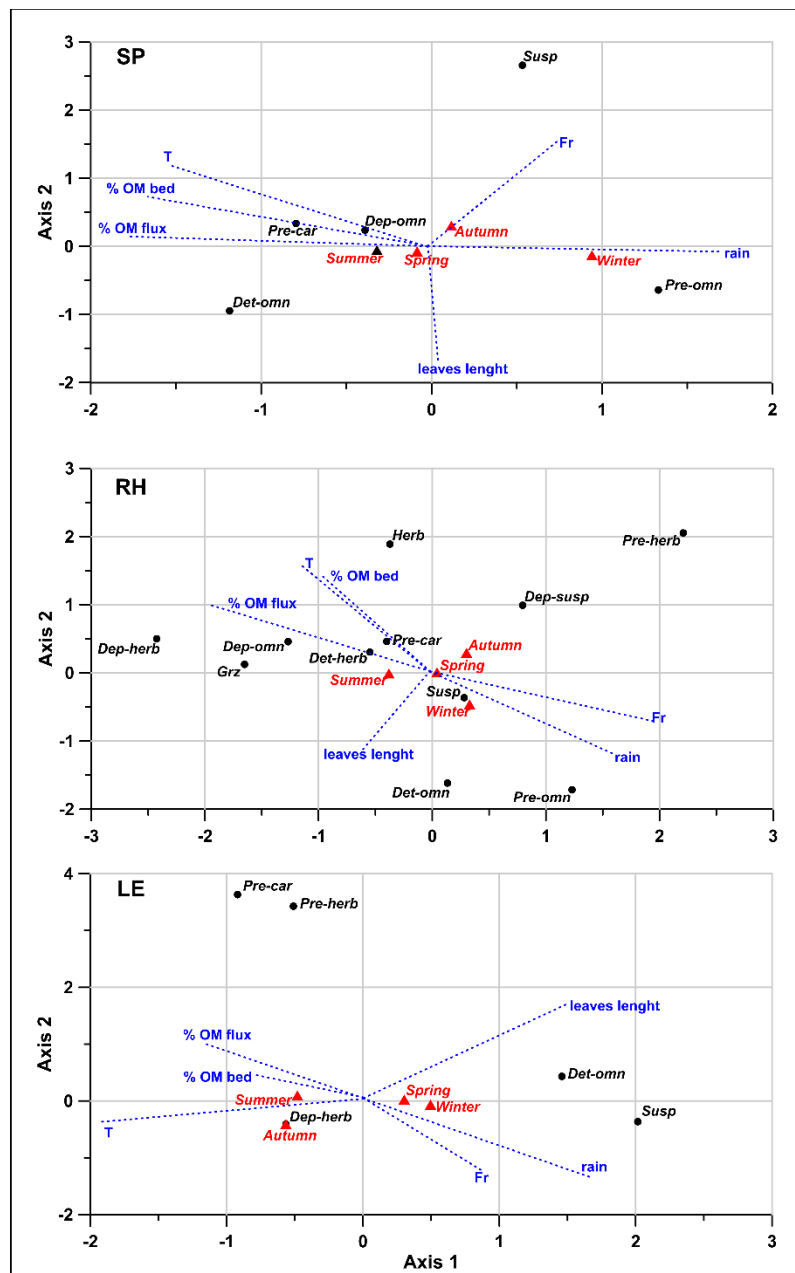


Fig.9 CCA analysis of feeding guilds of different macrohabitat

The axes for the CCA analysis of the feeding guilds of the macrohabitat SP account for 77.4% and 13.1%. The rain is ordered along the positive pole of the first axis and it is related to the winter and Pre-omn organisms. The Pre-car and Dep-omn organisms are ordered along the negative pole of the first axis and are related to the percentage of organic matter in the bed sediment. Along the positive pole of the second axis, the resuspension flux and Susp organisms are ordered.

The axes of the macrohabitat RH account for 55.6% and 28.3%. The winter season is related to Susp organisms and rain. Det-omn and leaf lengths are ordered along the negative pole of the second axis. Det-herb and Dep-omn are related to the percentage of organic matter in flux, which is ordered along the negative pole of the first axis. Seawater temperatures and the percentage of organic matter in the bed sediment are related to Pre-car.

The axes of the macrohabitat LE account for 91% and 8.3% of the total variance. The Det-omn are correlated with the leaf lengths and rain with respect to Susp organisms. The autumn season is ordered along the negative pole of the first axis and correlates with Dep-herb organisms.

3.4 Discussion

In this work, we analyse the seasonal variability of faunal assemblages in three macrohabitats of *P. oceanica* meadow, which were placed in shallow waters. We assess the relationships among *P. oceanica* and the dynamics of sedimentary processes and environmental factors. The physical factors in the environment are characterised by seasonal trends according to the climatology of the Mediterranean region (Lionello et al., 2013). Storms are most frequent and strong during the autumn and winter. During this time, larger resuspended components are found in the sediment traps. Variability in the sedimentary processes between the two different substrata are in agreement with the growth rhythms of *P. oceanica*, which drive the sedimentary processes that favour the settlement of particles and prevention of resuspension. This is especially the case during the maximum phase of growth for seagrass according to previous studies (Gacia & Duarte, 2001; Hendricks et al., 2008) and the well-known geomorphological role of this seagrass summarized by Vacchi et al. (2016). The sedimentary dynamics of organic matter is similar between the two substrata. There is a progressive increase in organic matter concentrations within the flux when proceeding from winter to summer. These behaviours contrast with those recorded for inorganic compounds, suggesting that the variability in the sedimentary processes between vegetation and a sand patch is constrained to inorganic matter. It is linked to the drag effect produced by different substrata on the flow and by the influence of seagrass meadow on the percentage of organic matter

in the flux and in the sand patch within the meadow. Gacia et al. (2002) demonstrated that 72% of the sedimentary carbon flux was contributed by sestonic particles, and the remaining 28% was derived from detritus of *P. oceanica* and its associated epiphytes. During winter, the growth of *P. oceanica* enhances the retention of materials and favours the settling of organic compounds. This explains the enrichment of organic matter that feeds the faunal assemblage development together with the abundant epiphytes typical during a summer (Buia et al., 2000). The concentration of organic matter found in bed sediment is comparable to other coastal sites previously analysed (Table 5). The variation observed in the sampling stations highlights the larger variability in unvegetated seabed than in vegetated seabed in which the concentration of organic matter is more stable during the year.

<i>Reference</i>	<i>Max (%)</i>	<i>Min (%)</i>	<i>Depth</i>	<i>Bottom</i>
Fabiano et al., 1995	2.91	0.93	10	Sandy sediments
Pusceddu et al., 1999	52.6	5.1	0.5-2	Lagoon deposit
De Falco et al. 2000	10.4	3.2	5-20	<i>Posidonia oceanica</i>
	3.7	1.6	5-20	Unvegetated gaps
Gacia et al., 2002	0.67	0.8	15	Bare sand
	1.47	0.71	15	<i>Posidonia oceanica</i>
Borg et al., 2010	0.62	0.4	9-11	Continuous <i>P. oceanica</i> meadow
	0.28	0.18	9-11	Fragmented <i>P. oceanica</i> meadow
This study	3.44	1.46	7	Sand pool
	2.75	2.21	7	<i>Posidonia oceanica</i>

Table 5. Previous and present information about OM concentration on sediments of Mediterranean coastal sites

The faunal assemblage during the year is characterised by marked fluctuations among the seasons, which is typical of shallow-water communities (Gambi et al., 1992). The greatest abundance in terms of species and individuals is found during the spring and summer. This result contrasts with previous findings where the greatest amount of biodiversity has been observed in the autumn and winter (Nelson, 1979; Mazzella et al., 1989; Gambi et al., 1992). This could be due to a number of factors, including the depth of the sampling site. The shallow-water seabed is intensely stressed by wave action, especially during the autumn and winter seasons, which has been reported by strong resuspensions and recorded by traps. This process is more intense in shallow waters than in deeper ones as a result of wave propagation processes. The effects of the wave exposure on macro-invertebrate assemblages have already been observed in Ischia Island (Bedini et al., 2015) where marked changes in the structure of benthic fauna are found after exposure to different

amounts wave action intensity. The sedimentary records obtained during the autumn and winter when leaves are short show a decrease in the capacity of the seagrass to attenuate the flow with a consequent reduction in the retention of materials under seagrass canopies (Gacia et al., 2002). The dynamic conditions during these seasons may disturb the larval dispersion and food supply with a consequent effect on the colonization of the seagrass (Commito et al., 1995; Harriague & Albertelli, 2007; Van Colen et al., 2010; Bedini et al., 2015). This thesis is supported by ANOVA results for the differences in the structure of populations among the seasons in the three macrohabitats. Specifically, significant differences are observed in the faunal assemblage of the meadow (RH and LE) following the progressive growth of seagrass. Meanwhile, the SP population is quite stable during the year.

The composition of assemblages found in the present study can be compared with those for other *P. oceanica* meadow. Our results regarding the leaves stratum agree with previous findings in which Crustaceans and Mollusca dominate (Russo et al., 1984, 1991; Scipione & Fresi, 1984; Mazzella et al., 1989, 1992; Gambi et al., 1992; Scipione et al., 1996; Borg & Schembri, 2000; Bedini et al., 2011, 2015; Belgacem et al., 2011, 2013; Zakhama-Sraieb et al., 2011; Urrea et al., 2013). The sampling performed at different levels of seagrass show the dominance of the Polychaeta and Amphipoda on rhizomes. On the SP, the sampling shows a predominance of Polychaeta, which is also observed in soft-bottom communities associated with *P. oceanica* in the Ligurian Sea (Harriague et al., 2006). In general, the main difference from previous studies is the scarcity of Gastropoda in the total sample, and this needs to be analysed in the future.

Another important consideration concerns the significant differences in terms of the species compositions on rhizomes and leaves during the autumn and winter. During these periods, the two strata lack common species. Instead, during the spring and summer, the presence of some common species has been observed between the two strata (i.e., *Photys longicaudata*, *Amphitoe helleri* and *Sphaerosyllis hystrix*). This behaviour can be explained by the progressive ability that the seagrass has to exert on water movement attenuation inside the canopy as a result of its growth, as well as seasonal wave energy fluctuations. This condition creates a more stable environment that reduces the difference between the two strata, favouring the colonization by common species. This hypothesis is supported by previous observations by Gambi et al., (1989, 1994), which demonstrate the influence of the physical environment (water movement) and *Posidonia* growth rhythms (Mazzella & Ott, 1984) on the species composition of rhizomes and leaves. Here, the leaf population was more susceptible.

In the SP macro-habitat, the most representative species are *Aponuphis brementi*, *Kefersteina cirrata* and *Gammarella fucicola*, which contribute to the maximum variance during the year. *Aponuphis brementi* is a species frequently associated with the seagrass meadow (Andrés et al., 2017), and the analysis reveals its dominance in winter when resuspension flux and rain are intense. *Kefersteina cirrhata* is a Polychaeta predator that is often collected in rhizomes and leaf stratum (Gambi et al., 1995) and it is linked to the growth of leaves in the spring. The presence of *Gammarella fucicola* in the summer seems to be related to the percentage of organic matter in the flux, particularly during the period when *P. oceanica* leaf litter covers the seabed. It is classified as a typical species associated with submerged detritus accumulation (Gallmetzer et al., 2005).

In RH, the most abundant Polychaeta is the mesograzer *Platynereis dumerilii*, which remains constant all year round. This organism is one of the most abundant species in *P. oceanica* beds and it is frequently recorded in environments with low competition (Giangrande, 1988), such as polluted hard bottoms (Bellan, 1980). Since the spring season, a rapid increase in some organisms (mainly represented by *Erichthonius punctatus*, *Leptocheirus guttatus* and *Microdeutopus chelifer*) has been observed, which mainly contributes to the total variance in the community as observed by SIMPER test results. These crustaceans correspond with variations in the percentage of organic matter on the seabed and in leaf lengths.

In LE, the most abundant species is the Crustacean *Hyppolite inermis*, which is a typical organism inhabiting the leaf stratum of shallow-water stands with high adaptability to the hydrodynamism and to the plant annual cycle (Gambi et al., 1992). The Mysidae *Syriella Clausii* is a common species of soft-bottom organisms associated with seagrass meadow (Barberà, et al., 2013) and it accounts for the largest variance within the populations on the leaf stratum during all of the seasons. This detritus-feeders species represents one of the most important links between primary producers and higher trophic levels because it exploits and mobilises organic detritus. At the same time, it is a common prey of fish and macrofauna (Gambi et al., 1992). This species correlates with the winter season. Previous studies confirm this observation, showing that it displays its maximum abundance during this season (Barberà et al., 2013).

The leaf stratum is the macrohabitat where Gastropoda are abundant (28.5%), and *Rissoa ventricosa* is the dominant species, especially during the winter and spring when it accounts for the largest variance together with *Syriella clausii*. This herbivorous deposit feeder correlates with the percentage of organic matter within the flux, and the grazing of epiphytes and particulate organic matter has a role in energy transfer at the level of the leaf stratum (Gambi et al., 1992).

The analysis of feeding guilds highlights the great variability in the trophic structure of the three macrohabitat assemblages. Herbivores dominate according to previous studies in LE (Gambi et al., 1992; Mazzella et al., 1992; Bedini et al., 2011). Meanwhile, in RH and SP, the most abundant feeding guilds are Suspension feeders (*Susp*) and Predators (*Pr*), respectively.

For SP, predators are always dominant during all of the seasons. In autumn, Dep-herb and Det-herb display a notable increase, which is probably because of the presence of abundant leaf litter on the sea floor generated by the leaves of *P. oceanica* that drop in the fall. This enhances decomposition (Manini et al., 1997). Dep-omn organisms correlate with the percentage of organic matter within the bed sediment and they reach maximal abundance in summer and spring. This is probably related to the higher concentration of chlorophyll a in the sediment (Danovaro and Fabiano, 1995).

In RH, Susp and Dep-Susp undergo a rapid increase during the spring, which varies according to the trends associated with resuspension flux and rain. Generally, these organisms indicate low hydrodynamic conditions or high sedimentation (Ledoyer, 1962). They correlate with resuspension flux, and rain may be interpreted as an inverse correlation with these factors. The decrease in spring rain and *P. oceanica* growth limits resuspension, favouring particle settling. During other seasons, this macrohabitat is dominated by predators and deposit feeders. Inside this guild, Dep-omn and Dep-herb organisms are linked to variations in the percentage of organic matter within the flux, which increase in the spring and summer when epiphyte activity reaches its maximum. This especially occurs in shallow depths (Buia et al., 1992).

In LE, Dep-herb consistently dominate the population, which correlates with the autumn season. In fact, only Dep-herb organisms colonize the leaf stratum during autumn. During the other seasons, they progressively increase in numbers following the seasonal growth of leaves and the associated increase in epiphyte abundance (Mazzella & Ott, 1984; Mazzella et al., 1989), which cause a greater availability of food (Borg et al., 2010). The secondary group is represented by Det-omn which are represented mainly by *Syriella clausii* (previously described).

The data herein presented are related to a single seasonal cycle of observations which is not sufficient to describe the seasonal variation of benthic community. For this purpose, another sampling cycle has been carried out between October 2015 and December 2016 but the collected fauna is still in the identification phase. Moreover, the macrozoobenthic communities will be compared with other samples, collected in the same period, in two other *P. oceanica* meadows, located in the coastal area of Civitavecchia and characterized by different depth (10 and 15m). and different growth substrates.

3.5 Conclusion

In this study, physical factors contribute to the variations in the benthic communities in three macrohabitats of *P. oceanica* meadow when placed in shallow water. This multidisciplinary approach clarifies the effect of coastal dynamics on the community structure over the course of one year. The resuspension process generated by waves that mainly drive coastal dynamics in shallow water is attenuated by vegetation by more than 50% during the maximum growth phase of the leaves. Sestonic particles, the biological activity of *P. oceanica* and its faunal assemblage are the major sources of organic matter. However, inter-relationships between wave energy and the leaf's ability to retain particles regulate the organic matter concentrations inside the canopy. Along the three different levels of seagrass, three different macro-zoobenthonic assemblages are observed. In sand pools, rhizomes are dominated by Polychaeta. However, the most abundant taxa are Amphipoda and Polychaeta. Meanwhile, on the leaf stratum, Gastropoda and Crustaceans (Mysida and Decapoda) are the most numerous. Proceeding from the bottom toward the leaves, a vertical gradient of stability is clearly recognized. The sand pool is characterised by the least amount of variation in faunal composition during the year. The most significant amount of variation is observed in the autumn when high decomposition activity occurs in sediments.

The faunal assemblage of rhizomes is more stable than the leaves, and the greatest variation is observed in the spring as a result of the incremental changes in the population of the suspension feeder Amphipoda. The leaf stratum is the most variable environment because it is strictly dependent on the growth rhythms of *P. oceanica*. It is probably linked to the seasonal development of the epiphyte community, which has been demonstrated by previous studies. Both macrohabitats (LE and RH) are strongly influenced by canopy growth, which create a more stable environment that prevents resuspension and attenuation of hydrodynamism. This condition reduces the difference between the two strata, favouring the colonization by common species. Meanwhile, during seasons characterized by reduced leaf covering and canopy heights, the two macrohabitats display different species compositions. The differences among these macrohabitats also reflect the feeding behaviour of the species. Predators dominate the communities in the sand pool. On rhizomes, suspension feeders and predators dominate, while the leaf stratum is characterised by abundant herbivorous deposit feeders. This study reveals the relationship between a dynamic species composition and their feeding mode, highlighting the greater correspondence between the percentage of organic matter in flux and sediments. This drives variation, especially with respect to the abundance of deposit feeders and detritus feeders. Moreover, during the taxonomic identification phases, two new species associated with the *P. oceanica* were reported in the northern Tyrrhenian Sea: the alien Isopod *Mesanthura* sp. and the Polychaeta Sabellid *Acromegalomma messapicum*.

The discovery of these two species highlights the importance of *P. oceanica* meadows as a biodiversity hotspot. It also emphasizes the ability of this plant to create various ecological niches useful for the colonization and sustenance of rare and alien species.

3.6 Analysis of the ecological quality (AMBI and M-AMBI indices).

The AMBI index (by AZTI), was designed to establish the ecological quality of European coasts investigating the response of benthic communities to natural and anthropogenic changes in water quality (Borja et al., 2000, 2003). It has been successfully applied in European marine waters (Baltic, North Sea, Atlantic and Mediterranean). Moreover, this index has been verified successfully in relation to a very large set of environmental impact sources such as harbour and dyke construction, heavy metal inputs, eutrophic processes, engineering works, diffuse pollutant inputs, dredging processes, mud disposal, sand extraction, oil spills, fish farming, etc (Borja et al., 2000, Muxica et al., 2005).

The AMBI can be used for the determination of the ecological quality status (EcoQ) within the context of the European Water Framework Directive (WFD) (Muxica et al., 2005). This biological index it is useful for the analysis of three parameters proposed by the EcoQ: diversity, species abundance and the presence/absence of indicators and stress-sensitive species (Borja et al., 2000, 2003). It is based essentially upon the distribution of five ecological groups of benthic macrofauna (Grall and Gleåmarec, 1997) and classifies the species in relation to their sensitivity to different stress levels:

- E.G I: disturbance-sensitive species;
- E.G. II: disturbance-indifferent species;
- E.G III: disturbance-tollerant species;
- E.G IV: opportunistic species;
- E.G V: first-order opportunistic species.

AMBI software is based upon a model (based upon ecological models, such as those of Gle'marec and Hily 1981 and Hily 1984) which permits the derivation of a biological coefficient which allows the subsequent statistical analysis of data (Borja et al., 2003).

Summary of the AMBI values and their equivalences (modified from Borja et al., 2000)				
Biotic coefficient	Dominating ecological group	Benthic community health	Site disturbance classification	Ecological status
$0.0 < \text{AMBI} \leq 0.2$	I	Normal	Undisturbed	High status
$0.2 < \text{AMBI} \leq 1.2$		Impoverished		
$1.2 < \text{AMBI} \leq 3.3$	III	Unbalanced	Slightly disturbed	Good status
$3.3 < \text{AMBI} \leq 4.3$		Transitional to pollution	Moderately disturbed	Moderate status
$4.3 < \text{AMBI} \leq 5.0$	IV-V	Polluted		Poor status
$5.0 < \text{AMBI} \leq 5.5$		Transitional to heavy pollution	Heavily disturbed	
$5.5 < \text{AMBI} \leq 6.0$	V	Heavy polluted		Bad status
$6.0 < \text{AMBI} \leq 7.0$	Azoic	Azoic	Extremely disturbed	

The last column shows the proposed equivalent ecological status for the application of the WFD (Borja et al., 2003b).

Fig. 1: summary of the AMBI values and their equivalences (Muxika et al., 2005).

Results:

In all the seasons the benthic community was more represented by the species of the first and second ecological groups.

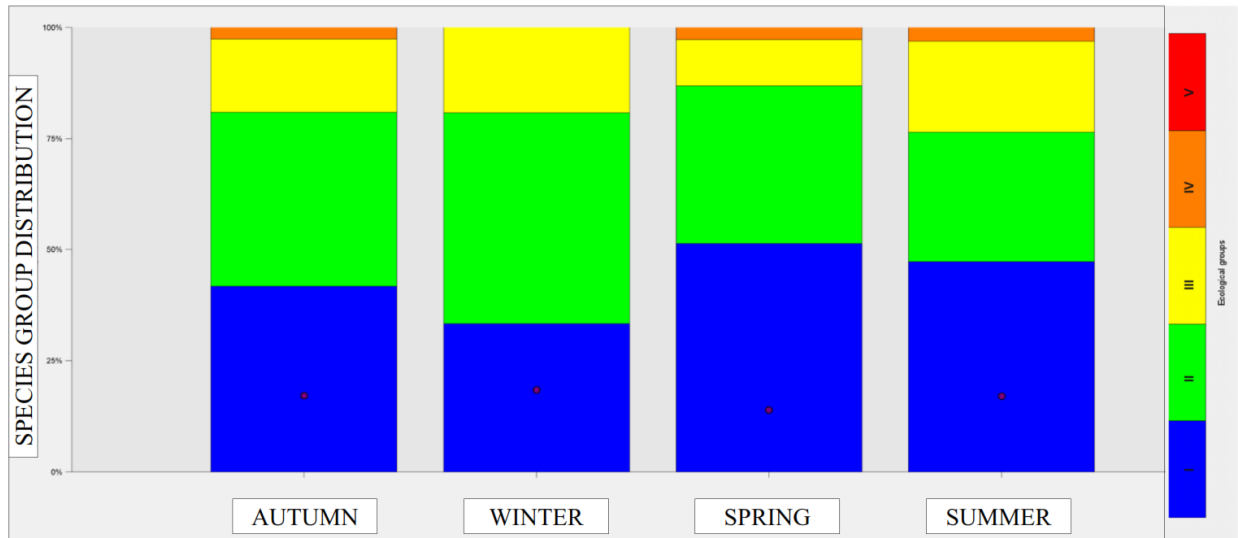


Fig. 2: sasonal variation of the species groups composition.

The biological coefficient (AMBI) ranges between 1.912 and 0.96 and this values indicate that the study area is classified as "slightly disturbed".

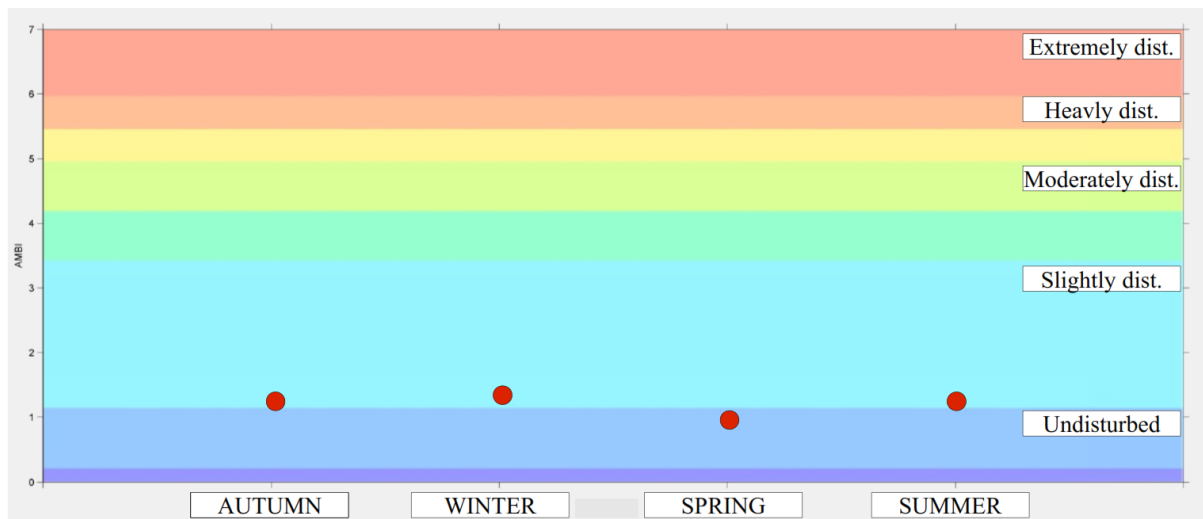


Fig. 3: Sasonal variation of the AMBI index.

The analysis of the Multivariate biological index (M-AMBI) show that the quality of the site was “High” during Autumn, Spring and Summer. In Winter the value of the M-AMBI index drops to 0.74 (Good), this slight decrease of the biological quality was probably linked to the adverse marine conditions that characterize this season.

Season	AMBI	Diversity	Richness	X	Y	Z	M-AMBI	Status
Autumn	1,199	5,9291	101	-0,64723	-0,42296	0,022431	0,86194	High
Winter	1,2877	5,0756	71	-0,05858	0,243	-0,0082228	0,74339	Good
Spring	0,96957	6,0264	148	-1,2019	-1,1928	0,029822	0,98624	High
Summer	1,1912	6,2785	138	-1,0984	-1,0509	0,039126	0,96323	High

Fig. 4: seasonal variation of the values of the AMBI and M-AMBI index.

4. Sedimentary process in a shallow water *Posidonia oceanica* meadow.

Paladini de Menzoza, F., Fontolan, G., Mancini, E., Scanu, E., Scanu, S., Bonamano, S., Marcelli, M., 2018. *Marine Geology* (Accepted, moderate revision, 13/03/2018).

Abstract

The study about the dynamics of vertical sedimentation flux over a *Posidonia oceanica* meadow seabeds is herein presented as the result of over one year of investigation. Total sedimentary flux was monitored in the northern Latium coast (Italy) of Central Tyrrhenian Sea using sediment traps, from October 2015 to December 2016, in three stations: bare sand, *Posidonia oceanica* meadow and sand patch into the meadow. Traps were deployed during 11 surveys planned on the basis of weather conditions and growth phase of seagrass. Trap content is analysed in term of amount of mass trapped and grain-size statistics useful to describe sedimentary processes during storms. Meteorological data, *Posidonia oceanica* parameters and sand patch evolution during the year were analysed in order to put them into relation with vertical sedimentation flux. Shallow-water dynamics is characterised by the dominance of resuspension process and *Posidonia oceanica* mainly buffers resuspension especially during calm sea condition. In presence of high energetic regime of flow, near the bottom vegetation enhances the deposition of particles transported from adjacent unvegetated area as testified by sedimentological tracer. During late summer the leaf litter deposited on the unvegetated seafloor buffers seabed sediment particles preventing resuspension. In this study, the sedimentary dynamics in shallow water seagrass meadow is described detecting also an active transport of material from sand-patch to the meadow dependent by energetic regime of flow that leads to a double role of vegetation that is able to prevent resuspension and promote deposition.

Keywords

Posidonia oceanica, sedimentary processes, sediment traps, grain-size, resuspension, coastal zone, seagrass

4.1 Introduction

P. oceanica meadows are recognised to be coastal hotspots for biodiversity (Myers et al. 2000), and considered a “mayor carbonate factory” of the Mediterranean inner shelf (Canals and Ballesteros 1997;

Fornos and Ahr 1997, 2006; De Falco et al. 2008, 2011; Mateu-Vicens et al. 2012). Its diffuse regression (Telesca et al, 2015), in last decades, has generated a worldwide scientific interest oriented to understanding the ecological factors that influence this ecosystem, in order to perform an efficient management and conservation. Several studies focused on the role of *P. oceanica* on hydrodynamic and sedimentary processes observing its effect on turbidity filtering and trapping particles (Hendriks et al. 2008) and the capacity to promote deposition and reduce the resuspension processes awarding a biogeomorphological role (Vacchi et al., 2016). This process is due to a direct effect produced by the collision between the sediment particles and the seagrass leaves (Hendriks et al. 2008) and to an indirect action due to the reduction of flow and turbulence (Scoffin 1970; Fonseca et al. 1982; Gambi et al. 1990; Ackerman and Okubo 1993; Koch 1996; Gacia et al. 1999; Koch and Gust 1999; Nepf and Vivoni 2000; Jumars et al. 2001; Peterson et al. 2004; Koch et al. 2007) and wave motion (Fonseca and Cahalan 1992; Koch and Gust 1999; Granata et al. 2001; Bouma et al. 2005; Koch et al. 2007; Stratigaki et al. 2011; Manca et al. 2012).). Investigations in natural condition were conducted on *P. oceanica* meadows placed at depth greater than 10 m (Gacia et al. 1999; Terrados and Duarte 2000; Gacia and Duarte 2001) where it was demonstrated the role of vegetation on resuspension processes comparing unvegetated and vegetated seabed. Flume experiments have reproduced hydrodynamic features in shallow waters (Stratigaki et al. 2011; Manca et al. 2012) demonstrating the capacity of flow attenuation in presence of low energy waves. Seagrass cover is a more sensitive indicator of eutrophication at intermediate water depths and in deep water, where light plays a major regulating role, than in shallow water, where physical exposure has a marked influence (Borum et al., 2004). Different types of gaps have been defined (Bianchi et al., 2008; Boudouresque et al., 2009; Lasagna et al, 2011) and all types may have natural or anthropogenic origins. Flume experiments demonstrate that the presence of patches or gaps influences hydrodynamic paths (El Allaoui et al., 2016; Folkard, 2005) within a meadow, leaves the bottom exposed to both waves and currents, leading to a greater probability of fragmentation of the meadow. In particular, the patch separation, the width of the gaps and the density of vegetation influence the sheltering capacity of the meadow on wave and currents.

Despite several works on the effect of *P. oceanica* on hydrodynamic and sedimentary processes it is recognised the complexity and variability of the particle-trapping process (Gacia and Duarte 2001). In situ observations about the effect of vegetation in shallow waters during high energy conditions are still lacking. In shallow waters, the frequent exposure of the bottom to waves action produces a significant movement of sediment particle and sedimentological features are a tracer of energetic regime of flow. We have conducted experiments with sediment traps on a fragmented *P. oceanica* meadow placed in a

shallow-water coastal area observing along one year the variability of sedimentation flux inside a fragmented meadow. The sedimentary processes were analysed considering the annual growth cycle of seagrass, different energetic conditions observing the role of vegetation on mass and textural features of deposited particles.

4.1.1 Sedimentary processes

Coastal dynamic processes drive sedimentary and bio-chemistry evolution of the benthic layer. The water-sediment interface is characterised by a high chemical and biological activity, and the importance of sediment processes relative to processes in the water column increases with reduced water depth (Smith, 1974). Waves and currents generate shear stress and turbulence that drive diffusive boundary layer fluxes (Boudreau, 1997), ventilation of porous bottoms (Shum and Sundby, 1996), as well as resuspension (Blomqvist and Larsson, 1994; Soulsby, 1997). The total sedimentary flux (Fig.1) is composed by flux of primary settling matter (F_p) and flux of resuspended sediment (F_r) (Pejrup et al., 1996). The primary settling matter is defined as sediment particles, including terrigenous matter, dead autochthonous organic matter, or shell and skeletal fragments that have not yet been deposited at the bottom at the measuring site. Resuspended sediment consists of the same components, but has been deposited from one to several times previously.

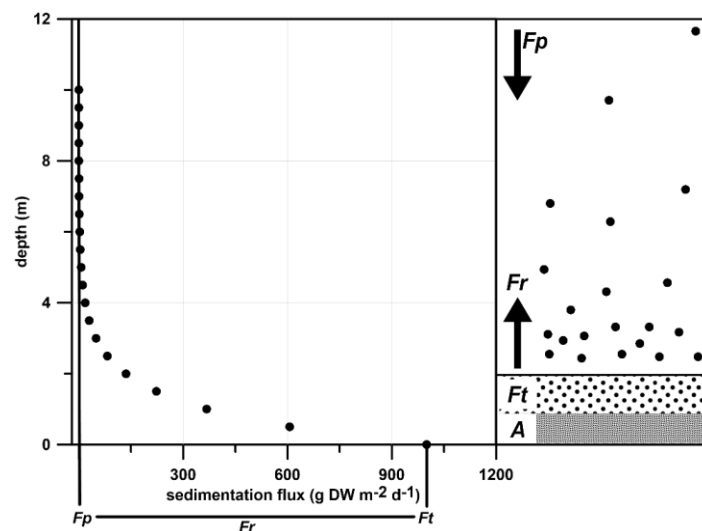


Fig.1 Sketch of sedimentary processes where resuspension (F_r) and settling flux (F_p) contribute to total sedimentary flux (F_t). The balance of sedimentary processes beneath the benthic mixing layer determine the accumulation rate (A).

Resuspension process is induced by wind-induced surface waves (Lesht et al., 1980; Aalderink et al., 1984; Sanford, 1994), internal waves (Cachione & Southard, 1974) or currents (Sanford et al., 1991). Resuspension in coastal areas is mainly caused by surface waves and tides, while in deep sea resuspension is primarily due to currents. The total downward flux (F_t) is the sum of F_p and F_r , and gross deposition rate is defined as F_t at the sediment surface. The accumulation rate (A) is the amount of sediment permanently deposited beneath the benthic mixing layer. The dynamic of inorganic fraction of particle sedimentation flux into the sea is mainly driven by energetic regime of water flows while the depositional processes of organic fraction are more complexes and variables.

Part of the organic matter flux is mineralized after deposition. The knowledge on the mineralisation of organic matter in coastal sediments is important for the understanding of carbon cycle. Organic matter mineralisation causes an exchange of nutrients that may affect the biological productivity in the water column. Mineralisation rate depends on many factor among which physical forcing governing exchange processes between the sediment and the water mass.

The resuspension play an important role in the mineralisation process enhancing the mineralisation rates, for example by the exposure of a larger surface area of recently settled organic material to microbial attack. Laboratory tests demonstrated the ability of resuspension in doubling, or more, the mineralisation rates compared to sediments not subjected to water turbulence (Stahlberg et al., 2006).

4.2 Study site

The study area is located in the northern Latium coast (Italy) of central Tyrrhenian Sea, which is characterized by a spring tidal range of 0.3 m and is exposed to waves mainly from the SW and to southerly and northerly winds. The study site is located along a coastal stretch south of Civitavecchia between the port breakwater in the north and the Pecoraro cape in the south (Fig.1.1a); data was collected at a depth of 7 m in front of Lega Navale (Fig1c). The wave climate exhibits a seasonal fluctuation with a maximum during the winter and autumn and a minimum in the summer. Most of the wave energy is constrained in a wave power range of 5 – 40 kWm^{-1} that corresponds to waves with a significant wave height (H_{m0}) of about 1.5 – 3 m and a peak period (T_p) of 6 – 9 s (Paladini de Mendoza et al., 2016). On the basis of rainfall records of the last 12 years (2003-2016) retrieved from the Hydrographic Service of Latium Region (<http://www.idrografico.roma.it/>), the average annual precipitation in Civitavecchia is 481 ± 163 mm and is subjected to seasonality with a maximum intensity in the autumn (225 ± 45 mm) and a minimum intensity in the summer (59 ± 34 mm).

The coastal morphology is characterized by a dominance of terraces where the irregular seabed is composed by rocky outcrops and natural depression covered by sediments. Along the coast, there are only several minor streams that originate from the nearby Tolfa Mountains, while the largest river (i.e., the Mignone river) is located 11 km north of the study site. The sediment contribution from the Mignone river does not influence the study site because sediment transport along the shore is oriented northward (Anselmi et al. 1976, Berriolo and Sirito, 1985, Noli et al. 1996). In the examined coastal site (Fig.1.1a), the coverage of *P. oceanica* consists of two wide areas (Special Area of Conservation, SAC, according to EU Habitats Directive) that extend from approximately 10 m to 30 m in depth. In the study site (Fig.1.1c), the *P. oceanica* meadow appears from a depth of 3 m, and the architecture exhibits a fragmented coverage determined by the presence inside the meadow of several sand patches of various dimensions. Moving from northwest to southeast parallel to the shore, the meadow is interrupted by a wide sand channel, which is a transitional zone between the rocky outcrops and the meadow (Fig. 1.1c).

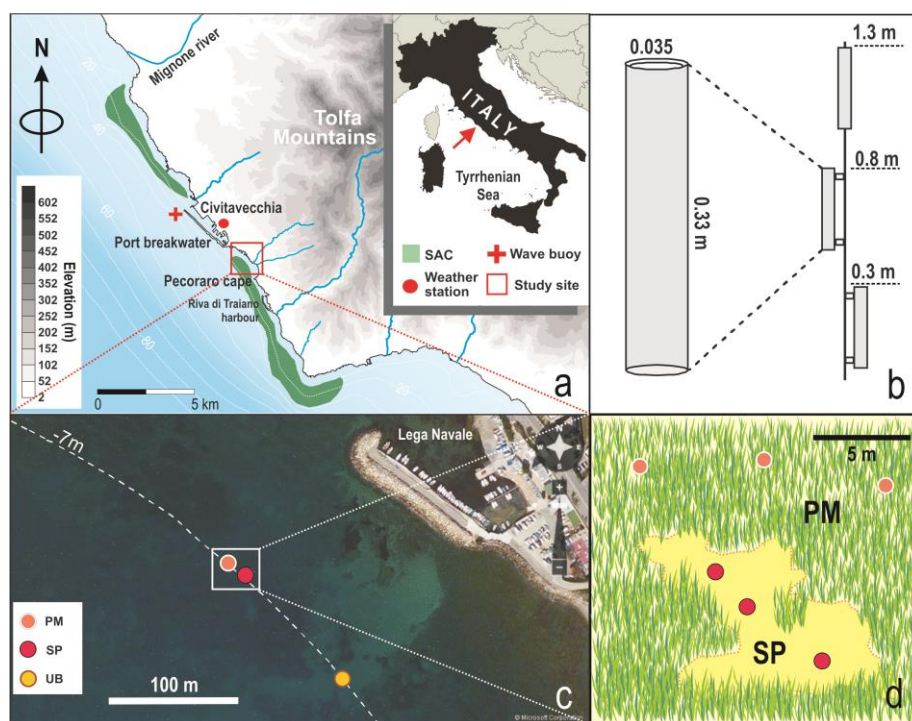


Fig.1.1 a) Extended study area showing the location of the Special Area of Conservation (SAC), wave buoy, weather station and study site. The mainland topography is the result of Digital Elevation Model (DEM) of Tarquini et al. 2012. b) Sketch of traps. c) Study site and position of sampling stations. d) Configuration, position and distance of the steel rods where traps were mounted in the sand patch (SP) and inside the meadow (PM).

4.3 Methods

In the study site three measuring stations (Fig.1.1c) were located, respectively, on the meadow (PM), on the sand patch inside a meadow (SP) and on the unvegetated sandy bottom (UB). The distance between the stations are approximately 10 meters between PM and SP (Fig.1d), whereas UB is approximately 150 meters further away from the others (Fig.1.1c). Considering previous findings on the role of *P. oceanica* on particle retention (Gacia and Duarte, 2001) by the comparison of particle sedimentation fluxes inside a meadow and on a bare sand, the measurements on UB station, which is located in a wide bare-sand channel, were conducted only four times choosing different weather conditions over the year as a control respect to the observation on the sand patch.

The total sedimentary flux was monitored in all stations using sediment traps from October 2015 to December 2016. The traps (Fig.1.1b) were constructed using polyethylene cylindrical tubes with an opening diameter of 0.035 m and a length of 0.33 m; this provided an aspect ratio of 9.4, which is near the optimal aspect ratio suggested for minimizing the over- and under-trapping (Gardner 1980; Hargrave and Burns 1979). The traps were mounted on a steel rod at three elevations from the seabed (i.e., 0.3 m, 0.8 m and 1.3 m) (Fig.1.1b) in three replicate units located within a radius of approximately 3-6 meters always at the same depth.

Before the installation, the traps were filled with surface water; then, they were covered with caps, which scuba divers removed at the start of survey.

The experiment involved 11 surveys extended over a year; the surveys were planned on the basis of weather conditions and seasonality as well (Table 1). Each survey lasted for a period ranging between 2 and 17 days. Bed sediments were sampled seasonally at the PM and SP stations using a 0.20-m diameter corer during October and December 2015 and March and July 2016.

Survey	Date	Cumulative rainfall (mm)	Wind max speed (ms^{-1})	Wind direction	Max wave power (kWm^{-1})	Wave direction	Site
1	25-30/10/15	34	12.53	SE	6.39	SE-SW	SP PM
2	16/11- 3/12/15	8.6	22.39	S-NE	93.77	SW	SP PM
3	11-20/03/16	2.3	17.43	N-NE	4.79	SE	SP PM

4	21/04-5/5/16	24.8	20.46	N-SE	26.25	S-SE	SP PM
5	8-10/6/16	34.5	9.46	SE	0.93	S-SW	SP PM
6	1-4/7/16	0.1	9.38	SE	6.29	S-SW	SP PM
7	20-22/7/16	0	10.41	SE	0.41	N-S	SP PM UB
8	30/8-1/09/16	7	7	N	0.13	N-S	SP PM
9	12-20/9/16	50.2	16.8	SW	13.87	S-SW	SP PM UB
10	17-19/10/16	0.7	12.21	SE-SW	0.39	S-SW	SP PM UB
11	1-4/12/16	0	8.6	SE	1.01	SW	SP PM UB

Table 1 Timeline and characteristics of surveys

The contents of the sediment traps were collected in two ways depending on the amount of the trapped material: for trapped content lower than 1g, the material was collected by filtration onto pre-combusted 47-mm GF/F filters; for trap content greater than 1 g, the wet sediment was placed into a pre-weighed aluminium tray. In both cases, the collected material was dried in an oven for a minimum of 24 hours at 60 °C until a constant weight was obtained (precision of 1 mg). Grain-size analyses were carried out on the bed-sediments samples and on trap samples recovered after surveys characterized by storms (this was the only condition that permitted the trapping of enough material for determination). The grain-size analyses were carried out using a *Malvern Mastersizer 2000* laser diffraction particle size analyzer. Sediments were sieved using a 2-mm mesh in order to separate the gravel biogenic component from the sand and mud. Only the latter fractions ($< -1 \phi$) were analysed. Grain-size data are represented using the Krumbein's ϕ notation, and the main components were computed following the Udden-Wentworth scale.

The statistical parameters of the grain size—that is, mean size (Mz), sorting (s) and skewness (Sk)—were calculated following Folk and Ward (1957).

The load of the traps was converted in flux ($\text{g m}^{-2}\text{d}^{-1}$) considering the geometry of the traps and the duration of the survey. According to Pejrup et al. (1996), the total sedimentary flux at the bottom (Dr) is the sum of resuspended material and the natural settling material (primary). Following the methodology of the same authors, the resuspension flux (Fr) can be fitted by an exponential function where the load declines exponentially with increasing height above the sediment source. Fr can be estimated as the intercepts at the sediment surface of the fitted exponential relationship between the downward depositional flux and the height of the sediment traps above the bottom. As a general rule, primary flux can be obtained by considering the vertical asymptotic value of the exponential function. The availability of the method is ensured when resuspended flux does not involve the upper trap. Otherwise, when resuspension is the dominant effect on the sea-bottom, as it may occur during extreme storms, the contribution of the primary flux on the total sedimentary flux can be considered to be negligible.

The *P. oceanica* meadow was analysed at the depth where the traps were placed by defining the percentage of cover of seagrass and other type of substrata as well as seagrass density and biometry of leaves.

For percentage cover, we used the *LITs* methodology (Line Intercept Transects) of Bianchi et al. (2004) and Montefalcone et al. (2007). During May 2016, three sampling stations were chosen and in each station, four transects, each of 10-m length (Marcos-Diego et al., 2000), were positioned; transects extended radially in opposite directions from a fixed point in the middle of the sampling station. This analysis was carried out at the PM station and at two points respectively positioned 50-m north and south from the PM station and always at the same depth (i.e., 7 m). Plant and substrate cover were assessed along each transect. A centimetre-marked line was laid on the bottom along which a scuba diver recorded the occurrence of live *P. oceanica* and the nature of the substrate (i.e., sand, rock or dead matte). The percentage cover was obtained by dividing the length of each substrata by the total length in order to provide information of the amounts of different substrata and live *P. oceanica* that covered the sea bed.

The biometry of leaving leaves (foliar shoots) was determined seasonally on 10 shoots according to Giraud (1977); the Leaf Area Index (LAI, leaf surface area per shoot, m^2m^{-2}) was also calculated. The shoot density was evaluated at the PM station by counting the number of shoots using $0.4 \times 0.4 \text{ m}^2$ standard quadrates (10 runs). In addition, we collected photographs and measurements of the dimensions of the sand patch in order to record its evolution throughout the year.

Meteorological data during sampling periods were recorded by a weather station (i.e., wind speed, direction and precipitation) and a wave buoy (i.e., significant wave height, peak period and direction). The wave buoy and weather station were located in proximity of the study site (Fig.1). The wave buoy data were used to determine the bed shear stress and predict the theoretical transport capacity of waves useful for the interpretation of trap results. The formulations used for bed shear stress come from Komar and Miller (1973), where, following linear wave theory, the maximum horizontal velocity at the bottom produced by waves associated with elliptical motion of orbits is:

$$U_x = \frac{\pi H}{T \sinh(2\pi d / L)} \quad (1)$$

where H is the wave height, T is the wave period, d is the depth and L is the wave length.

The bed shear stress (τ_0) is given by:

$$\tau_0 = 0.5 C_f \rho U_x^2 \quad (2)$$

where C_f is the wave friction factor (0.004, according to Jonsson, 1966), and ρ is the water density.

The bed shear stress was computed on the time series recorded by the wave buoy; we subsequently imposed a threshold of motion considering the value proposed by Berenbrock and Tranmer (2008) for fine silt, that is the finest significant grain-size class featuring the local sediments. The transport capacity (Ct) of waves during each survey was determined using a filtered time series (by threshold):

$$Ct = \int_{t_0}^{t_1} \tau_0 dt \quad (3)$$

where t_0 is the start time of the filtered time series, and t_1 is the end time of the filtered time series.

Pearson correlation coefficients were determined to define correlations between meteorological forcing and sedimentation flux. The temporal changes of the *P. oceanica* meadow descriptors were analysed using ANOVA for repeated measurements. The statistical significance on differences about depositional rates and bed sediment composition over time and between stations was defined by non-

parametric tests, including the Wilcoxon Signed Ranked test and the Kruskal-Wallis test applied for more than two groups (Hollander and Wolfe 1999).

4.4 Results

4.4.1 Meteorological conditions

Meteorological conditions from 10/2015 to 12/2017 were characterized by a total rainfall of about 670 mm [maximum in October 2016 (136 mm) and a minimum in July (0.6 mm)]. The cumulative rainfall observed during the surveys ranged from 0-50.2 mm (Table 1), and the maximum occurred in September 2016 during survey 9. The prevailing wave directions and the intensity that occurred during sampling periods are inside the variability of the study area according to the local wave climate with a wave power between 0.13 and 93.7 kWm⁻¹ (Table 1). The maximum wind speed shows a magnitude between 7 and 22 ms⁻¹ with a prevailing wind direction from the SE. Three severe storms ($H_s > 1.8$ m) occurred during surveys 2, 4 and 9, corresponding to maximum wave powers of 93.77, 26.26, 13.87 kWm⁻¹, respectively. Two less-intense storms of comparable maximum wave power (6.39 and 6.29 kWm⁻¹) occurred during surveys 1 and 6.

4.4.2 Seasonal changes of *Posidonia oceanica* meadow characteristics

The total percentage of cover of the different substrata assessed by the LIT methodology provides information regarding on the amounts of different substrata and live *P. oceanica* covering the sea bed. Live *P. oceanica* cover 69% of the seabed, 17% is covered by sand and 14% consists of mixed rocks and sandy bottom.

The unvegetated areas are mostly represented by sand patches with circular shape and various dimensions ranging from 1 to 6 meters. The average densities sampled in different stations (Fig.2b) range between 289 and 309 shoots m⁻² and do not show significant differences (ANOVA $p = 0.8$).

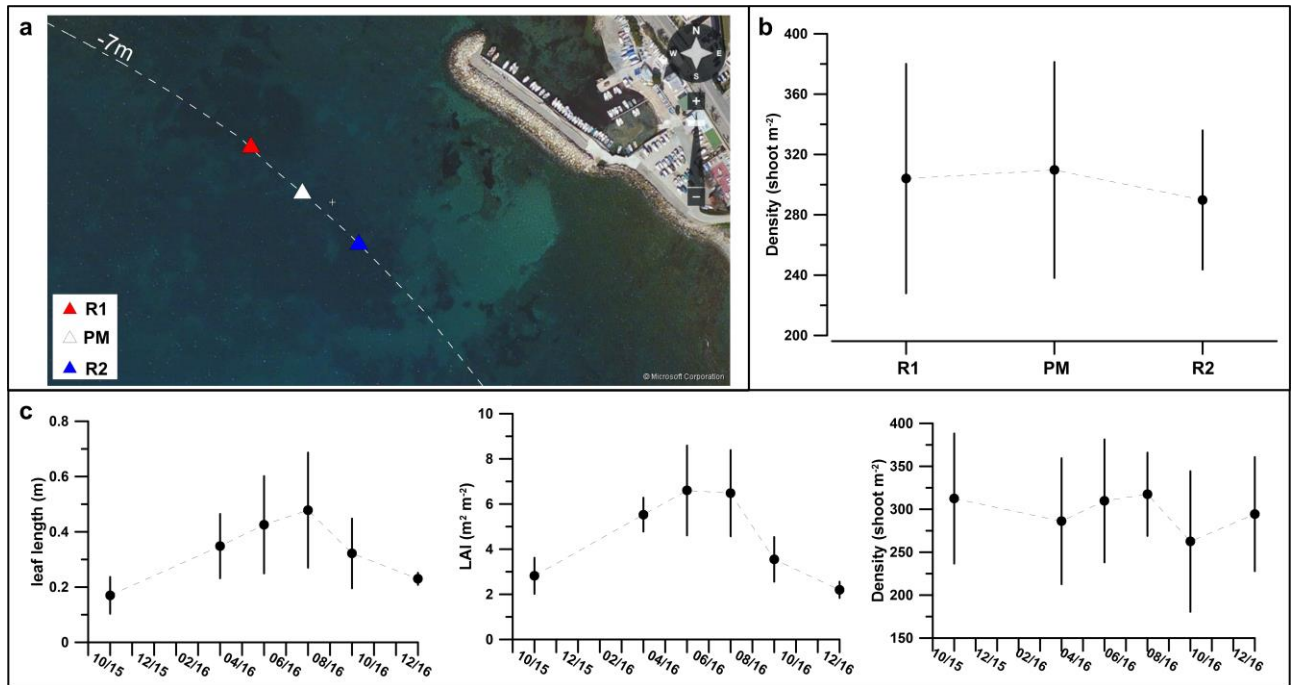


Fig.2 a) Sampling stations used for LIT and density assessment; b) *P. oceanica* density in each station; c) Variation of *Posidonia oceanica* descriptors over the year. From left to right: Leaf Length, LAI and Density on PM station.

The PM station is sampled over the year, the length of leaves shows a significant variation over the seasons (ANOVA $p < 0.001$); the minimum is in the autumn (October), with an average value of 0.17 ± 0.06 m, and the maximum is in the summer (July), with an average value of 0.47 ± 0.20 m (Fig. 2c). The growth of leaves also influences the LAI, which shows the same trend of leaf length, reaching its maximum value in May (6.6 ± 1.99 m² m⁻²) and minimum value in October (2.82 ± 0.8 m² m⁻²) (Fig.2c). Density does not show a significant variation over the year (ANOVA $p = 0.9$); it remains quite constant in the range of 260-312 shoots m⁻² (Fig.2c).

The sand patch, at the SP station, shows large changes during the seasons (Fig.3). In autumn, the sand patch presented, apparently, the maximum extension, as reported in Fig.3a, while during the summer, the growth of seagrass halved the bare surface (Fig.3c). During strong autumn and winter storms, the bed of the SP station shows erosive features, such as large ripple marks and outcropping of bedrock (Fig.3b). In the late summer, *P. oceanica* started to shed leaves, which progressively covered the seafloor with leaf litter (Fig.3d). The leaf litter remained on the seafloor until the first storm, at the end of which it was largely transported away.

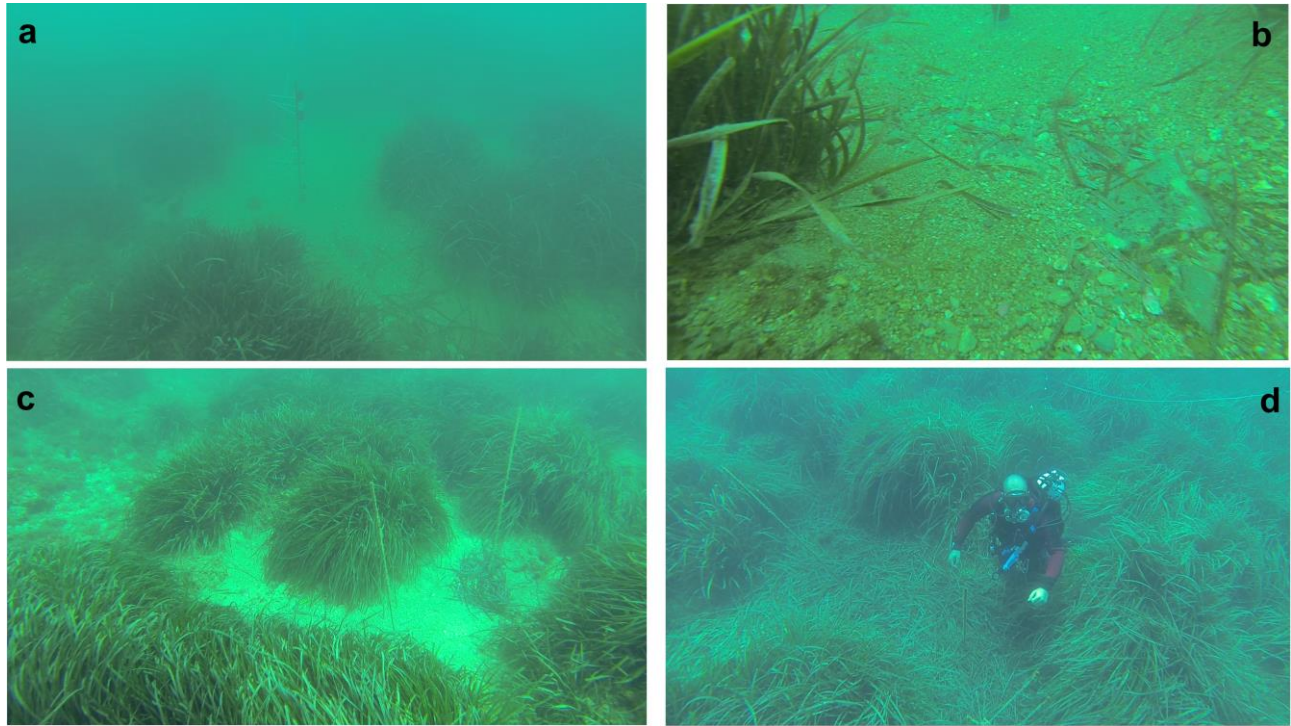


Fig.3 Sand patch evolution during the year. a) autumn phase, b) detail of the bedrock outcropping after an extreme event, c) summer phase, d) late summer phase.

4.4.3 Bed sediment composition

The bed sediments were collected seasonally at the PM and SP stations. In Fig.4, the cumulative distribution curves and textural bar plots show the general coarse nature of bed sediment. Gravel accounts for more than 40% in SP station and 10% in PM station. The cumulative distributions of grain size each show a bimodal shape with a change in slope around 3ϕ , which indicates the presence of two populations of grains. The grain mode 1 (Fig.4a) can be attributable to a tractive transport, while the grain mode 2 can be attributable to a suspended transport. The biogenic component in the bed sediment is dominant and is produced by biological activity of organisms living in the *P. oceanica* ecosystem and in the surrounding substrate (infralittoral and mesolittoral rocks). The gravel fraction is totally formed by bioclasts composed of shells and skeletal fragments. Comparing PM and SP cumulative distributions (Fig.4a), it is evident that there is a generally finer composition of PM sediment compared to SP; this is also apparent from the mean size (Mz) and the 95th percentile values ($D95$) (Fig.4b). During the year, there are some changes in textural composition of bed sediments (Fig.4c), which are slight for the SP samples and marked for the PM samples. In particular, in the PM

samples, a large variation occurs over the seasons (Kruskal-Wallis test $p < 0.05$), especially from winter to summer, where there is a great increase of sand and mud fractions in the composition of bed sediment (Fig.4c). During the year, the PM station is more variable than the SP station, suggesting the influence of vegetation on sedimentation processes. The bivariate relationships between grain-size statistical parameters permits us to further distinguish PM from SP, as data are plotted in two distinct fields (Fig.4c). Only the PM sample collected in winter falls within the SP sample area, featuring the coarsest mean size and highly positive skewness. During winter, the energy and frequency of storms are large, whereas during spring and summer, the storms become less frequent and less intense. This trend need to be considered together with the growth of seagrass that moves from winter to summer.

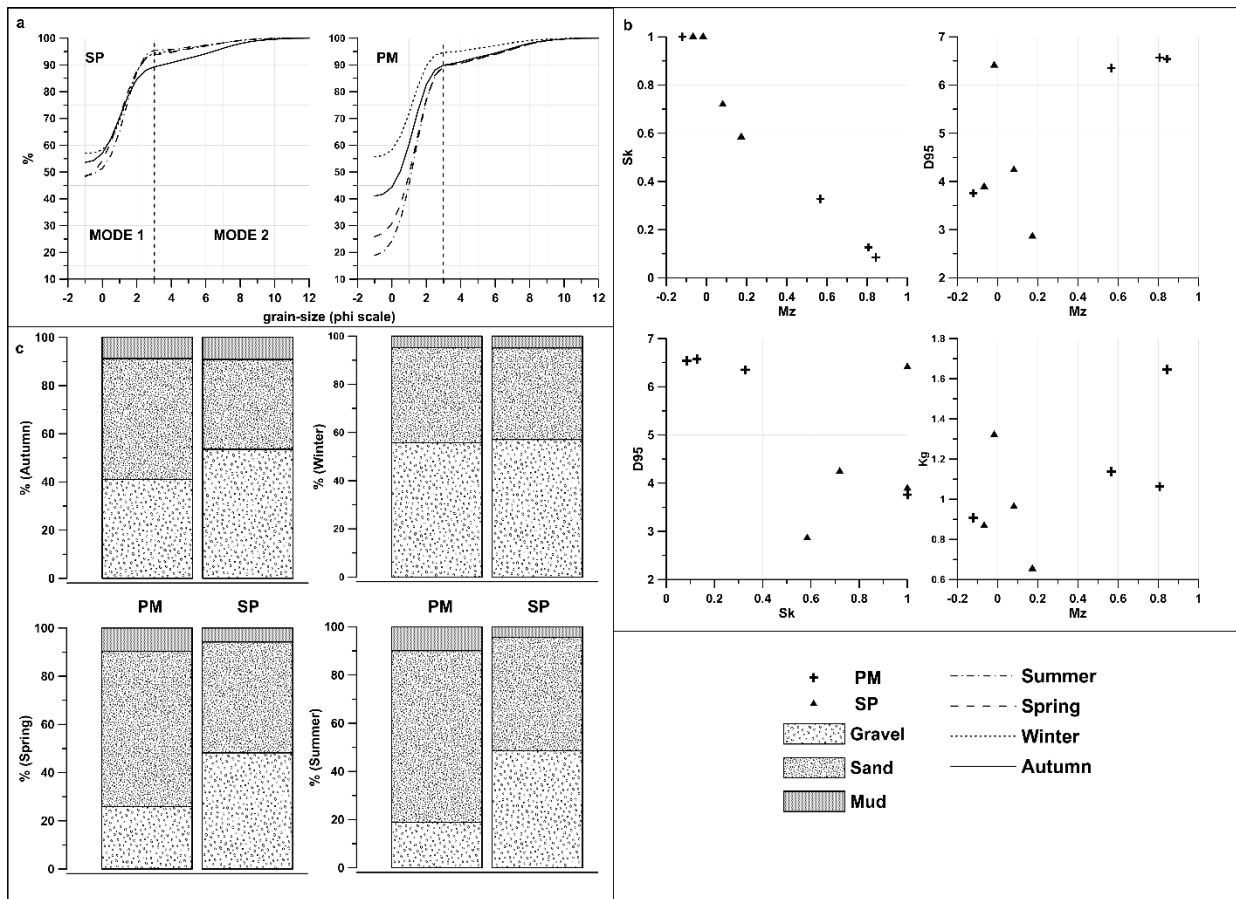


Fig.4 Results of sedimentological analysis of bed sediment samples; a) cumulative distributions; b) bivariate plots of Folk and Ward statistical parameters; c) textural composition.

4.4.4 Particulate sedimentation flux

The vertical sedimentation flux at different elevations from the seabed was evaluated seasonally and during different weather conditions (Fig.5). During the year, the maximum depositional rate was recorded in November 2015 with $9640 \pm 2848 \text{ g DW m}^{-2}\text{d}^{-1}$, while the minimum was recorded in October 2016 with $3.89 \pm 0.28 \text{ g DW m}^{-2}\text{d}^{-1}$. Along the vertical profile, the total sedimentary flux generally increases toward the seabed, showing larger values during the autumn and winter seasons (Fig.5). In particular, sedimentary flux has a substantial increase when rainfall is larger than 20 mm and mostly in the presence of wave power greater than 5 kWm^{-1} . Slight rainfall and calm seas determine sedimentary flux values less than $66 \text{ g DWm}^{-2}\text{d}^{-1}$ in bare-sand stations and less than $12 \text{ g DW m}^{-2}\text{d}^{-1}$ over the seagrass. The sedimentary flux at the bottom is generally larger at the bare-sand stations (SP and UB) with the exception of three cases where the total sedimentary flux at the bottom in PM is larger than SP.

The depositional rates at 1.3 m over the sediment surface were highly correlated and not significantly different ($R > 0.95$; $p < 0.0001$; Kruskal-Wallis test $p = 0.37$) in different stations and over time, while depositional rates at the bottom (0.3 m) and at the intermediate level (0.8 m) show significant variations (Kruskal-Wallis test $p < 0.05$) among stations, suggesting a possible role of vegetation in constraining the sedimentary process within a layer almost 0.8 m thick.

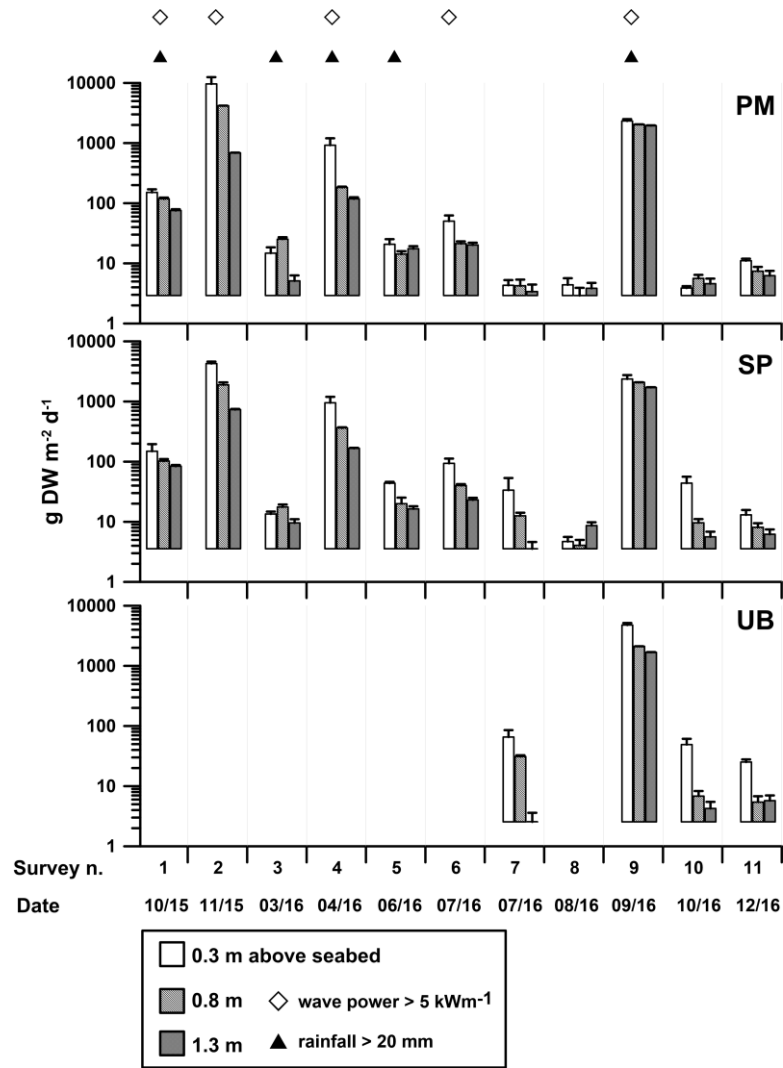


Fig.5 Bar plot of vertical sedimentation flux at different levels above the seabed; white square and black triangles represent respectively events with wave power > 5kWm⁻¹ and precipitation > 20mm.

The vertical profiles of sedimentary flux (Fig.5) show the dominance of an increasing trend of sedimentary flux towards the seabed especially in the SP and UB stations suggesting resuspension process. Table 2 reports data on sedimentary flux distinguished between the resuspension (Fr) and the primary settling (Fp) components (Table 2). The best-fit statistics are reported in the form of R^2 , according to the exponential function proposed by Pejrup et al. (1996), and significant fitting indicate the presence of a resuspension process.

The exponential trend due to resuspension best fits in the 81% of the measurements at the SP station, while at the PM station, resuspension is less frequent, occurring in 54% of the cases (Table

2). In the unvegetated sandy bottom (UB), during all surveys vertical profiles are characterised by resuspension.

Other vertical-profile patterns show nearly uniform depositional flux without evidence of resuspension, especially at the PM station.

The comparison among stations highlights the general trend of larger Fr at the SP station compared to the PM station. The average contribution of resuspended material to the total depositional rate amounts to 94% in UB, 81% in SP and 72% in PM.

Information on the effect of leaf growth as a possible constraint in the resuspension processes can be obtained by comparing the sedimentary fluxes and gradients recorded in PM during different vegetation phases and comparable wave intensities (Fig. 6). In this figure, the modification of the vertical profile in presence of vegetation is particularly evident especially during calm sea conditions. The sedimentation profiles are characterised by resuspension on unvegetated stations, while inside the meadow records show a homogeneous trend along the vertical profiles. In presence of strong and moderate storms, the resuspension process always occurs inside vegetation, but its magnitude is governed by the length of leaves.

<i>Class</i>	<i>Survey</i>	<i>Date</i>	<i>Fr</i>	<i>Fp</i>	<i>Dr</i>	<i>%Fr</i>	<i>%Fp</i>	<i>R²</i>	<i>Site</i>
1	2	16/11-3/12/15	17508	-	17508	100	-	0.84	PM
			7112	-	7112	100	-	0.98	SP
	4	21/4-5/5/16	2164	28	2192	98.7	1.3	0.85	PM
			1554	103.3	1657.3	93.8	6.2	0.89	SP
	9	12-20/9/16	584.8	1850.3	2435.2	24	76	0.75	PM
			985.3	1635.8	2621.1	37.6	62.4	0.62	SP
			5786.6	1033.4	6820	84.8	15.2	0.93	UB
2	1	25-30/10/15	187	70.8	257.8	72.5	27.5	0.65	PM
			176	70.7	246.7	71.3	28.7	0.8	SP
	3	11-20/03/16	0	14.7	14.7	0	100	0.16	PM
			0	13.4	13.4	0	100	0.17	SP
	6	1-4/7/16	57	12	69	82.9	17.1	0.75	PM
			133.1	14.6	147.7	90.1	9.9	0.91	SP
3	5	8-10/6/16	0	15	16	0	100	0.15	PM
			50.9	10.2	61.1	83.2	16.8	0.89	SP
	11	1-4/12/16	7.8	5.1	12.9	60.4	39.6	0.78	PM
			12	5.1	17.1	70.2	29.8	0.71	SP

			49.4	1.4	50.8	97.2	2.8	0.88	UB
4	7	20-22/7/16	0	3.3	3.3	0	100	0.15	PM
			59.6	2.8	62.4	95.5	4.5	0.64	SP
			111.7	6.6	118.4	94.4	5.6	0.95	UB
	8	30/08-1/9/16	0	3	3	0	100	0.29	PM
			0	9.6	9.6	0	100	0.63	SP
	10	17-19/10/16	0	5.1	5.16	0	100	0.08	PM
			98.4	1.6	100	98.4	1.6	0.88	SP
			147.2	0.6	147.8	99.6	0.4	0.84	UB

Table 2 Results of separation between resuspended *Fr* and primary *Fp* fluxes for each survey grouped into intensity classes; the depositional rate at the bed (*Dr*) is also reported as well as the contribution of resuspended (%*Fr*) and settled (%*Fp*) material on the total depositional rate are also reported. R^2 refers to the significance of exponential function that best-fit with measured values. The fitting is significant ($p < 0.05$) with $R^2 > 0.61$. In survey 2 the *Fp* was not determined because all the traps have been involved in resuspension.

During strong storms ($>10\text{kWm}^{-1}$, 1st class), the resuspended flux is larger or very similar inside the vegetation (PM) compared to the sand patch (SP). On these samples, the sedimentological analysis allows to better describe the sedimentary process during high energetic events.

The 2nd class of wave intensity (Fig.6) shows a slight effect of vegetation in presence of short leaves, but there is a reduction of resuspended flux (*Fr*) of about 70% with the lengthening of leaves at the PM station. The 3rd class shows the neglection of resuspended flux in the summer when the leaves are long while during December sampling when the height raised by leaves are less than 0.3m resuspension occur inside vegetation. During calm sea conditions (4th class: wave intensity less than 1 kWm^{-1}) resuspended component of flux is always absent in the PM. In all of the cases mentioned above, measurements at the unvegetated sandy station (UB) show the constant presence and greater magnitude of resuspension.

Grain-size determination was performed on samples recovered after four storms (surveys 1, 2, 4 and 9). Table 3 shows the frequency of main sediment classes (gravel, sand and mud), while Fig. 7 represents the grain-size distributions in a synoptic scheme for comparison with bed shear stress and rainfall. During survey 1, the bed shear stress induced by waves exceeds the threshold of 5ϕ grain size (Fig.7a), which corresponds to the peak of sediment distribution, further enhanced by rain contribution (34 mm in 24 hours).

Station	Elevation	Survey 1 (25-30/10/2015)			Survey 2 (16/11-03/12/2015)			Survey 4 (25/04-05/05/2016)			Survey 9 (12-20/09/2016)		
		Gravel	Sand	Mud	Gravel	Sand	Mud	Gravel	Sand	Mud	Gravel	Sand	Mud
PM	0.3	0	38	62	25.75	58.1	16.15	0	77.47	22.53	0	51.57	48.43
	0.8	0	35.3	64.7	18.01	65.16	16.83	0	49.98	50.02	0	47.3	52.7
	1.3	0	28.7	71.3	1.33	71.3	27.46	0	49.5	50.5	0	48	52
SP	0.3	0	31.5	68.5	15.67	67.33	17	10.49	53.47	36.04	0	42.81	57.19
	0.8	0	29.7	70.3	10.55	67.14	22.3	0	59.41	40.59	0	45.18	54.82
	1.3	0	26.9	73.1	2.22	65.25	32.51	0	48.65	51.35	0	37.9	62.1
UB	0.3	-	-	-	-	-	-	-	-	-	1	58.83	40.17
	0.8	-	-	-	-	-	-	-	-	-	0	45.27	54.73
	1.3	-	-	-	-	-	-	-	-	-	0	44.13	55.87

Table 3 Frequency of gravel, sand and mud fractions of trap samples

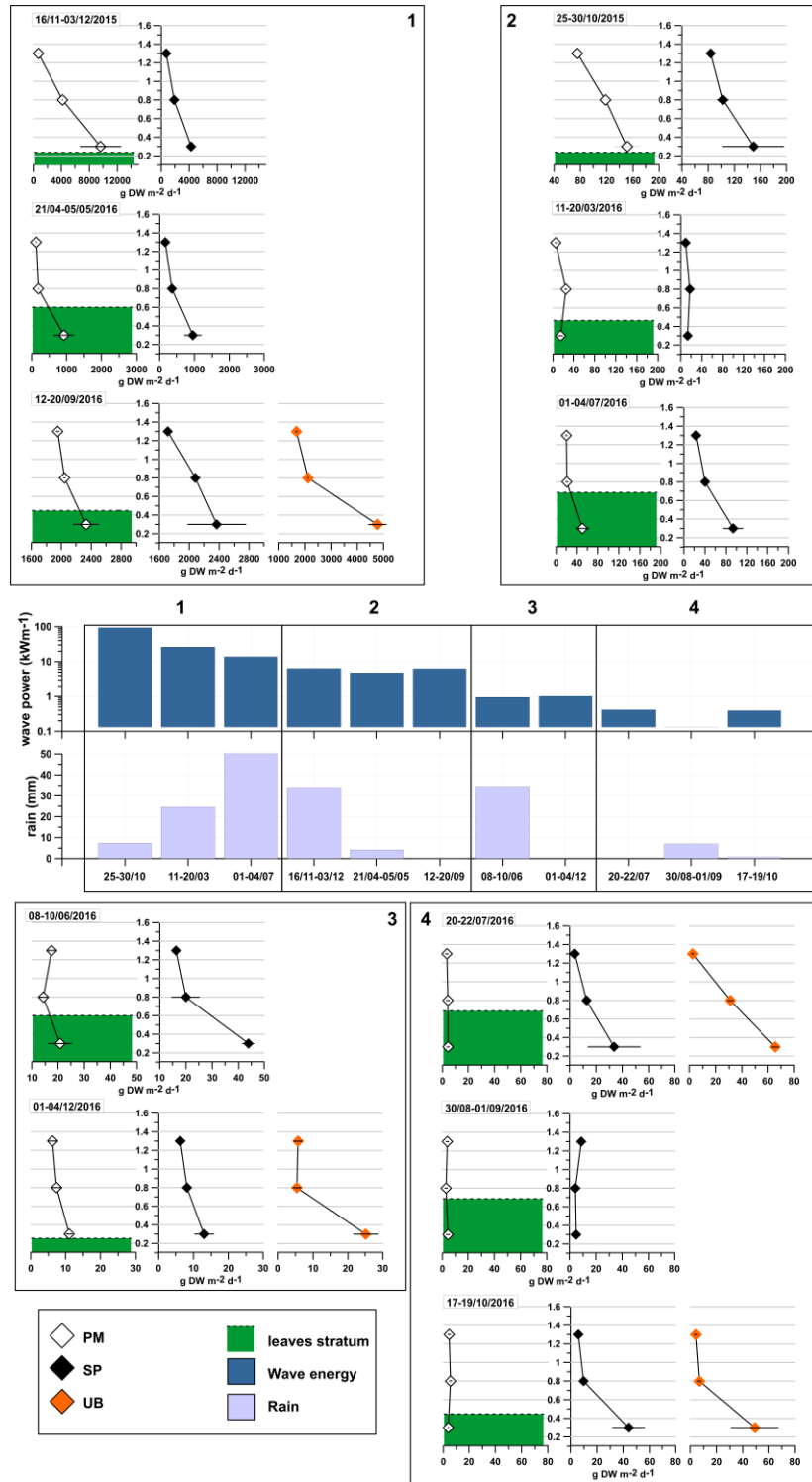


Fig.6 Sedimentary flux (x-axis) measured at progressive distances from the seabed (y-axis) within *P. oceanica* (PM), sand patch (SP) and unvegetated bottom (UB) from October 2015 to December 2016. The surveys were grouped into intensity classes as defined in table 2. The symbols indicate the mean, while the bars indicate the standard deviations of the runs. The dotted line that limits the green area indicates the height reached by leaves of *P. oceanica*.

The shape of the frequency distribution does not change along the vertical profile; slight inflections are only visible in the bottom trap (0.3 m) of both stations around 2ϕ , which is attributable to the weak resuspension of the coarse sediment fraction (Fig.7b). The sand concentration at the different levels above the sea bed decreases 10% upward at the PM station, while at the SP station, the decrease is about 5%. The absence of a marked variation in the distributions of stations PM and SP is also apparent from survey 2. In both surveys 1 and 2, *P. oceanica* was in the period of a short-shoot-length phase, which is typical of autumn. During survey 2, the huge shear stress induced by storm waves was able to move the coarse fraction, which was trapped at all elevations, indicating that resuspended particles moved at least up to 1.3 m (Fig.7 b,c). Moreover, strong currents were developed during storms, digging the seabed and causing the outcropping of bedrock in SP as described before (Fig.3b).

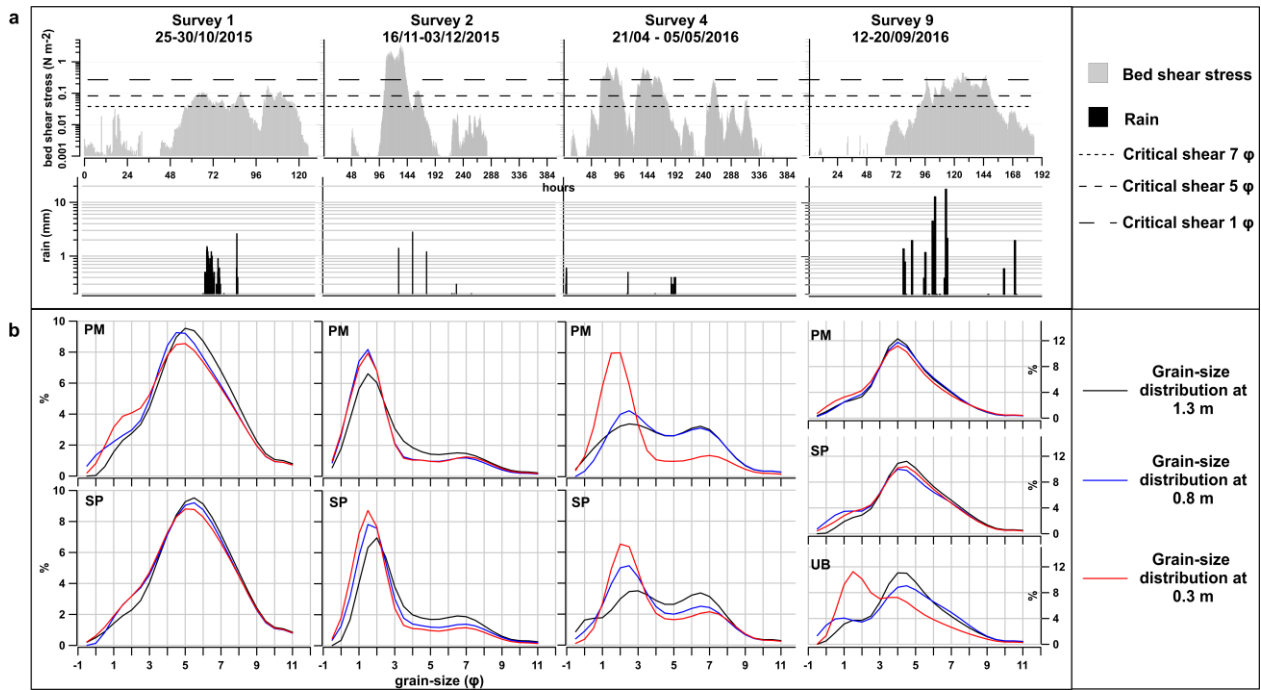


Fig.7 Summary diagram of the results. a) In the top, grey bars represent the wave-induced bed shear stress computed from wave data and dotted lines indicate threshold of motion for different grain-size defined in the legend; down, black bars indicate hourly precipitation occurred during surveys; b) grain size distributions of trap samples.

Grain-size distributions feature a sudden fall in the peak at the PM station compared to the gradual lowering found in the SP station. Moreover, the gravel fraction shows a larger decrease along the vertical profile in PM (24%) than the 13% observed in SP, where a greater amount of gravel was also found in the high trap (Table 3 and Fig.7c).

Survey 4 was carried out during a long-leaves phase (Fig.3c): the storm that occurred during the survey induced a bed shear stress that was able to trigger resuspension of the coarse component as highlighted by the highest modal peak of the grain-size distribution of bottom traps in both the PM and SP stations (Fig.7a, b). Considering that the gravel component (Table 3) was collected only at the SP station, we can infer a different energetic regime between stations. The coarse mode at the SP station gradually decreases along the vertical profile, while at the PM station, it undergoes a sudden decay, leading to the balance with the fine mode already at the intermediate elevation (0.8 m) (Fig.7b). Furthermore, along the vertical profile, the sandy fraction has a larger decrease in PM (28%) than SP (4.8%) (Table 3).

Although during survey 9 the bed shear stress triggered by the storm exceeded the threshold of the coarsest component, the coarse mode was significantly captured only in the bottom trap of UB station, which was also characterised by gravel traces (1%) (Table 3). In the highest traps, the coarse component is clearly subordinate, although it is still observable as a secondary mode at -0.8 m and as an inflection at 1.3 m (Fig.7b). In stations SP and PM, the grain mode is placed around 4.5 phi, while a coarser secondary component emerges just as a slight inflection on the bottom trap of the SP station (Fig.7b). This survey was affected by two further fundamental factors as a significant precipitation of 50 mm of rainfall in 24 hours and leaf litter covering the seabed (Fig.3d), which probably further constrained the sedimentary dynamics.

<i>Station</i>	<i>Trap elevation (m)</i>	<i>Ct</i>		<i>Rainfall</i>	
		<i>R</i>	<i>p-val</i>	<i>R</i>	<i>p-val</i>
PM	0.3	0.85	<0.001	0.36	0.27
	0.8	0.83	0.001	0.51	0.09
	1.3	0.31	0.32	0.65	0.02
SP	0.3	0.86	<0.001	0.56	0.06
	0.8	0.67	0.02	0.63	0.04
	1.3	0.38	0.22	0.65	0.02

Table 4 Pearson correlation coefficients and related probabilities of the relationships between sedimentary flux measured at different elevation vs transport capacity (*Ct*) and rainfall.

The evaluation of the relationships among transport capacity (C_t) of wave-induced bed shear stress, precipitation and sedimentation flux was made using Pearson's correlation coefficients (Table 4). Correlation with cumulative rainfall was made considering the sedimentation flux of the only-suspended sediment fraction ($> 3\phi$) represented by the secondary mode of bed sediment grain-size distribution, linked mainly to mainland run-off. This fraction is directly determined on trap samples analysed for grain-size, whereas for those samples with very scarce trapped material, the sediment texture was reasonably considered entirely larger than 3ϕ .

The results, reported in Table 4, show significant correlation in both stations between transport capacity (C_t) and total sedimentation flux, which loses significance in the highest traps (1.3 m).

Correlation of C_t and Fr , which is driven only by wave effect on the bottom, indicates larger correlation in SP station ($R = 0.95$; $p < 0.001$) than PM ($R = 0.91$; $p < 0.001$).

The correlation with rainfall (Table 4) in both stations is significant only in traps placed at 1.3m above the seabed while only in SP the significance occurs also at the intermediate level (0.8 m). Moreover, in both stations over time, the Signed Rank Test, applied to Fp and sedimentation flux of fraction $> 3\phi$ at 1.3m traps, shows no statistical differences ($p > 0.83$).

4.5 Discussion

The architecture of *P. oceanica* meadow at the study site exhibits, at the depth of sampling stations, a cover of 69% where gaps are composed by patches of sand and rocks and shoot density between 289 and 309 shoots m^{-2} . Sediments of sand patch are composed mainly by biogenic component which is the result of the biological activity of organisms living in the *P. oceanica* ecosystem and in the surrounding substrate (infralittoral and mesolittoral rocks). The *P. oceanica* began to grow progressively from winter to summer, during which it reached its maximum extension. On the contrary, *P. oceanica* sheds leaves from late summer to autumn, as observed in other Mediterranean coastal areas (Mateo and Romero 1996), causing the accumulation of leaf litter on the seabed, which also covers the adjacent unvegetated areas. The leaf litter remains on the seabed until the flow energy is not able to transport it away; after storms, they are usually deposited on the beachface with the formation of seagrass beach-cast leaf litter deposits, known as "banquettes" (Boudouresque et al. 2015) in Mediterranean Sea. The variation of the textural composition of bed sediments that result in the enrichment of sand and mud fractions during spring and summer is according to the growth of leaves. This result indicates how the growth of leaves increases the effect of energy reduction at the

bottom, favouring fine particle deposition. By comparing the depositional rates at different elevations from the seabed in the different stations and over the time, we observed significant differences between the patch and vegetation as well as observed between the bare sand (UB) and the meadow. The variations induced by presence and absence of seagrass occur inside a layer thickness of 0.8 m.

The measured depositional rates, in proximity to the bottom, were compared with others collected in previous studies (Table 5). The maximum value recorded in this study is reasonably larger than the others, considering the depth where the measurements were made. In shallow water, waves have a greater probability to induce sediment transport. In Table 5, we did not report flux data obtained during survey 2, when a huge storm occurred. During that survey, the maximum depositional rate was $9640 \pm 2848 \text{ g DW m}^{-2} \text{d}^{-1}$ in the PM station and $4275 \pm 335 \text{ g DW m}^{-2} \text{d}^{-1}$ in the SP station, highlighting a larger depositional rate inside the canopies.

Reference	Max	Min	Depth	Bottom
Burns et al. 1985	5.3	0.2	100	Water column
Monaco et al. 1990	181	2.7	10	Water column
Buscail et al. 1990	171(2379)	8.3	25	Water column
Bavestrello et al. 1995	17.5	2.5	15	Rock
Bavestrello et al. 1995	20	2.5	20	Rock
Bavestrello et al. 1995	20	2.5	25	Rock
Charles et al. 1995	107	0.6	18	Sand
Gremaire et al. 1997	318	0.6	18	Sand
Gacia and Duarte 2001	494	1.5	15	Sand
This study	5000	23.08	7	Sand
Dauby et al. 1995	10(40)	0.3	36	<i>Posidonia oceanica</i>
Gacia and Duarte 2001	215	2	15	<i>Posidonia oceanica</i>
This study	2520	3.58	7	<i>Posidonia oceanica</i>

Table 5 Summary of depositional rate ($\text{gDWm}^{-2}\text{d}^{-1}$) measured in coastal environment of previous and present studies.

The near-bed vertical sedimentation fluxes show the dominance of the resuspension phenomena which is frequent inside the vegetation (54%) and it is always linked to high energy events and modulated by the length of leaves. The high frequency of resuspension process inside the vegetation

in shallow water is due to the larger interaction of waves with the bottom and by the “*monami*” effect that enhances the penetration of turbulent stress into the canopy (Ghisalberti and Nepf 2002).

Between the canopy and the sand patch, marked differences of sedimentary flux occur in presence of long leaves. Comparing surveys with similar wave conditions during which the resuspended flux decreases by about 52% and 100% with the increase of the length of leaves. During calm sea conditions vegetation totally prevents resuspension except when the leaves are less than 0.3-m-long, while during storm events less than 10 kWm^{-1} the lengthening of leaves of 0.5m reduces resuspended component of about 70%.

Most of the wave-height decay occurred within the first few metres of the meadow, as observed in the flume experiment (Manca et al. 2012), and in natural shallow seagrass beds (Bradley and Houser 2009). Therefore, waves are also generally attenuated by vegetation when they travel over a sand patch inside the meadow rather than over an open unvegetated area. The sand patch shows intermediate features when compared to an open unvegetated area and the intermediate response of the SP station is also visible when comparing the contribution of resuspended flux to the total depositional rate. The average contribution amounts to 72% in the PM station, 81% in SP and 94% in UB.

This value is less than that observed within the meadow of Fanal Point (85%) by Gacia and Duarte (2001); this is probably due to the different distances from the coastline, which could determine a greater influence of mainland run-off on sedimentary balance. In this study, the flux of the fine fraction component (grain mode 2) during storm events fluctuates between 20% and 60% of the total sedimentary flux at the bottom. At an elevation of 1.3 m from the bottom, the suspended component, which dominates the total sedimentation flux at this height, is correlated to the rainfall that directly governs mainland run-off in the study site. The settling flux of fine particles over the meadow fluctuates within a wide range of $2.48 - 1971 \text{ g DW m}^{-2}\text{d}^{-1}$, which is strictly dependent on the rain intensity.

During strong storm events the dynamic is complex and sedimentological analysis allowed to clarify the sedimentary processes. Grain-size analyses reveal additional evidences about the load capacity of waves in particle movement and demonstrate the trap effect induced by canopies that produce an increment of sedimentary flux inside the vegetation. The fine fraction of sediment, which is suspended during storms, undergoes deposition when the storm ends, while it is the dynamics of the coarse fraction during storm conditions that mark the variations of energy flux near the seabed. Survey 2 was the only survey where a storm drove an intense winnowing of the seabed sediment,

resuspending coarse material on the whole investigated sea layer and causing the outcrop of rocky substrata in the sand patch. The trap effect induced by vegetation is testified by the sudden fall in the peak of grain size distribution observed inside the canopy station compared to the gradual lowering found in the sand patch. This process is clear when the leaves are long while during short leaves phase (autumn) the process is weak. Long leaves in spring prevent the resuspension of the gravel bioclasts and induce a sharp decay of the coarse component peak along the vertical profile inside the vegetated station.

A very similar consideration concerns the late-summer period when leaf litter widely covers the seabed. Both the PM and SP stations are affected by a significant attenuation of the wave-induced bed shear stress, which is evident by the prevention of the coarse fraction resuspension. As a control, the same component is found in the UB station free from leaf litter. Similar to “banquettes”, which are constituted by accumulation of seagrass necromass (leaves and rhizome), they are able to dissipate some portion of storm energy (Simeone and De Falco 2012) and to suppress wave run-up and to limit beach change on the low-energy condition (Nordstrom and Jackson 2012), the leaf litter deposited on the seafloor buffers sediment particle, thus acting as a temporary armouring that prevents resuspension. This feature could be added to the biogeomorphology of *P. oceanica* summarized by Vacchi et al. (2016).

The annual dynamics of sedimentary processes observed in shallow waters extends the previous finding in coastal areas at larger depths (Gacia and Duarte 2001). These experimental evidences in natural conditions are in agreement with results obtained by flume experiments: Stratigaki et al. (2011) and Manca et al. (2012) studied the wave attenuation induced by a seagrass bed with a density of artificial shoots within a range $180 - 360 \text{ shoot m}^{-2}$, which is comparable with the density of natural meadow of this study ($260 - 312 \text{ shoot m}^{-2}$). Flume experiments have demonstrated the ability of meadows to reduce shear stress at the bottom, especially if caused by low energy waves. This corresponds with our results when during normal wave conditions the canopies produce clear attenuation or prevention of resuspension process.

In this study we found that the trap effect induced by canopies might act in two ways depending on the hydrodynamic regime near the bed. During weak hydrodynamic conditions, the dominant process is the attenuation of resuspension induced by canopies, while over a threshold of transport capacity of waves, the trap effect of canopies translates into an increment of depositional rate fed by the advection of coarse material, which is resuspended from the adjacent unvegetated patches testifying the capacity of the meadow to enhance the deposition (Scoffin 1970; Short and Short 1984;

Walker et al. 1996), but it also gives further confirmation regarding the complexity and variability of the particle-trapping process (Gacia and Duarte 2001).

4.6 Conclusions

This study expands the current knowledge regarding the role of *P. oceanica* meadow on sedimentary processes highlighting its role on the sedimentation processes as a function of different energetic regime and different phases of *P. oceanica* growth. The analysis of sediment texture has been fundamental for the understanding of sedimentary processes in shallow waters where energetic regime of flows have a large fluctuation. The resuspension process dominates at 7-meter depth and is attenuated by vegetation by more than 50% during the phase of maximum growth phase of leaves. Records on UB station suggest that waves that propagated over a vegetated field bottom are generally damped compared to an unvegetated bottom, and in a fragmented meadow, the local wave interaction caused by the sudden change in bottom friction encountered by the waves produce more resuspension in the sand patch. *P. oceanica* mainly buffers resuspension mostly during calm conditions and long leaves but in the presence of high energetic regime of flow near the bottom the canopies favour the deposition of particles transported from adjacent unvegetated area which is testified by sedimentological signatures. During late Summer the leaf litter deposited on the unvegetated seafloor buffers seabed sediment particles preventing resuspension at least for the duration of a storm able to induce drag forces that carry away all of the leaf litter. In this study, we add some elements that lead to an improvement in the knowledge of the sedimentary dynamics affecting the *P. oceanica* meadow systems.

5. Rare and alien species associated with *Posidonia oceanica*

5.1 Addition to the knowledge on *Acromegalomma messapicum* (Giangrande & Licciano, 2007)

(Annelida, Sabellidae) Giangrande, A., Mancini, E., Tiralongo, F., and Licciano M, 2018

The European Zoological Journal (TIZO). DOI: 10.1080/24750263.2018.1437227.(IN PRESS).

Abstract

The genus *Acromegalomma* has been recently introduced as *nomen novum* for the polychaete genus *Megalomma* Johansson, 1926. Recently specimens of *A. messapicum* were collected from Tyrrhenian coasts and re-collected from the type locality (Brindisi) allowing to examine additional fresh material and to add some useful morphological and biological information to the original description. Present data widens the distribution of the species. The possibility to examine several specimens of *A. messapicum* even collected in different areas, allowed to certainly state the absence of variability as concerns both the radiolar eyes distribution and the collar shape. The new findings revealed a colouration pattern present in the thorax and in the branchial crown, as well as the presence of large pygidial eyes previously not reported. Specimens have very broadly hooded chaetae, especially at the beginning of the abdomen, becoming more slender and therefore narrowly hooded, proceeding towards the end of the abdomen. This could explain the wrong statement in the original description of the presence of abdominal narrowly hooded chaetae as characterizing *A. messapicum*.

Present data also allowed some biological observations. *Acromegalomma messapicum* is gonocoric with eggs measuring about 120 µm in diameter. Most of the specimens were collected in cold months but ripe specimens were found in warm months.

In addition a modified scheme of groups of *Acromegalomma* species previously proposed by different authors is given, where some taxa have been moved to different groups on the basis of a new interpretation of the collar features.

Keywords: *Sabellidae*; *Acromegalomma*; *A. messapicum*; *morphology*; *biology*.

5.1.1 Introduction

The genus *Acromegalomma*, recently introduced as a replacement name for the polychaete genus *Megalomma* Johansson, 1926 (Annelida, Sabellidae) (Gil & Nishi, 2017), is characterized by the presence of large terminal compound eyes in at least the dorsal-most radioles (Fitzhugh 1989). Eye development and distribution together with the features of the collar are considered important diagnostic characters. According to the extent to which compound eyes occur in the radioles, the mid-dorsal collar margins are fused to the faecal groove, and the dorsolateral margins of the collar form pockets, species of the genus were grouped by Knight-Jones (1997) into two main groups and four artificial categories. The number of categories, however, increased with the addition of new descriptions and increasing species variability (Capa & Murray 2009). Tovar-Hernández & Carrera-Parra (2011) tried to individuate a combination of morphological features regarding the shape of the collar dorsal margin and proposed four stages of development of dorsal lappets. Later, this scheme was modified by Giangrande et al. (2015) which included more intermediate steps towards the progressive reduction of dorsal lappets and dorsal pockets.

The diagnosis of the genus was emended several times: Fitzhugh (2003) stated that radiolar appendages of the dorsal lips do not have an internal skeleton, and that dorsal pinnular appendages can be either present or absent. Tovar-Hernández & Salazar-Vallejo (2008) added the possible presence of a caruncle, interrampal eyespots and a long dorsalmost pair of radioles. Capa & Murray (2009) provided a good synthesis of the form and development of the dorsal margins of collar, and the chaetal shape, describing an additional feature present in the peristomium (keel), in addition, the presence of dorsal lappets in the collar and the shape of abdominal chaetae were considered taxonomically discriminant features. The variation of the collar margin was formalized by Tovar-Hernández & Carrera Parra (2011) and later revised by Giangrande et al. (2015). Capa & Murray (2009) also proposed a cladistic analysis to test the validity of the previous artificial classification by Knight-Jones (1997). According to these authors, the presence of dorsal collar margins fused to the faecal groove and the presence of pockets characterized an apomorphic clade of *Acromegalomma* species corresponding to Group 1 sensu Knight-Jones (1997), while the basal topology included species with dorsal collar margins not fused to the faecal groove traditionally recognized within Group 2. This hypothesis, however, was not supported by further analysis performed by Tovar Hernández & Carrera-Parra (2011) who found species nested in group 2 comprising one of the most derived clades. Thus, the phylogeny

of the genus still needs to be better understood. However, the collar dorsally fused to the dorsal groove is a feature widely distributed in most of the species described up to now, therefore it is likely that the hypothesis by Tovar- Hernández & Carrera Parra (2011) is the most acceptable.

Acromegalomma genus includes 36 species properly named from world-wide localities (Giangrande & Licciano 2008; Capa & Murray 2009; Tovar- Hernández & Carrera Parra 2011; Mikac et al. 2013; Giangrande et al. 2015; Gil and Nishi 2017). Several authors revised the taxa present in the Mediterranean basin (Giangrande & Licciano 2008; Mikac et al. 2013; Giangrande et al. 2015), where up to now 6 species have been reported: *Acromegalomma vesiculosum* (Montagu 1815), *Acromegalomma lanigera* (Grube 1846), *Acromegalomma cfr claparedei* (Gravier 1908), *Acromegalomma messapicum* (Giangrande and Licciano 2008), and *Acromegalomma pseudogesae* (Mikac et al. 2013); *Acromegalomma adriaticum* (Giangrande et al. 2015), and *Acromegalomma longoventralis* (Giangrande et al. 2015). All these taxa, except for *A. vesiculosum*, were collected along the Italian coasts. *Acromegalomma pseudogesae* and *A. adriaticum* are endemic to the northern Adriatic Sea, *A. messapicum* and *A. cfr claparedei*, are restricted to the southern Adriatic, whereas *A. lanigera* and *A. longoventralis* are more widely distributed.

The species *A. messapicum* was described examining specimens colonizing *Posidonia oceanica* ryzhomes and collected in 1987 along the south Adriatic coasts (Giangrande et al. 2008). This material appeared badly preserved and with most of the specimens not entire. For this reason some features, especially that concerning the collar, were poorly described and the iconography was not well representative. In addition, no indication on intraspecific variability was possible. This often occurs in the description of *Acromegalomma* taxa because in most cases are found with a relatively low number of specimens (Capa & Murray 2009).

Recently specimens of *A. messapicum* were collected from Tyrrhenian coasts and re-collected from the type locality allowing to examine additional fresh material and to add some useful morphological and biological information to the original description.

Moreover, previous groups of species separated considering some traditionally used characters, were revised on the basis of the new interpretation of the collar features by Giangrande et al. (2015).

5.1.2 Material and methods

Specimens of *A. messapicum* from Tyrrhenian Sea was collected in different times (October, March, May and August) during the years 2015-2016 on *P. oceanica* meadow, at 7 m depth on the coastal area of Civitavecchia (North Latium, central Italy , 42.08436° N, 11.79900° E) (Fig1). Material from South Adriatic Sea (Fig 1) was collected along the coast of Brindisi (40°38'18"N 17°56'45"E). However, *A. messapicum* specimens were found only in material collected in July 2010, at a depth of 5 m.

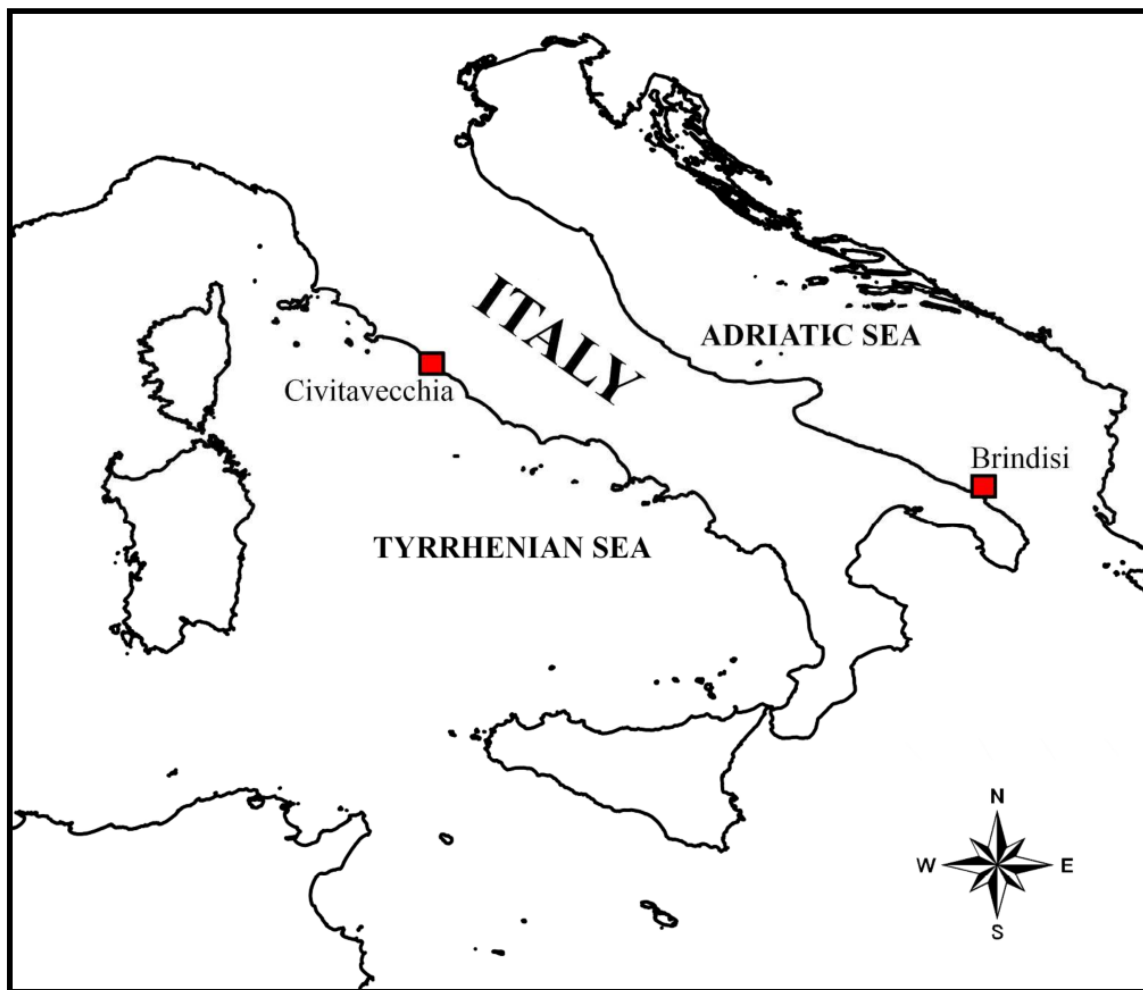


Fig.1 Map of the collecting sites

In both sampling sites worms were extracted from rhizomes collected by scuba diver by means of corers. The *Acromegalomma* specimens were fixed in 5% buffered formaldehyde seawater solution

and preserved in 70% ethanol. For each specimen, the diagnostic characters were examined. Drawings were made with the aid of a camera lucida attached to stereo and compound microscopes; photographs were taken using a stereomicroscope equipped with a Nikon Coolpix 990 camera.

Staining patterns were obtained using methyl green stain, while features of the collar were evidenced utilising a textile fibre identification stain (Shirlastain A).

Each specimen was measured and examined for the coelom content to individuate gametes.

5.1.3 Results

GENUS *Acromegalomma* Gil & Nishi 2017

Branchiomma [not K  lliker, 1858] — Clapar  de 1869: 162–163.

Megalomma [junior homonym, not Westwood, 1842] — Johansson 1926: 9–10; Johansson 1927: 130; Perkins 1984: 351–352; Fitzhugh 1989: 76; Knight-Jones 1997: 314; Fitzhugh 2003: 2013: 1514; Capa et al. 2014: 27–28; Giangrande et al. 2015: 522–523.

Type species: *Branchiomma kollikeri* Clapar  de 1869 (junior synonym of *Sabella lanigera* Grube 1846), according to recommendation 60A of the ICZN (1999). Type by monotypy, established by Johansson (1926).

Genus diagnosis:

Medium to large-sized species, with numerous radioles, palmate membrane and radiolar flanges absent. One or more pairs of compound eyes located on the inner radiolar margin, one terminal compound eye per radiole. Dorsal lips triangular, with radiolar appendage indicated by longitudinal ridge or “mid-rib” along entire length; distinct blood vessel and radiolar sheath tissue extending through length of appendages, without a branchial skeleton extension; dorsal pinnular appendages present or absent. Ventral lips and parallel lamellae present, usually inside branchial lobes and not visible externally. Posterior peristomial ring collar present. Inferior thoracic notochaete broadly hooded. Abdominal neurochaetal fascicles with elongate narrowly hooded chaetae. Thoracic uncini avicular with numerous very small teeth above the main fang, breast well developed, and a variable length of the handle. Companion chaetae with very thin distal ends perpendicular to the shaft. Abdominal uncini similar to thoracic ones, but with shorter handle.

Remarks:

The internal structures of the crown are very variable within the genus, starting from the length of dorsal lips, and the presence or absence of dorsal pinnular appendages. High variable are the shape of the ventral lips and associated structures. Ventral lips can be more or less rounded and in some species appear very elongated, as in the case of *A. longoventralis*, *A. phyllisae* (Capa & Murray 2009), *A. heterops* (Perkins 1984), *A. coloratum* (Chamberlin 1919), *A. bioculatum* (Ehlers 1887), *A. splendidum* (Moore 1905) and *A. georgense* (Tovar-Hernández & Carrera- Parra 2011). Some species also possess ventral sacs located inside the branchial lobes and not visible externally, as occurs in *Sabella* genus. According to Giangrande et al. (2015), the collar can be: fused to faecal groove with spatulate dorsal lappets covering the junction of the branchial crown, and with deep dorsal pockets; fused to faecal groove with dorsal lappets not covering the junction of the branchial crown, but still with deep dorsal pockets; fused to faecal groove, without dorsal lappets, and with dorsal pockets; fused to faecal groove, without dorsal lappets, and with scarcely developed dorsal pockets leaving uncovered the anterior peristomial ring; fused to faecal groove without both dorsal lappets and pockets, leaving uncovered the anterior peristomial ring; not fused to faecal groove. In Table I a modified scheme of groups proposed by Knight-Jones (1997) and subsequently revised by Capa & Murray (2009) is reported.

Some taxa have been moved to different groups after re-interpretation of the collar fusion, lappets and presence of pockets as suggested by Giangrande et al (2015). However, only 2 states were considered for eye distribution because, as pointed out by Tovar-Hernández & Carrera- Parra (2011), this last feature is too variable with up to 6 states. Therefore the groups are defined especially by the shape of the collar. The Group 1 sensu Knight-Jones and Capa & Murray (2009) (species with dorsal collar margin fused) split into 4 subgroups according to the development of the dorsal lappets. The Group 2 (dorsal collar margins not fused) although containing few species split into 4 groups as well and not in 5 as reported by Capa & Murray (2009), because *A. interrupta* and *A. kaikourense* are both placed in group 2A due to the eye distribution state here utilized.

Three types of inferior thoracic notochaetae were outlined: A subspatulate or broadly hooded with a long narrow tip; B subspatulate broadly hooded with a progressively tapering distal end; and C paleate with distal end surmounted by a mucronate tip (Tovar-Hernández & Carrera Parra 2011; Giangrande et al. 2015). Abdominal neurochaetae have been described as elongated, narrowly hooded chaetae (Perkins 1984; Fitzhugh 1989, 2003; Tovar-Hernández & Salazar- Vallejo 2008) but some species can have broadly hooded with long tips. According to Capa & Murray (2009) the length of the

thoracic uncini handle could vary from medium length (same length as the distance from main fang to breast) to long (twice the length of the distance from main fang to breast). However, Giangrande et al. (2015) proposed three different states showing a different length of the handle measured relatively to the height of the uncinus. The handle can be defined as long when the ratio (l/h) is > 1 , medium when the ratio is $= 1$, and short when the ratio is < 1 .

Lastly the thoracic companion chaetae possess a proximal shaft or handle, generally similar in length to the thoracic uncini handle, and a distal membrane that has been described as teardrop- shaped by most authors (Perkins 1984; Fitzhugh 1989, 2002, 2003), or as roughly symmetrical (Fitzhugh 1989; Tovar-Hernández & Salazar-Vallejo 2006; Giangrande et al. 2007), or as asymmetrical (Knight-Jones 1997). There is some variation in the form of the companion chaetae among different species, so also this character may be useful from a systematic point of view.

Group	Dorsal collar margin	Pockets	Dorsal lappets	Subdistal radiolar eyes	<i>Megalomma</i> species	Type locality
1-A	fused	present	present	most	<i>A. acrophthalmos</i> (Grube, 1878)	Philippines
	fused	present	present	most	<i>A. fauchaldi</i> Giangrande et al., 2007	Carrie Bow
	fused	present	present	most	<i>A. lanigera</i> (Grube, 1846)	Unknown (Mediterranean)
	fused	present	present	most	<i>A. perkinsi</i> Tovar-Hernández & Salazar-Vallejo, 2006	Florida
	fused	present	present	most	<i>A. suspiciens</i> (Ehlers, 1904)	New Zealand
	fused	present	present	most	<i>A. vesiculosum</i> (Montagu, 1815)	England
	fused	present	present	most	<i>A. longoventralis</i> Giangrande et al., 2015	Adriatic Sea (Rovignj)
1-B	fused	present	present	Less than half radiole number	<i>A. mashaense</i> (Gravier, 1908)	Red Sea
	fused	present	present	Less than half radiole number	<i>A. quadrolatum</i> (Willey, 1905)	Ceylon
1-C	fused	present	absent	most	<i>A. clapparedei</i> (Gravier, 1908)	Red Sea
	fused	present	absent	most	<i>A. carunculata</i> Tovar-Hernández & Salazar-Vallejo, 2008	Eastern Tropical Pacific
	fused	present	absent	most	<i>A. lobiferum</i> (Ehlers, 1887)	Florida
	fused	present	absent	most	<i>A. circumscriptum</i> (Moore, 1923)	California
	fused	present	absent	most	<i>A. multioculatum</i> Fitzhugh, 2002	Thailand
	fused	present	absent	most	<i>A. adriaticum</i> Giangrande et al., 2015	Adriatic Sea (Brindisi)
	fused	present	absent	most	<i>A. heterops</i> Perkins, 1984	Florida
1-D	fused	present	absent	most	<i>A. pacifici</i> (Grube, 1859)	Costarica
	fused	present	absent	Less than half radiole number	<i>A. splendidum</i> (Moore, 1905)	Alaska
	fused	present	absent	Less than half radiole number	<i>A. cinctum</i> Fitzhugh, 2003	Taiwan
	fused	present	absent	Less than half radiole number	<i>A. coloratum</i> (Chamberlin, 1919)	California
	fused	present	absent	Less than half radiole number	<i>A. modestum</i> (Quatrefages, 1866)	Perù
	fused	present	absent	Less than half radiole number	<i>A. roulei</i> (Gravier, 1908)	Perù
	fused	present	absent	Less than half radiole number	<i>A. inflata</i> Capa & Murray, 2009	New South Wales (Australia)
2-A	Not fused	present	absent	Less than half radiole number	<i>A. messapicum</i> Giangrande et al., 2008	Adriatic Sea (Brindisi)
	Not fused	present	absent	Less than half radiole number	<i>A. kaikourense</i> Knight-Jones, 1997	New Zealand
2-B	Not fused	absent	present	most	<i>A. interrupta</i> Capa & Murray, 2009	Queensland
2-C	Not fused	absent	absent	most	<i>A. nechamae</i> Knight-Jones, 1997	Red Sea
2-D	Not fused	absent	absent	Less than half radiole number	<i>A. trioculatum</i> Reish, 1968	Marshall Islands
	Not fused	absent	absent	Less than half radiole number	<i>A. bioculatum</i> (Ehlers, 1887)	Florida
	Not fused	absent	absent	Less than half radiole number	<i>A. gesae</i> Knight-Jones, 1997	El Salvador
	Not fused	absent	absent	Less than half radiole number	<i>A. pigmentum</i> Reish, 1963	California
	Not fused	absent	absent	Less than half radiole number	<i>A. miyukiae</i> Nishi, 1998	Thailand
	Not fused	absent	absent	Less than half radiole number	<i>A. georgiense</i> Tovar-Hernández & Salazar-Vallejo, 2011	Georgia (USA)
	Not fused	absent	absent	Less than half radiole number	<i>A. pseudogesae</i> Mikac et al., 2013	Adriatic Sea (Rovignj)

Tab 1: Groups of Acromegalomma species revised on the basis of the new interpretation of the collar features by Giangrande et al. (2015)

Acromegalomma messapicum Figure 2-3

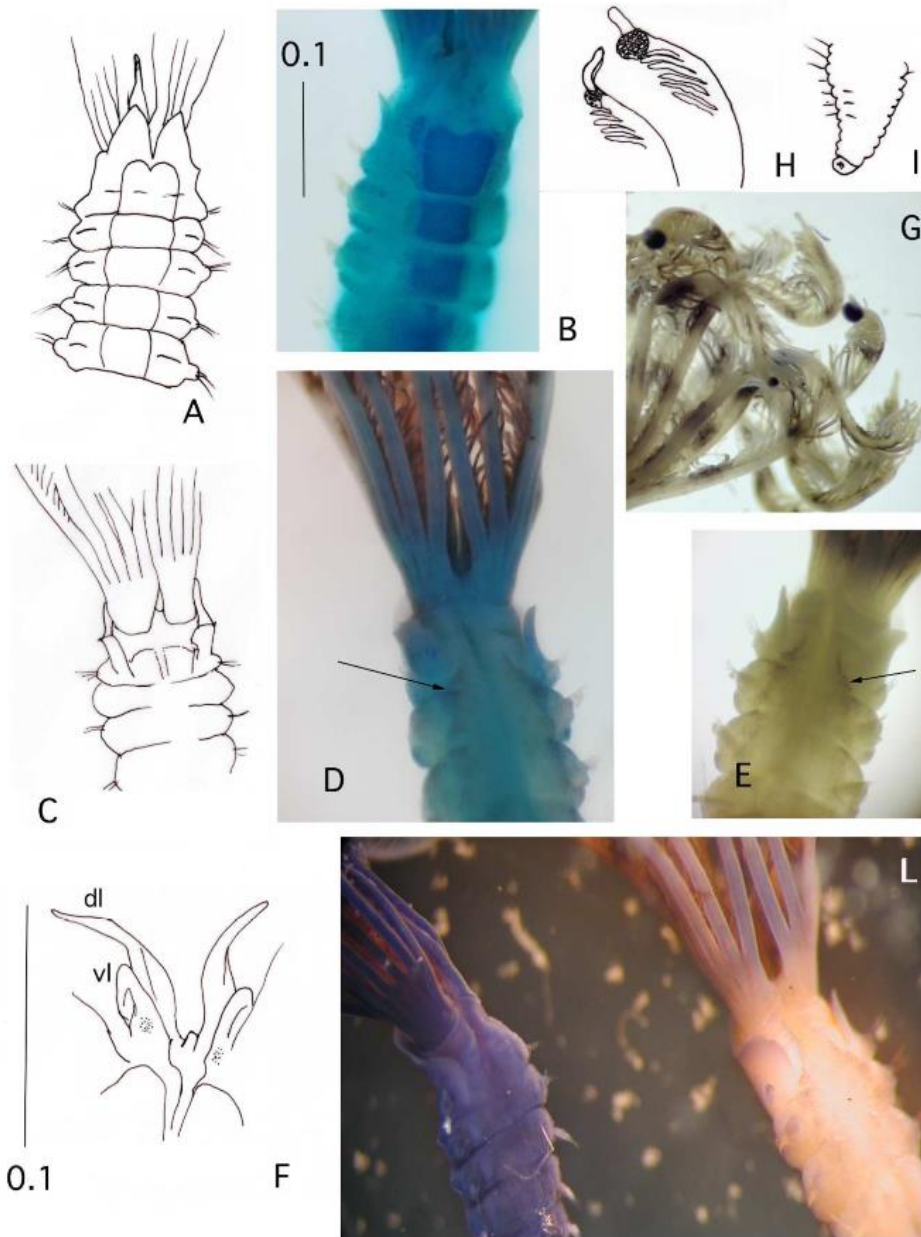


Fig.2 *Acromegalomma messapicum*. A) Anterior ventral view; B) Anterior ventral view methyl green pattern; C) Anterior dorsal view; D) Anterior dorsal view methyl green pattern; E) photograph of anterior dorsal view; Arrows indicate coloured spots evident both in methyl green coloured and in not coloured specimens; F) Internal structures of the crown. DL=dorsal lip with radiolar appendage; VL=ventral lip; G) Particular of the crown; H) Terminal eyes of the radioles, the larger one is referred to the dorsalmost radioles (First radiole), the smaller one to a lateral radiole; I) Pygidium; L) Comparison between a specimen from Adriatic Sea (on the left) and one from Thyrranian Sea (on the right). Specimens treated with SHIRLASTAN colourant.

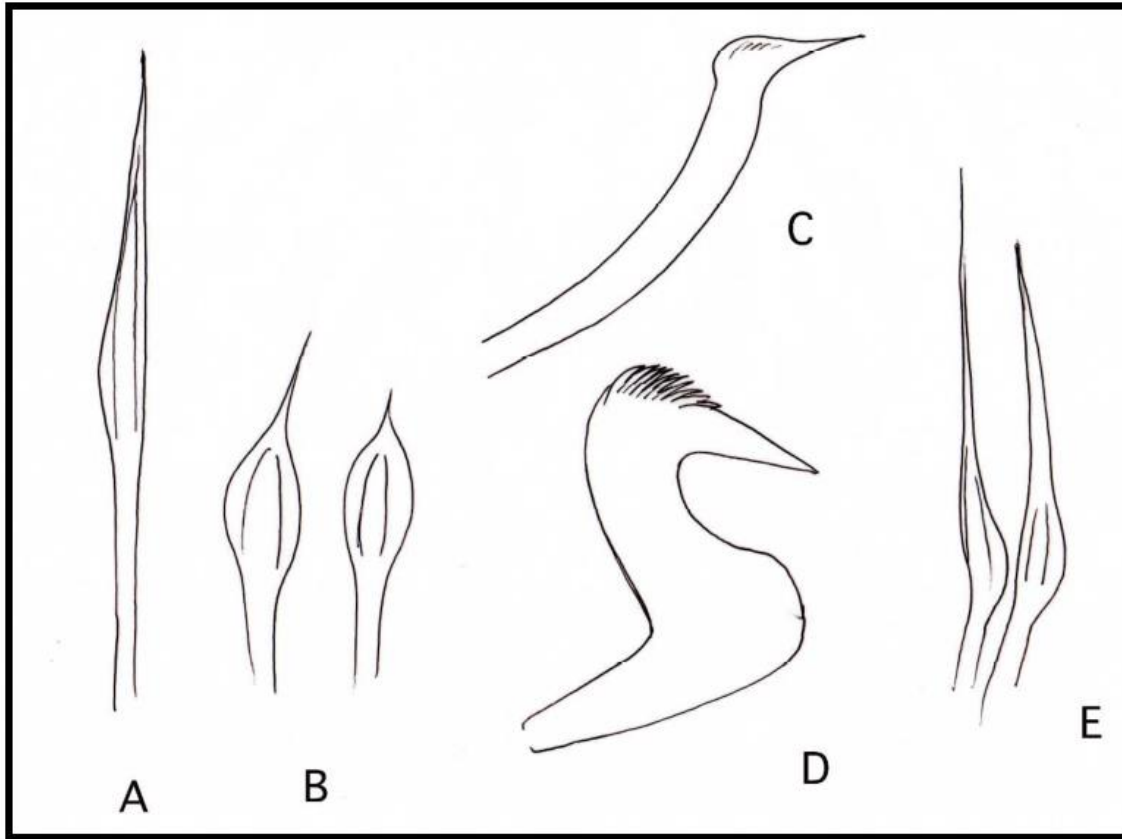


Fig 3: *Acromegalomma messapicum*. A) Thoracic notochaeta from superior fascicle; B) Thoracic notochaetae from inferior fascicle; C) Companion chaeta; D) Thoracic hook; E) Neurochaetae from an anterior abdominal

Material examined:

10 specimens from Tyrrhenian Sea, and 4 from Adriatic Sea.

The following description concerns Tyrrhenian material that was in very good condition: Specimens have from 7 to 9 thoracic chaetigers, being 8 the most common number, and from 20 to 55 abdominal chaetigers. Body length was 13.2 ± 1.4 mm (without branchial crown), 1.5 mm wide at chaetiger 4. Branchial crown length was 3.5 ± 0.7 mm. Dorsal margin of the collar fused to the faecal groove, leaving exposed the base of the crown, but also a large part of the peristomium, dorsal lappets absent, dorsal margin of the collar fused with the peristomium, but laterally forming small pockets (Figure 2 A, B, C, D). Dorsal collar showing brown spot colouration present also in all the thoracic chaetigers (Figure 2 D, E).

Collar oblique laterally, with a small lateral cleft becoming higher ventrally, with well-developed ventral lappets, pointed, not overlapped as long as the collar ventral shield, (Figure 2 A, B, L). Ventral shield of the first chaetiger squared, bilobed and longer twice the following shields, visible also without staining with methyl green (Figure 2 A, B). Dorsal lips pointed, with mid-rib, about 0.7 mm long, less than one quarter the length of the branchial crown, (Figure 2 F). Dorsal pinnular appendages present. Ventral lips long and rounded (Figure 2 F) terminating in parallel lamellae, but ventral sacs not detectable. From eight to nine pairs of radioles, without palmate membrane or flanges, with three pairs of brown coloured bands (Figure 2 G); radioles with several rows of cells and rounded margin. Dorsalmost radiole bearing large rounded eyes with a small free tip; (Figure 2 H); eyes absent on the following three radioles; other three radioles with smaller eyes degrading in size and with longer tip (Figure 2 H); last radioles without eyes. Length of the radioles degrading towards ventral side. Superior thoracic notochaetae elongate narrowly hooded, numbering four (Figure 3 A). Inferior thoracic notochaetae subspatulate broadly hooded with a progressively tapering distal end (Type B), numbering five (Figure 3 B). Thoracic uncini arranged in a short arc leaving a wide gap between torus and ventral shield (Figure 2 A, E) numbering 10, avicular, with a well-developed breast and short handle (Figure 3 D). Companion chaetae with roughly asymmetrical tips, teardrop-shaped membrane, and with a large dentate region (Figure 3 C). Abdominal uncini avicular, with manubrium shorter than the thoracic ones. Abdominal neurochaetae in two transversal rows of broadly hooded chaetae, wider hood in anterior abdominal chaetigers (Figure 3 E). Pygidium with eyes (Figure 2 I). The methyl green pattern was evidenced only in the ventral shield (Figure 2 D).

Examined worms were all adults and analysis of the coelom content revealed the species to be gonocoric. Gametes were detected only in specimens collected in warm months with a mean egg diameter of about 120 μm .

5.1.4 Conclusions

Results from the present study allowed a better description of the species. The fusion of the dorsal margin of the collar to the fecal groove, the presence of dorso-lateral pockets, and eyes located on dorsalmost and lateral radioles, suggest *A. messapicum* belonging to the Group 1 C sensu Knight-Jones). The finding of this new material allowed to confirm the peculiar distribution of the eyes within radioles of the species, that is consistent in all the examined specimens. Moreover, the better quality of fixation and preservation of this material compared to that of the type material, allowed to better

define collar features, which appeared consistent among specimens from both Tyrrhenian and Adriatic Sea. *Acromegalomma messapicum* collar is characterised by “dorsal margin fused to ventral groove without lappets, but with well defined dorsal pockets corresponding to a quite uncommon shape within the genus reported as “D state” by Giangrande et al. (2015). The dorsal margin of the collar is very low leaving uncovered the anterior peristomial ring, a condition almost corresponding to the “E state” sensu Giangrande et al (2015) which, however, considered a further reduction of the dorsal margin of the collar due to the lack of pockets. These authors, however, comparing *A. messapicum* with the newly described *A. adriaticum* in order to provide Keys for Mediterranean taxa, incorrectly reported *A. messapicum* as lacking “dorsal pockets”. Actually, the pockets are absent in *A. adriaticum* whilst *A. messapicum* distinguishes from the former species by the ventral margin of the collar which is very low, without lappets, but forming two visible ventral pockets. In the original description (Giangrande & Licciano 2008), the collar of *A. messapicum* was described as having two small pockets with bases not reaching the posterior end of the first chaetigers, whereas results from the present work show that the pockets are more developed and reach the first chaetiger.

The better preservation of these new findings revealed a colouration pattern present in the thorax and in the branchial crown, as well as the presence of large pygidial eyes previously not reported. As already pointed out, the lack of pigments on the radioles may be due to the long preservation period of the material from Brindisi that was utilized for the original description of the species (Giangrande et al. 2008).

As far as the shape of the abdominal chaetae, we found that specimens have very broadly hooded chaetae, especially at the beginning of the abdomen, becoming more slender and therefore narrowly hooded, proceeding towards the end of the abdomen. This could explain the wrong statement in the original description of the presence of abdominal narrowly hooded chaetae as characterizing *A. messapicum*.

According to Fitzhugh (2003), “diagnostic features” may be misinterpreted when a low number of specimens are examined. Examples are provided by some *Acromegalomma* species showing variation in the number and development of subdistal compound eyes, which may not necessarily be related to the size of the specimens (Nishi 1998). As highlighted by Capa & Murray (2009), usually a low number of specimens of *Acromegalomma* taxa are collected and recorded in ecological and taxonomic studies, therefore several *Acromegalomma* species described during the last few decades (Giangrande & Licciano 2008; Capa & Murray 2009; Tovar- Hernández & Carrera-Parra 2011; Mikac et al. 2013), including *A. messapicum*, were erected despite the paucity of the examined material preventing

to document for intraspecific variability. By contrast, intraspecific variability can be high when a large number of specimens are available, as reported for instance by Giangrande et al. (2012) for *A. lanigera* population from Faro Lake (South Italy, Ionian Sea). These authors highlighted how some diagnostic features, such as the shape and measurement of soft structures, are actually useless as they could reflect artefacts and deformations due to fixation and preservation processes.

The possibility to examine several specimens of *A. messapicum* even collected in different areas, allowed to certainly state the absence of variability as concerns both the radiolar eyes distribution and the collar shape.

Acromegalomma messapicum had been until now reported only for the South Adriatic Sea, where it was firstly collected in 1987, and more recently in 2010. Present data widens its distribution also to the Tyrrhenian Sea. In both the areas specimens were collected on *Posidonia* beds. The coastal morphology of the sampling site in the Tyrrhenian Sea (Civitavecchia) is characterized by dominance of terraces where the irregular seabed is composed by rocky outcrops and natural depression covered by sediments. *P. oceanica* meadow in the study site appears from 3 m depth and the architecture exhibits an almost continuous cover with the presence of several different sized sand patches. Density does not change over the year showing a quite constant range of 260-312 shoots m⁻². The sediment input from the mainland is scarce and represented only by few small streams originated from the nearby Tolfa Mountains. The bed sediment is composed by gravelly coarse sand where the gravel fraction (20 – 60%) is totally formed by bioclasts composed by shells and skeletal fragments. The coastal site is interested by moderate – high wave conditions, with sediments dynamic constrained by resuspension processes reaching the maximum in autumn and winter and the minimum in summer according to seasonal oscillation of wave intensity (Paladini de Mendoza et al. 2016).

Finally present data allowed some biological observations. *Acromegalomma messapicum* is gonocoric with eggs measuring about 120 µm in diameter. Most of the specimens were collected in cold months characterised by short leaves of *P. oceanica* and large resuspension of sediment induced by waves. Ripe specimens, however, were found in warm months when minimum sediment resuspension occurs and *P. oceanica* is in the maximum growth phase (Gacia & Duarte 2001). Up to now reproductive information on species of *Acromegalomma* genus is known for *A. vesiculosum* reported as free spawner species with seasonal cycle and eggs measuring 150 µm in diameter (Giangrande, 1997), for *A. pacifici* (Sanders 2014) gonocoric as well and with continue reproduction, and for *A. cinctum* (Fitzhugh 2003), which is reported to be dioecious, but also characterized by asexual reproduction.

5.2 New Mediterranean Biodiversity Records (December 2017)

(in *Mediterranean Marine Science* 18 (3):534-556.)

Abstract

The “New Mediterranean Biodiversity Records” series includes new records of marine species found in the Mediterranean basin and/or information on the spatial distribution of already established species of particular interest. The current article presents information on 20 marine taxa classified per country according to their geographic position in the Mediterranean, from west to east. The new records per ecoregion are as follows: Algeria: the first record of the fish *Etrumeus golanii* is reported along the Algerian coast. Tunisia: the alien jellyfish *Phyllorhiza punctata* is reported for the first time in the Gulf of Gabès. Italy: the first record of *Siganus rivulatus* in the Strait of Sicily and a new record of *Katsuwonus pelamis* from the central Tyrrhenian Sea are reported. The establishment of the isopod of the genus *Mesanthura* in the northern Tyrrhenian with some notes on its ecology are also included. Croatia: signs of establishment of the Lessepsian *Siganus luridus* and the occurrence of the alien mollusc *Rapana venosa* are reported. Albania: the first record of *Siganus luridus* the elasmobranch *Alopias superciliosus* and a recent sighting of the rare monk seal *Monachus monachus* in Albanian waters are given. Greece: signs of the establishment of the fish *Parupeneus forsskali* and of the ascidian *Hermania momus* in Hellenic Aegean waters are reported. Turkey: a new record of the fish *P. forsskali* and of the *Acareia* of the genus *Acaromantis* and *Simognathus* are given, while the first case of *Remora austral forsskali* is in association with delphinids and the occurrence of the sea star *Coscinasterias tenuispina* are reported. Also, the establishment of the two alien species *Isognomon legumen* and *Viriola* sp. [cf. *corrugata*] are presented. Egypt: the fish *Bathygobius cyclopterus* is reported for the first time in Mediterranean Sea waters. Also, a new record of *Pagellus bogaraveo* and a first record of *Seriola fasciata* in Egyptian Mediterranean waters are reported. Lebanon: the first record of *Dondice banyulensis* is presented.

First records of the genus *Mesanthura* (Isopoda: Anthuridae) of in the northern Tyrrhenian Sea and notes about its ecology.

5.1.1 Introduction

Biodiversity is probably a form of biological insurance that ecosystems adopt to face environmental fluctuations (Naeem & LI, 1997), and also an indicator for measuring ecosystem health. Natural and anthropogenic events shaped the biodiversity of the Mediterranean Sea (Bianchi & Morri, 2000) composing a biodiversity hot spot of global interest. Over the last years, scientific efforts to collect detailed biodiversity data have been intensified with exotic species attracting vivid interest.

In the context of the above, Mediterranean Marine Science, through a series of collective articles focusing on new Mediterranean biodiversity records, aims at a constant update and renewal of Mediterranean basin bio- diversity. This work presents new records per country according to their geographic position in the Mediterranean, from west to east.



Fig. 1: Locations of records of new species in the Mediterranean Sea presented in “New Mediterranean Biodiversity Records”. Details are presented in Table 1.

The location of the new records is depicted on a map (Fig.1). Altogether, new records are provided for 20 taxa (Table 1), belonging to five Phyla, namely Chordata (twelve records), Arthropoda (five records), Mollusca (two records), Cnidaria (one record) and Echinodermata (one record). The reports include a first record in the Mediterranean Sea, new distribution points for thirteen species and the

establishment of one alien species in Mediterranean areas. Furthermore, behavior patterns of *Remora australis* are discussed and evidence of the presence of monk seal *Monachus monachus* at different Ionian Sea sites is provided.

Taxon	SS	SC	Country	Location	LN
Phylum Chordata					
<i>Etrumeus golanii</i>	A	1.1	Algeria	Near Cherchell	1
<i>Katsuwonus pelamis</i>	N	3.1	Italy	Central Tyrrhenian Sea	3
<i>Siganus rivulatus</i>	A	3.2	Italy	Lampedusa harbour	4
<i>Siganus luridus</i>	A	4.1	Croatia	Molunat Bay	6
<i>Alopias superciliosus</i>	N	5.1	Albania	Dhermi (Vlorë)	8
<i>Parupeneus forsskali</i>	A	6.1	Greece	SE Rodos Isl	10
<i>Parupeneus forsskali</i>	A	7.1	Turkey	Muğla province	12
<i>Bathygobius cyclopterus</i>	A	8.1	Egypt	East of Suez Canal	18
<i>Pagellus bogaraveo</i>	N	8.2	Egypt	East of Suez Canal	19
<i>Seriola fasciata</i>	N	8.3	Egypt	off Alexandria	20
<i>Monachus monachus</i>	N	5.2	Albania	Albanian coasts	9
<i>Remora australis</i>	N	7.2	Turkey	Antalya Bay	13
<i>Herdmania momus</i>	A	6.1	Greece	SE Rhodes island	11
Phylum Arthropoda					
<i>Mesanthura</i> spp.	A	3.3	Italy	Northern Tyrrhenian	5
<i>Acaromantis</i> spp.	N	7.3	Turkey	Yakamoz Beach	14
<i>Simognathus</i> spp.	N	7.5	Turkey	Yakamoz Beach	15
Phylum Mollusca					
<i>Isognomon legumen</i>	A	7.5	Turkey	Dalyan, Iztuzu	16
<i>Viriola</i> sp. [cf. <i>corrugata</i>]	A	7.5	Turkey	Dalyan, Iztuzu	16
<i>Dondice banyulensis</i>	N	9.1	Lebanon	Tabarja	21
<i>Rapana venosa</i>	A	4.2	Croatia	Istrian coast	7
Phylum Cnidaria					
<i>Phyllorhiza punctata</i>	A	2.1	Tunisia	Gulf of Gabès	2
Phylum Echinodermata					
<i>Coscinasterias tenuispina</i>	N	7.6	Turkey	Mersin Bay	17

Table 1. Species included in “New Mediterranean Biodiversity Records (December 2017)”. SS = species status (A, alien; N, native), SC = subchapter, LN = location number as in Figure 1.

5.2.1 First records of the genus *Mesanthura* (Isopoda: Anthuridae) in the northern Tyrrhenian Sea and notes about its ecology.

Tiralongo, F., Paladini, F., Mancini E., (2017). New Mediterranean Biodiversity Records (December 2017). Mediterranean Marine Science 18 (3):534-556. DOI: 10.12681/mms.15823.

Abstract

Several specimens of *Mesanthura* sp. were collected from shoots and leaves of *Posidonia oceanica* in the northern Tyrrhenian Sea (Italy), near the harbour of Civitavecchia. Morphological and color-pattern analysis showed that the species (very similar to *Mesanthura romulea*) is the same of that found in recent years at Taranto (northern Ionian Sea, Italy) and Salerno (southern Tyrrhenian Sea, Italy). Our results represent the first record of the genus in the northern Tyrrhenian Sea and support the introduced origin and the establishment of this exotic species in the area.

Keywords: alien species, Isopoda, introduced species, Anthuridae, *Mesanthura*.

5.2.1.1 Introduction

Isopods of the genus *Mesanthura*, with about 45 species (Schotte *et al.*, 1995 onwards), belonging to the suprafamilial taxon of the Anthuridea. This latter group inhabits a great variety of marine habitats, from deep-sea soft bottoms to shallow waters with vegetation (Negoescu & Wägele, 1984); most species occur in shallow tropical waters (Negoescu, 1997). In Italian seas, the knowledge of the Anthuridea comes from the studies of Wägele (1979a, b, 1980, 1981a, b, c). In recent years, several studies (Gambi, 2001; Dappiano 2005; Lorenti 2006; Lorenti *et al.*, 2009) showed the presence of *Mesanthura* sp. from two Italian harbours: Taranto (northern Ionian Sea) and Salerno (southern Tyrrhenian Sea). These latter studies represent the first records of the genus *Mesanthura* from the Italian waters and western Mediterranean too. In the eastern part of the Basin, a relatively recent record of the genus was that of Samaan *et al.* (1989), in Egypt. Species identification of the genus *Mesanthura* is based both on dorsal color pattern and on some morphological characters. In this study, we have recorded for the first time several specimens of the genus along the coast of Civitavecchia (northern Tyrrhenian Sea), near the harbour area. From morphological and color-pattern analysis we can confirm that the species is the same of that found in recent years by Lorenti *et al.* (2009) in Italian seas.

5.2.1.2 Material and Methods

Specimens of *Mesanthura* were collected in the coastal area of Civitavecchia, near the harbour (42.08436° N, 11.79900° E). Sampling was performed during the year 2015-2016 at season scale (from autumn 2015 to summer 2016) on *Posidonia oceanica* meadow, at a depth of 7 m. For each of the four sampling days, forty rhizomes of *Posidonia oceanica* were collected by hand during SCUBA dive and preserved in alcohol 80%. Shoots and leaves were examined in laboratory and all the associated invertebrate fauna was sorted and identified to the lower taxonomic level possible. All the specimens of *Mesanthura* were measured with an ocular micrometer to the nearest of 0.01 mm. Data were boxplotted to visualize seasonal variability in size. Seasonal variations in size were tested with ANOVA.

5.2.1.3 Results

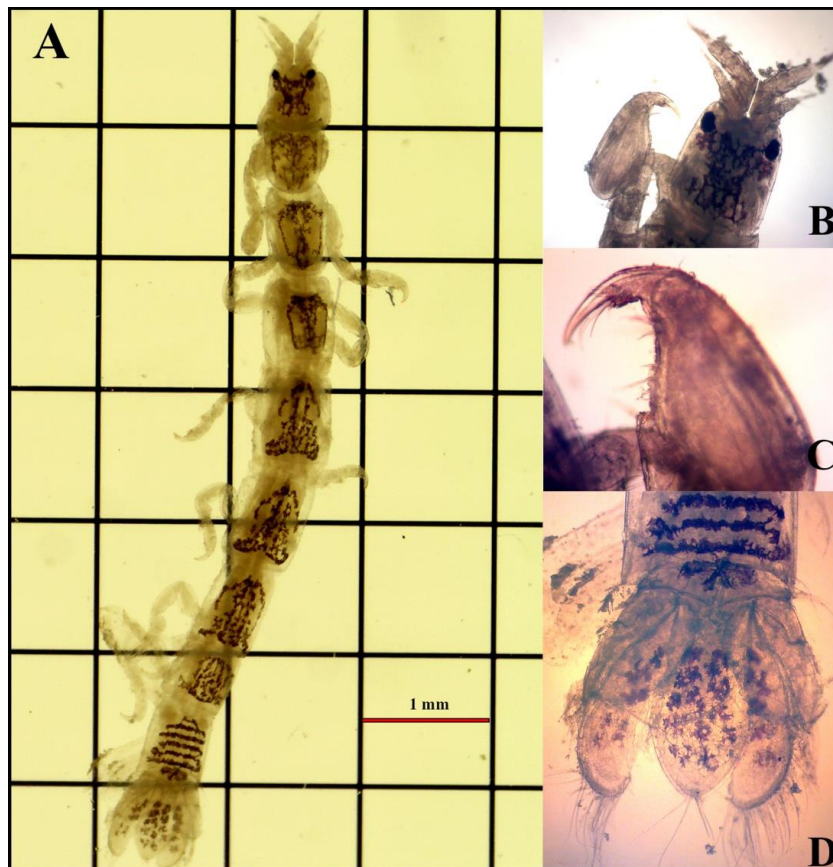


Fig. 1. A specimen of *Mesanthura* sp. sampled in Civitavecchia during this study. Whole animal in dorsal view (A) with particular of head and pereopod 1 (B), pereopod 1 (C) and telson and uropod (D).

During the four sampling days, on the basis of morphological and color-pattern analysis (Fig.1), a total of 21 specimens were identified as belonging to the genus *Mesanthura*: 4 on 25th October 2015, 8 on 11th March 2016, 4 on 22th May 2016 and 5 on 31th August 2016. All the 21 specimens showed the following morphological and color pattern characteristics: cephalotorax slightly longer than wide, with rostral point not extended beyond anterodistal angles; anterolateral eyes present; peduncle of antenna 1 with three articles of the same length, flagellum with short setae distally; peduncle of antenna 2 with five articles, flagellum with numerous setae; pereopod 1 subchelate, unguis shorter than dactylus, with a lobed expansion on inner rear margin and 4-6 long setae; palm of propod crenulated, basal margin with rounded projection and 3-4 long setae; telson linguiform with rounded posterior margin, four pairs of marginal setae on apex; endopods of uropod slightly longer than telson, margins crenulated and fringed with a large number of long setae; uropodal exopod oval, with a distal slightly concave and crenulated margin, with a few simple and numerous plumose marginal setae; darkish-brown dorsal patches on cephalon, pereon, telson, endopods and exopods; cephalon with hourglass-shaped patch that extends from the eyes to the posterior margin; all the pereonites show a characteristics mask-shaped patch; pleon with six progressive size increase dark rows and a small butterfly-shaped patch on the sixth pleonite; telson, endopods and exopods show some irregular circular spots. The mean total length was of 5.29 mm in autumn, 6.00 mm in winter, 7.75 mm in spring and 3.43 mm in summer.

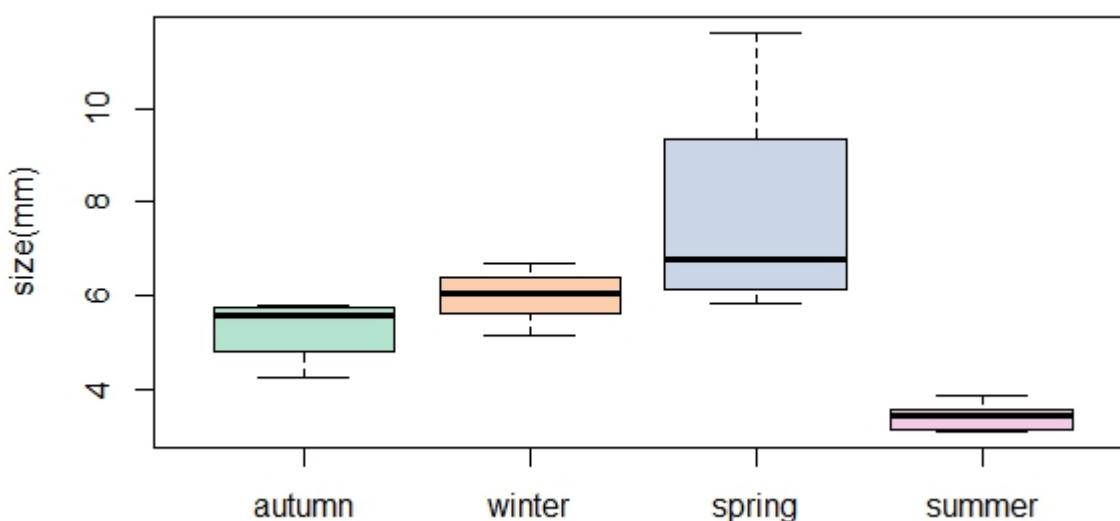


Fig. 2. Seasonal boxplots of the size of the 21 specimens of *Mesanthura* sp. sampled in this study.

The maximum size was of 11.6 mm (an ovigerous female sampled in May). Boxplots clearly show that specimens increasing in size from summer to spring (Fig. 2). The ANOVA test showed a significant differences in size on seasonal scale (d.f.=3, F=10.07, $p<0.05$). The most abundant associated species were Polychaeta (*Nereis rava*, *Polyophthalmus pictus*, *Megalomma* sp., *Syllis* spp.), Amphipoda (*Microdeutopus chelifer*, *Leptocheirus guttatus*, *Gammaropsis maculata*, *Ampithoe helleri*) and Tanaidacea (*Chondrochelia savignyi*).

5.2.1.4 Discussion

From the comparison between our results and that of Lorenti *et al.* (2009) in particular, we can confirm the presence of *Mesanthura* sp. also in the northern Tyrrhenian Sea. On the basis of the comparison of several taxonomic characters with *Mesanthura* species, we can also confirm the similarity with *M. romulea*, a species discovered in Australia (Poore & Lew Ton, 1986). From this comparison, we cannot ignore the similarity with our specimens. The color pattern in particular is very similar. However, since it was not possible to compare our specimens with specimens of *M. romulea* and since our comparison was between the specimens that we found and the drawing in Poore & Lew Ton (1986), we agree with Lorenti *et al.* (2009) and our identification does not go beyond the genus level. The fact that our specimens were found in the vicinity of the harbour of Civitevecchia and the lack of previous records in the area and in other Italian seas, support the hypothesis of their recent introduction (probably through ballast waters or hull fouling of international shipping) and of an exotic origin too. The presence of an ovigerous female in spring and of small (juveniles) specimens in summer suggests that the peak of the breeding season falls in spring. Indeed, size of specimens increasing from summer to spring. Our work represents the second record of *Mesanthura* from the western part of the Basin. Further studies in the quay wall of the harbour of Civitavecchia could show the presence of the species in this habitat too, as in the cases of the harbours of Salerno and Taranto. Indeed, artificial substrate of quay walls of harbours and marinas are ideal habitat for many alien invertebrates (Galil, 2000; Occhipinti Ambrogi, 2000; Marchini *et al.*, 2015; Tiralongo & Mancini, 2016). Without targeted studies, however, because of the small size of the specimens, the presence of the species could be difficult to detect. Further studies may demonstrate the presence of this alien species, mostly in or near several harbour areas of the Mediterranean Sea.

5.3 New Mediterranean Biodiversity Records (July 2016)

(in *Medit. Mar. Sci.*, 17/2, 2016, 608-626)

Abstract

This contribution forms part of a series of collective articles published regularly in Mediterranean Marine Science that report on new biodiversity records from the Mediterranean basin. The current article presents 51 geographically distinct records for 21 taxa belonging to 6 Phyla, extending from the western Mediterranean to the Levantine. The new records, per country, are as follows: Spain: the cryptogenic calcareous sponge *Paraleucilla magna* is reported from a new location in the Alicante region. Algeria: the rare Atlanto Mediterranean bivalve *Cardium indicum* is reported from Annaba. Tunisia: new distribution records for the Indo-Pacific lionfish *Pterois miles* from Zembra Island and Cape Bon. Italy: the ark clam *Anadara transversa* is reported from mussel cultures in the Gulf of Naples, while the amphipod *Caprella scaura* and the isopods *Paracerceis sculpta* and *Paranthura japonica* are reported as associated to the also allochthonous bryozoan *Amathia verticillata* in the Adriatic Sea; in the latter region, the cosmopolitan Atlantic tripletail *Lobotes surinamensis* is also reported, a rare finding for the Mediterranean. Slovenia: a new record of the non-indigenous nudibranch *Polycera hedgpethi* in the Adriatic. Greece: several new reports of the introduced scleractinian *Oculina patagonica*, the fangtooth moray *Enchelycore anatina*, the blunthead puffer *Sphoeroides pachygaster* (all Atlantic), and the lionfish *Pterois miles* (Indo-Pacific) suggest their ongoing establishment in the Aegean Sea; the deepest bathymetric record of the invasive alga *Caulerpa cylindracea* in the Mediterranean Sea is also registered in the Kyklades, at depths exceeding 70 m. Turkey: new distribution records for two non-indigenous crustaceans, the blue crab *Callinectes sapidus* (Atlantic origin) and the moon crab *Matuta victor* (Indo-Pacific origin) from the Bay of Izmir and Antalya, respectively; in the latter region, the Red Sea goatfish *Parupeneus forsskali*, is also reported. Lebanon: an array of records of 5 alien and one native Mediterranean species is reported by citizen-scientists; the Pacific jellyfish *Phyllorhiza punctata* and the Indo-Pacific teleosts *Tylerius spinosissimus*, *Ostracion cubicus*, and *Lutjanus argentimaculatus* are reported from the Lebanese coast, the latter notably being the second record for the species in the Mediterranean Sea since 1977; the native sand snakeeel *Ophisurus serpens*, rare in the eastern Mediterranean, is reported for the first time from Lebanon, this being its easternmost distribution range; finally, a substantial number of sightings of the lionfish *Pterois miles* further confirm the current establishment of this lessepsian species in the Levantine.

Introduction

Being both a biodiversity hot-spot and a sensitive confined system, the Mediterranean Sea is currently facing threats and challenges that are expected to persist or escalate in the following years: habitat degradation emerges as the most important, followed by climate change and fishing impact among several others (Bianchi et al., 2012). In this context, systematic recording of biodiversity and community composition changes, especially in coastal areas, is of key significance for identifying shifting trends, detecting potential impacts, and proposing policy action. The series of collective articles on new Mediterranean biodiversity records published in *Mediterranean Marine Science* at regular intervals offer the opportunity to collect and disseminate information that is vital for assessing the impacts of alien species and their role in the ongoing changes of biodiversity patterns in the Mediterranean Sea (Katsanevakis et al., 2014a). Submissions to the Collective Article are peer-reviewed by at least one reviewer and the editor. Contributing authors appear as co-authors and are also cited at the beginning of the sub-section corresponding to their record. Taxonomy follows the World Register of Marine Species (WoRMS Editorial Board, 2016). The new records are presented according to the major geographical zones of the Mediterranean Sea, from west to east, arranged in corresponding subchapters. The location of new records is illustrated on a map (Fig. 1).

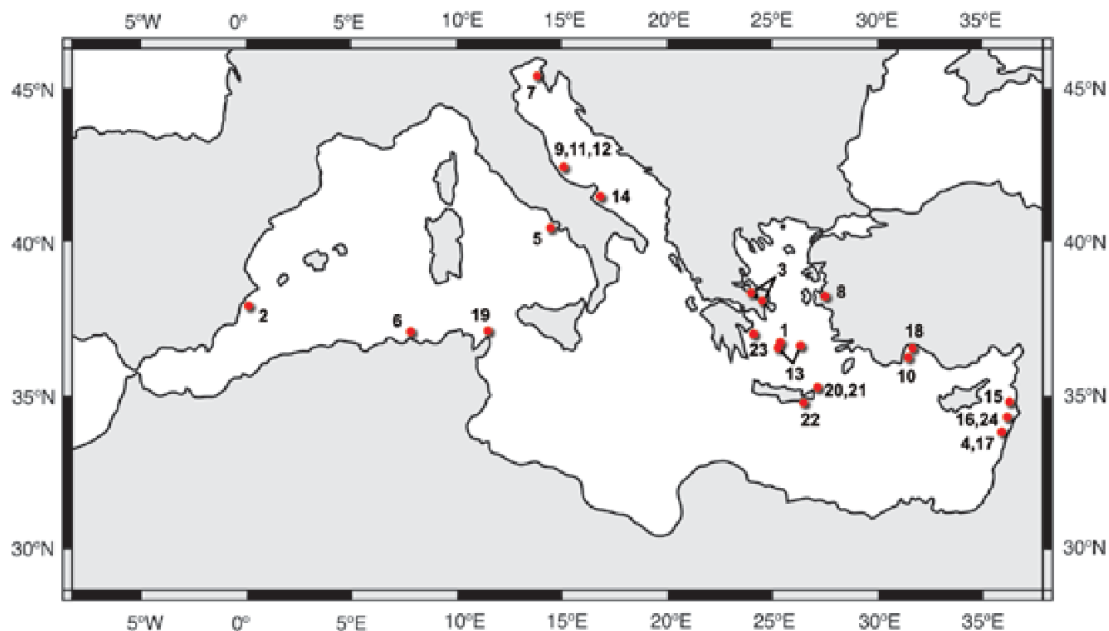


Fig. 1: Locations of records of new species in the Mediterranean Sea presented in “New Mediterranean Biodiversity Records (July 2016)”. Numbers of locations are given in Table 1.

Altogether, new records are provided for 21 taxa, belonging to 5 Phyla: Chlorophyta, Porifera, Cnidaria, Mollusca, Arthropoda, and Chordata (Table 1). The reports include new distribution points and range expansion for 18 non-indigenous taxa, as well as extended bathymetry records for the invasive alga *Caulerpa cylindracea*.

Taxon	SC	Location	Country	LN
Phylum CHLOROPHYTA				
<i>Caulerpa cylindracea</i>	3.1	Sifnos Island, Kyklades	Greece	1
Phylum PORIFERA				
<i>Paraleucilla magna</i>	1.1	Santa Pola Harbour, Alicante	Spain	2
Phylum CNIDARIA				
<i>Oculina patagonica</i>	3.2	North & South Evoikos Gulf	Greece	3
<i>Phyllorhiza punctata</i>	4.3	Sarafand	Lebanon	4
Phylum MOLLUSCA				
<i>Anadara transversa</i>	1.3	Gulf of Naples	Italy	5
<i>Cardium indicum</i>	1.2	Annaba	Algeria	6
<i>Polycera hedgpethi</i>	2.1	Škocjan Inlet, Koper	Slovenia	7
Phylum ARTHROPODA				
<i>Callinectes sapidus</i>	3.3	Sahilevleri, Izmir Bay	Turkey	8
<i>Caprella scaura</i>	2.2	Ortona Harbour	Italy	9
<i>Matuta victor</i>	4.1	Phaselis, Antalya	Turkey	10
<i>Paracerceis sculpta</i>	2.2	Ortona Harbour	Italy	11
<i>Paranthura japonica</i>	2.2	Ortona Harbour	Italy	12
Phylum CHORDATA				
<i>Enchelycore anatina</i>	3.4	Ios & Polyaigos Isls, Kyklades	Greece	13
<i>Lobotes surinamensis</i>	2.3	Manfredonia	Italy	14
<i>Lutjanus argentimaculatus</i>	4.3	Tripoli	Lebanon	15
<i>Ophisurus serpens</i>	4.3	Beirut	Lebanon	16
<i>Ostracion cubicus</i>	4.3	Tyr, Beirut	Lebanon	17
<i>Parupeneus forsskali</i>	4.2	Konyaalti, Antalya	Turkey	18
<i>Pterois miles</i>	1.4	Zembra Island & Haouaria	Tunisia	19
	3.6	Kavo Sidero, NE Crete	Greece	20
	3.6	Kouremenos, NE Crete	Greece	21
	3.6	Agios Panteleimonas, SE Crete	Greece	22
	4.3	Lebanese coast	Lebanon	*
<i>Sphoeroides pachygaster</i>	3.5	Saronikos Gulf	Greece	23
<i>Tylerius spinosissimus</i>	4.3	Beirut	Lebanon	24

Table 1: List of species presented in “New Mediterranean Biodiversity Records (July 2016)”, including sub-chapter (SC), locality of record and country. LN = location number (Fig. 1). [* Due to multiple sightings, no point location is given for *Pterois miles* records from Lebanon].

The records of three rare native species, the Atlanto-Mediterranean bivalve *Cardium indicum*, the Atlantic tripletail *Lobotes surinamensis*, and the sand snakeeel *Ophisurus serpens*, the latter two being for the first time confirmed as present in the Adriatic Sea and the Levantine region respectively, are noteworthy. Moreover, the establishment of the Indo-Pacific lionfish *P. miles* in the Mediterranean is currently ongoing, as suggested by 3 new records of the species in eastern Crete. The substantial contribution of citizen science to the monitoring and recording of biodiversity is highlighted in this article, since for 8 out of the 21 total taxa reported herein, at least one observation or specimen is provided

by volunteering non-professionals. Some of those reports are of particular significance, such as the confirmed finding of the Mangrove red snapper *Lutjanus argentimaculatus*, the second record for the species since it was first reported from the Mediterranean four decades ago. Moreover, the reported 47 sightings of the introduced lionfish *Pterois miles* by divers spanning over just four years underline the importance of a participatory approach to biodiversity data collection. Overall, in a shifting Mediterranean ecosystem, citizen science could prove valuable for timely recording of induced changes over an extended geographic range.

5.3.1 Alien crustaceans associated to *Amathia verticillata* (delle Chiaje, 1822): new Mediterranean records in Italian waters of *Caprella scaura* Templeton, 1836, *Paracerceis sculpta* (Holmes, 1904) and *Paranthura japonica* Richardson, 1909F.

Tiralongo, F., Mancini E., (2016). New Mediterranean Biodiversity Records (July, 2016). Mediterranean Marine Science 17 (2):608-626. DOI: 10.12681/mms.1734.

Abstract

Three non-indigenous peracarid species were found on *Amathia verticillata* colonies in the central Adriatic Sea (Ortona harbour): *Caprella scaura*, *Paracerceis sculpta* and *Paranthura japonica*. In the Mediterranean Sea, the association of these species on *A. verticillata* seems to be common.

Keywords: non-indigenous species, alien crustaceans, peracarid species, Bryozoan, ship hulls, invasive species, harbour, marinas, Adriatic Sea.

The bryozoan *Amathia verticillata* (delle Chiaje, 1822) is a widespread species. Its spreading is explained by its ability to produce vegetative fragments able to survive and growth on hard substrates (Robinson, 2004). In this way, it can be introduced elsewhere as fouling on ship hulls. It was often recorded in harbours and marina areas from different seas around the world, especially in the last years (McCann *et al.*, 2015). About its real native origin there have been various hypothesis; however, actually it is considered to be native of the Caribbean Sea (Galil & Gevili, 2014).

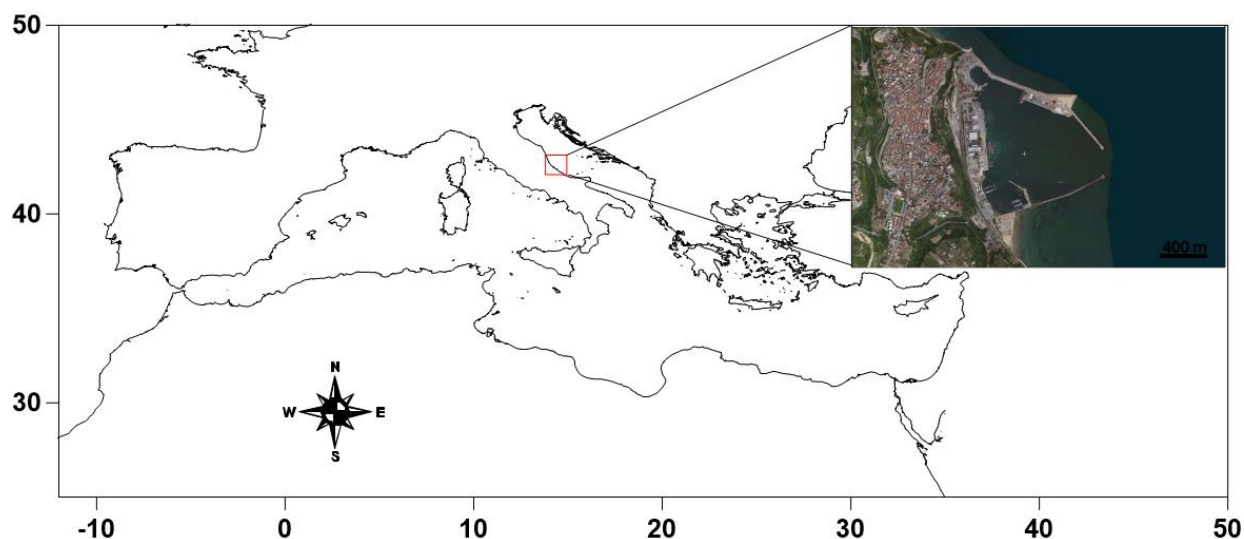


Fig.1. Location of the sampling site, Ortona Harbour (Adriatic Sea), in the Mediterranean Sea.

This non-indigenous species may facilitate the transport of other alien species, as demonstrated by this study and others. In particular, the recent case study of Marchini *et al.* (2015), in France, reported the same associated peracarid fauna.

The study area was the harbour of Ortona (42.34813 N, 14.41034 E), located in the central Adriatic Sea, Italy (Fig.1). Benthic macrofauna was collected on 18th August 2015 by scraping the fouling organisms of the walls, few centimeters under the sea level. The sampled surface was for the most part covered by *A. verticillata* colonies. A total of 4 m² were sampled. All the samples were immediately preserved in alcohol for subsequent laboratory analysis. All species were examined under a stereomicroscope and identified to the lowest possible taxonomic level. In the sampled substrate, together with *A. verticillata*, they were found the following encrusting organisms: *Scrupocellaria* sp., *Schizoporella* sp., *Sabella spallanzanii* (Gmelin, 1971), *Hydroides elegans* (Haswell, 1883), *Mytilus galloprovincialis* Lamarck, 1819 and *Ulva* sp.. The associated fauna was composed by 22 species of invertebrates. Among these, Amphipoda, with 9 species, where the main group. *Elasmopus rapax*, with a total of 294 sampled specimens, was the dominant species, representing 60.49% of the total. Three non-indigenous peracarid species were found on *A. verticillata* colonies: *Caprella scaura*, *Paracerceis sculpta* and *Paranthura japonica* (Fig.2), representing, respectively, 2.26% (11 specimens), 13.79% (67 specimens) and 1.44% (7 specimens) of the total sampled specimens. Furthermore, associated with *P. sculpta*, we found an additional alien species, the serpulid *Hydroides elegans* (Haswell, 1883), considered as invasive (Schwan *et al.*, 2016) and widespread. All sampled species were deposited in the collection of the Ente Fauna Marina Mediterranea. This study give support to the common association of the three non-indigenous crustacean species mentioned previously with *A. verticillata*. Comparing our results with that of Marchini *et al.* (2015), we have found the same species association. The presence of these non-indigenous species as associated fauna in *A. verticillata* underline the role that the spread of this latter species can have on the introduction of other alien species through transport on vessel hulls, that is considered the main way of introduction of *A. verticillata*.

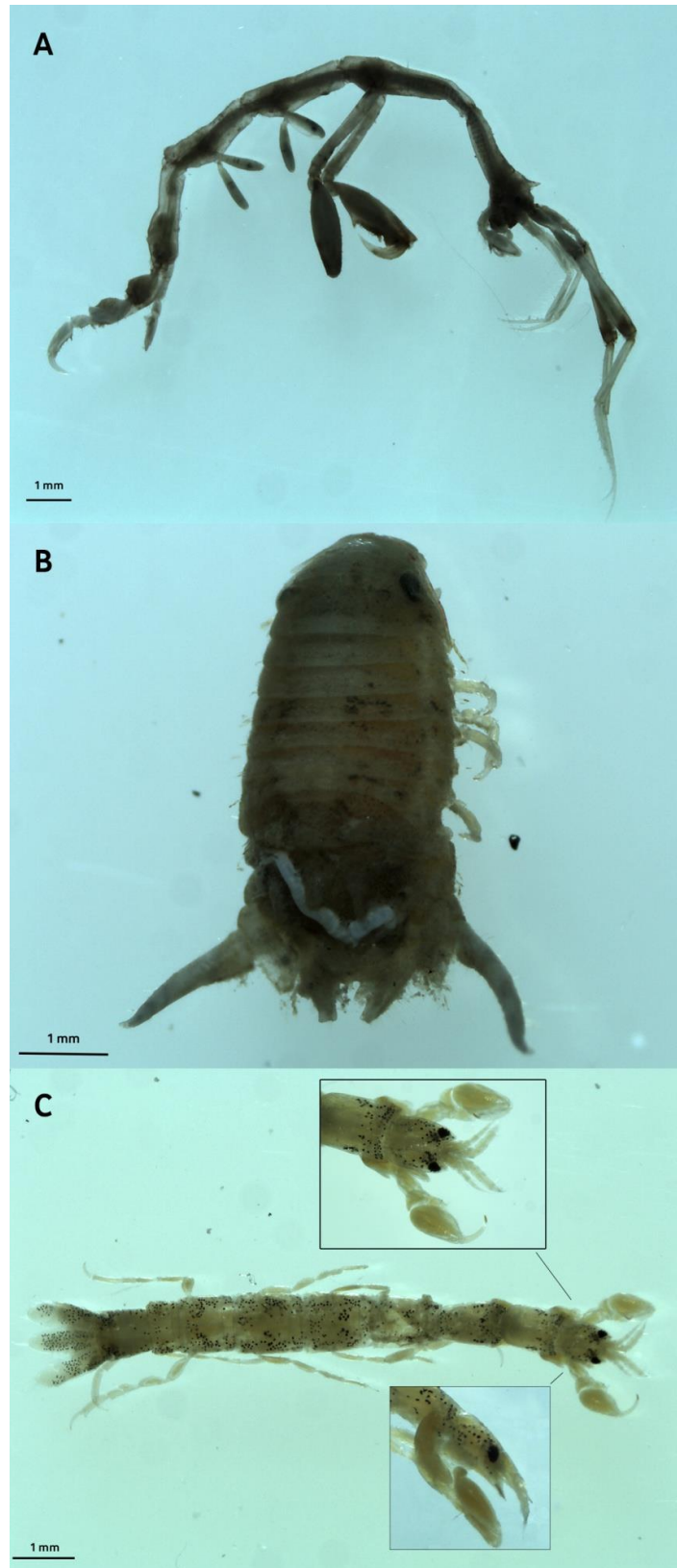


Fig.2. Sampled specimens of (A) *Caprella scaura*, (B) *Paracerceis sculpta* (with the serpulid *Hydroides elegans*) and (C) *Paranthura japonica* with details of the dorsal (above) and lateral (below) view of the anterior part of the body. All the species were found on *Amathia verticillata*.

6. The effects of *Posidonia oceanica* leaf litter on the *Sabellaria alveolata* bioconstructions

6.1 Introduction

The honeycomb worm *Sabellaria alveolata* is a gregarious bioconstructor polychaete worm belonging to the family Sabellariidae. This worm is an ecosystem engineer species being able to modify the coastal environments and so it is considered the most important building organism in temperate shallow environments (Naylor and Viles, 2000). *S. alveolata* increases the heterogeneity of preexisting substrates by creating complex three-dimensional biocostructions. These bioconstructions constitute new suitable hard substrates for the settlement of a great amount of characteristic and rare invertebrates, both sessile and vagile species and are also able to provide coastal protection (Dubois et al. 2002, 2006; La Porta and Nicoletti 2009; Schlund et al. 2016; Lisco et al. 2017).

These polychaetes are widely distributed along the European Atlantic coast, from Ireland to the south of Morocco (Firth et al. 2015) and punctually in the Mediterranean Sea (Sparla et al. 1992; Gambi et al. 1996; Nicoletti et al. 2001, La Porta & Nicoletti 2009, Scimmenti et al. 2016).

However the *Sabellaria* reefs are included in the European Red List of Habitats (Gubbay et al. 2016), because of its great vulnerability to anthropogenic disturbance (e.g. pollution, beach nourishment, trampling) (Dubois et al. 2002; Plicanti et al. 2016). For the aforementioned reasons, honeycomb worms bioconstructions are considered as valuable and vulnerable marine habitats that must be evaluated for protection by European Union (EU) legislation, including the Habitats Directive (Directive 92/43/EEC), the Water Framework Directive (Directive, 2000/60/EC) and the Marine Strategy Framework Directive (Directive, 151 2008/56/EC).

The bioconstructions of *S. alveolata* are commonly found in two forms: small colonies built as structures adhering to rocks ('veneers'), which are typical of the intertidal zone; 'reefs' structures, which develop at the lower level of the intertidal zone (Gruet, 1982). According to Gruet (1986) it is possible to distinguish four different phases of reef development: (1) primary settlement phase, (2) growth phase, (3) stagnation phase, (4) destruction phase. The study of the morphological characteristics of *S. alveolata* biocostructions (percentage of tubes with "sand crown", tube orientations, compactness, the presence/absence of epibionts, and the status of the reef surface) it is useful to understand the evolution phase of the reef and to determine the quality and the health status of the bioconstructions (Gruet 1970, 1986, La Porta & Nicoletti 2009). Moreover Gruet (1971, 1982) and Gruet and Bodeur (1997) have observed that the biodiversity of the associated

benthic macrofauna decreases in areas with high densities of the *S. alveolata* individuals, and highlighting that species richness is higher in degraded reef zones.

In the present work the seasonal variation in morphological features of a small *S. alveolata* reef associated with a cyclic presence of *P. oceanica* banquettes were analyzed with the aim of: (1) investigating the relationship between the temporal variation of the physical structure of the biocostruction and the presence of *Posidonia oceanica* fragments; (2) assess and describe the seasonal variation of the fauna assemblage associated with the reef and its epibionts community.

6.2 Study area

The *S. alveolata* reef is located in the Northern Tyrrhenian Sea (Italy). The reef is situated on the Civitavecchia coast between the Commercial harbor (7 Km North) and the mouth of Mignone River (1km South).

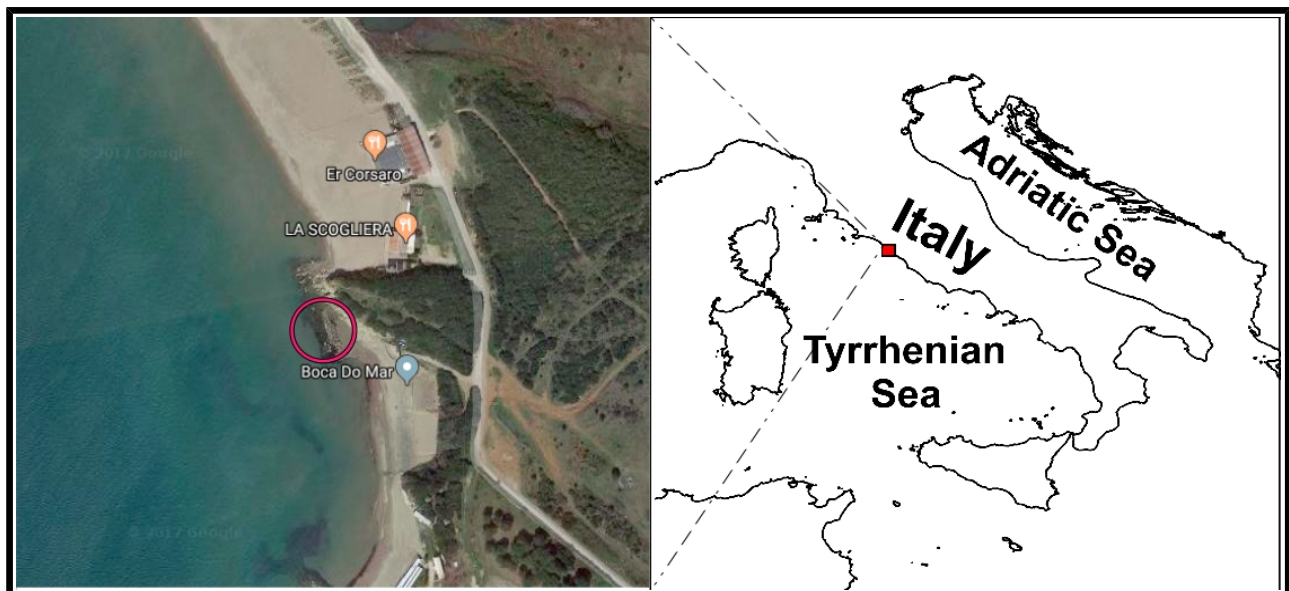


Fig. 1: study area.

This reef is a small biocostruction associated with a on-shore breakwather positioned at the base of a small rocky promontory that delimits the northern area of the private sandy beach called “Boca Do Mar” (Fig.1).

The biostructures are located at the mid-level of intertidal zone and mostly grows in sheets and ribbons like aggregations. Approximately the 80% of the biocostruction develops surrounding (encrust) the rocks and inside the interspace between them (Fig.2).

Moreover this *S. alveolata* reef is associated with a seasonal presence of *Posidonia oceanica* banquettes and a has been observed a cyclic covering of the biocostruction by *P. oceanica*.

Fragments (Fig.3).



Fig. 2: morphologies of the bioconstructions.

6.3 Materials and methods

Sampling surveys were carried out seasonally between April 2016 to March 2017. According to Gruet (1982), samples were taken in three seasonal replicates with each block measuring 20 x 20 x 20 cm (Fig.4). Each replicate was sampled in different reef areas characterized by different environmental conditions (wave exposure, *P. oceanica* fragment presence and depth) (Tab.1). Moreover, for the analysis of the benthic community a substrate sample (5L) near the *S. alveolata* bioconstructions was collected. All the samples were preserved in a 70% ethanol solution.



Fig. 3: sampling stations.

AREAS	BANQUETTES PRESENCE	DEPTH	WAVE EXPOSURE
1	Yes	20 – 40 cm	Sheltered
2	Only fragments	1 m	Moderated exposed
3	No	1.5 – 2 m	Exposed

Tab. 1: enviromental conditions of the three areas

In the laboratory each block was morphologically described following the metodologyes of La Porta and Nicoletti (2009) and Gruet (1970, 1982) in order to define: the percentage of tube with “sand crown” (%), the status and quality of the surface (erosion state and presence of fractured/crevices), presence/absence of epibionts, tubes orientations and block compactness.



Fig. 4: example of collected block.

For the description of eroded/fractured portions a semi-quantitative code was used (La Porta and Nicoletti, 2009): + isolated portions (5-10% of block surface), ++ reduced portions (11-30%), +++ wide portions (31-80%).

The reef associated fauna was sifted on 0.5 mm mesh, sorted and identified to the higher taxonomic level.

6.4 Results

6.4.1 Analysis of the seasonal variations of the blocks morphological features.

	SPRING 20/04/1015			SUMMER 21/08/2015			AUTUMN 16/11/2015			WINTER 15/02/2016		
	B 1	B 2	B 3	B 1	B 2	B 3	B 1	B 2	B 3	B 1	B 2	B 3
TUBE ORIENTATION	265° N-O	125° S-E	240° S-O	60° N-E	258° S-W	130° S-E	60° N-E	130° S-E	30° N-E	60° N-E	60° N-E	300° N-O
% OF "SAND CROWN"	0%	40%	70%	50%	90%	100%	20%	60%	90%	10%	30%	70%
ERODED	xxx	xx	no	xxx	no	no	xxx	xx	no	xxx	xx	x
OPENINGS/CREVICES	xxx	xx	no	xxx	xx	no	xxx	xx	no	xxx	xx	x
EPIBIONTS	si	si	no	si	no	no	si	no	no	si	si	no
COMPACTNESS	x	xxxx	xxx	xx	xxxx	xxxx	xx	xxxx	xxx	x	xxxx	xxxx
TUBE ORIENTATION	parallel	parallel	Chaot/paral	parallel	parallel	chaotic	chaotic	parallel	parallel	parallel	parallel	chaot/paral
N° OF S. ALVEOLATA	32	219	106	235	607	872	131	604	556	87	172	349
BANQUETTE						BANQUETTE						

Tab 2: results of the morphological analysis of the blocks.

The number of *S. alveolata* individuals, found inside the sampled blocks, shows a strong variation during the year: their maximums was observed during Summer and Autumn insted during Spring and Winter, when the bioconstructions are more influenced by the presence of *P. oceanica* fragments, the population of *S. alveolata* undergoes a significant decrease (Fig.5).

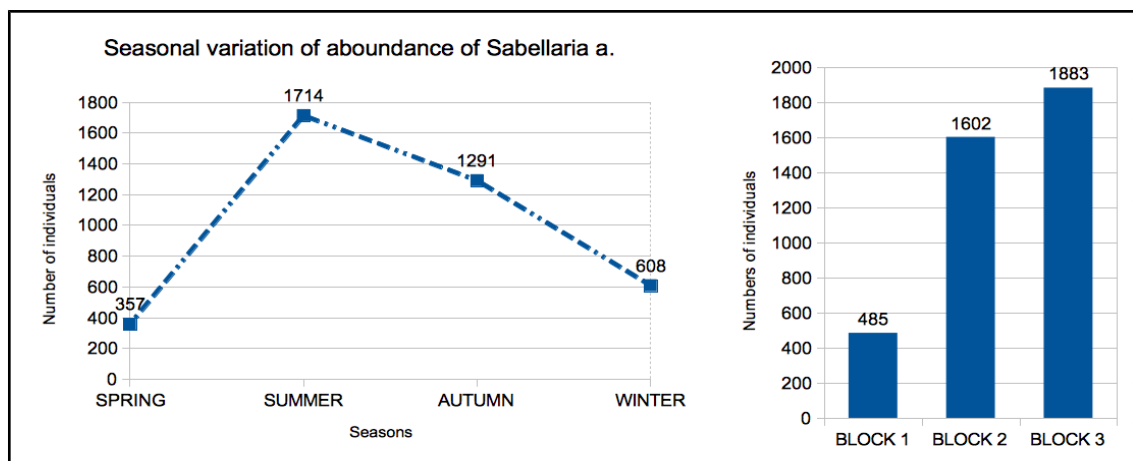


Fig. 5: spatio-temporal variation of the abundances of *S. alveolata*.

The morphological analisys of the blocks sampled in the three different areas of the reef show that (Tab.2) :

Area 1 is characterized by the cycling formation of a *P. oceanica* banquette. When the banquette is in its maximum expansion (Winter and Spring) the *P. oceanica* fragments cover the

biocostruction and the neighboring substrate. Moreover, this area has lowest depth (20-40 cm) and minimum exposure to the waves motions.

The Area 1 samples (Block 1) showed in all the seasons the lowest percentage of tubes with a “sand crown”(0-50%); the minimum has been registred in Spring (0%) followed by a big increase in Summer (50%) and by a costant decrease in Autumn (20%) and Winter (10%).

Moreover, a similar trend has been observed in the seasonal variation of the number of *S. alveolata* individuals: the blocks sampled in Area 1 recorded the lowest abundance values of individuals in all the seasons and show a minimum in Spring (32) and a gradual decrease passing from Spring (235) to Winter (87).

The blocks surface presented erosion and openings on “wide portions” in all the seasons and the compactness of the blocks decrease in Spring and Winter passing to fairly at very-friable.

The Tubes have a chaotic orientation in Autumn while in other seasons show a parallel orientation.

In this area the highest presence of epibionts on the blocks surface, both in number of species and in number of individuals, was recorded. The epibionts were present in all the year and are rapresented by the Polychaeta Serpulid *Pomatoceros lamarkii* (Quatrefages, 1866), the Bivalve mollusks *Irus irus* (Linnaeus, 1758) and *Mytilaster minimum* (Poli, 1795) and the green algae *Ulva* spp.

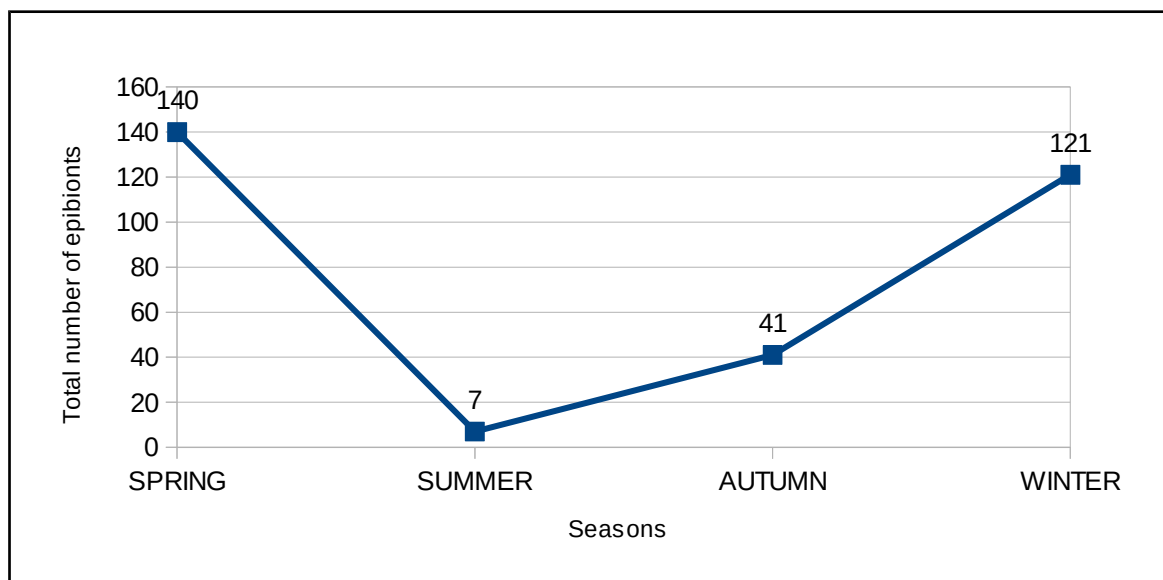


Fig. 5: seasonal variation of the abundances of epibionts in the Area 1.

A total of 309 epibionts was found in blocks 1 during the year. The maximum number of epibionts was observed in Spring (140) and Winter (121) when the biocostructions in this area are

covered by the *P. oceanica* banquettes. In summer the epibionts are less abundant (7) and undergo to an increment in Autumn (41) (Fig.5).

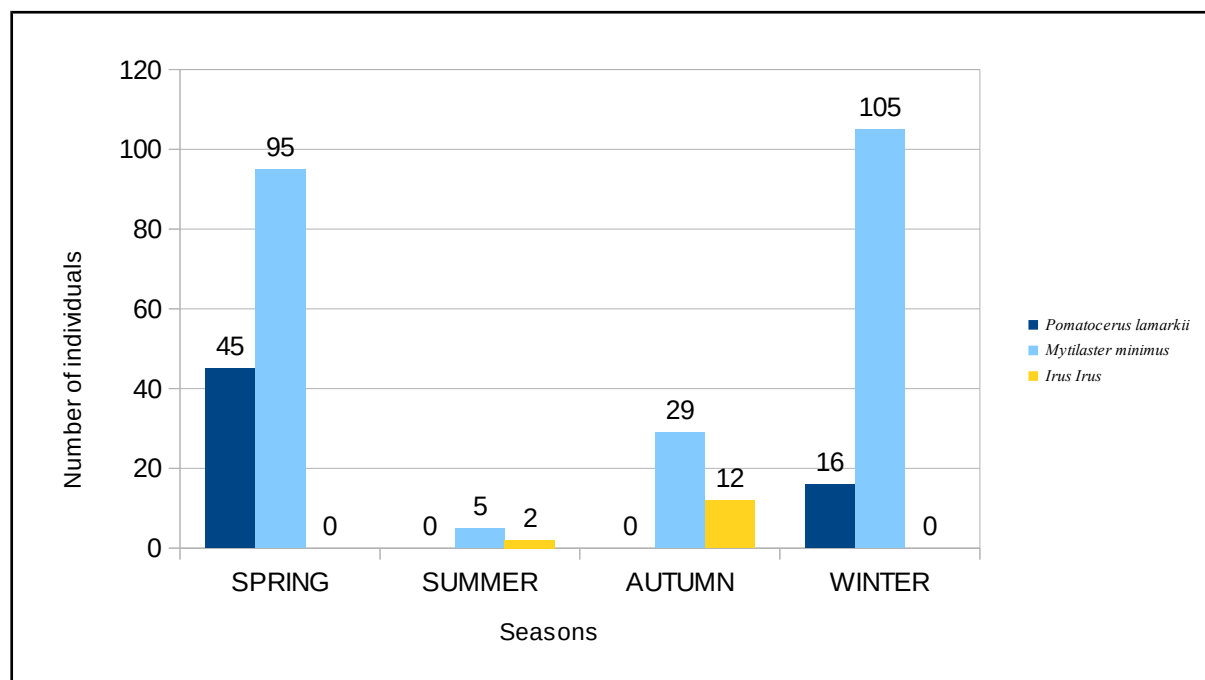


Fig. 6: seasonal variation of the three epibionts in the Area 1.

The most abundant species in all the seasons is the Mytilid mussel *Mytilaster minimus*; this species is representative of the 75.7% of the total epibionts community and shows their maximum abundance in Spring (95) and Winter (105) (Fig.6). This small mussel has been found inside the opening/crevices of the Blocks.

The Polychaeta Serpulid *Pomatocerus lamarkii* (19.7%) has been found only in Spring (45) and Winter (16) (Fig.6); in these seasons their encrusting tubes partially covered the surface of Blocks 1.

The Veneridae *Iruus irus* (4.5%) was observed inside the fractures of the biocostructions only in Summer (2) and Autumn (12) (Fig.6).

Furthermore, in all seasons, the presence of green algae *Ulva* spp. was observed on the surface of biocostructions (Fig.7).



Fig. 7: bioconstruction covered by epibionts and green algae (*Ulva* spp.).

The **Area 2** is characterized by a depth of about 1 m and a greater exposure to wave motion than the area 1; in this zone the banquettes are not present and only few resuspended *P. oceanica* fragments cover the biocostructions in Winter ad Spring.

Although in this area an increase in percentage of tubes with “sand crown” (20-90%) has been observed, the values show a seasonal trend similar to Area 1. The value reaches a minimum in Spring (20%), while in the Summer the percentage grow up and show the maximum (90%) and in Autumn (60%) and Winter (30%) a constant decrease has been observed.

A total of 1602 individuals of *S. alveolata* where collected during the year and their abundance range fluctuate between values of 172 in Winter and 607 in Summer. In Autumn 604 individuals has been found and in Spring the Block 2 records the maximum values of *S. alveolata* (206) in relation with the other areas .

The status of blocks surface do not show seasonal variation: in all the year the blocks have only reduced eroded portions (10-30%) and show a low percentage of opening/crevices (5-10 % of block surface).

The orienation of the tubes is parallel in all the seasons and the blocks appear very compact in all the samples.

In the blocks of Area 2 a total of 61 epibionts where found during the year. Their maximum abundance has been observed mainly in Spring (11) and Winter (42) most represented by the Polychaeta Serpulid *Pomatocerus lamarkii* (55.7%) and the mussel *Mytilaster minimus* (44.3%) (Fig.8).

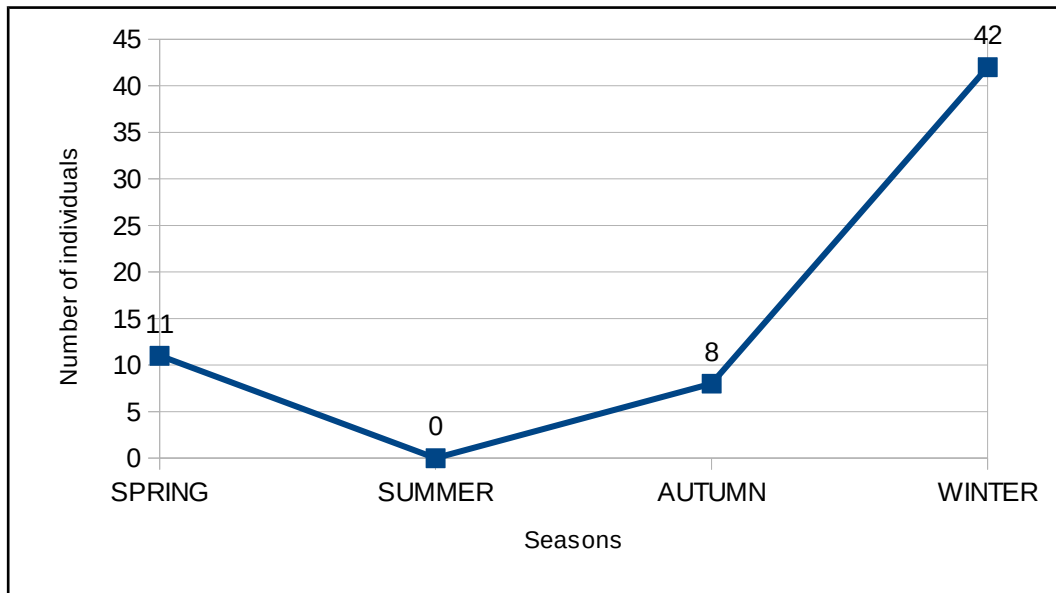


Fig. 8: seasonal variation of the abundance of epibionts in the Area 2.

Pomatocerus lamarkii was the most abundant species in Winter (27) and Spring (7) and in Autumn only the presence of *Mytilaster minimus* (8) has been observed (Fig.9). In Summer, the epibiontes community is not present in this area.

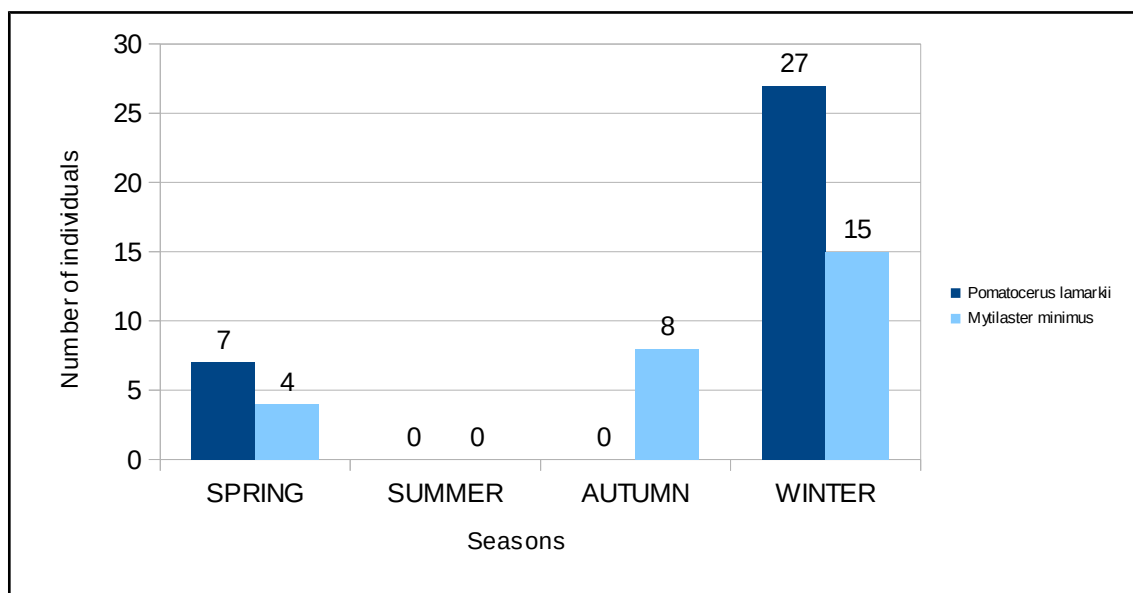


Fig. 9: seasonal variation of *P. lamarkii* and *M. minimus* in the Area 2.

Area 3 is characterized by the maximum depth (1.5-2m) of the breakwater and by the maximum exposure of the bioconstructions to the wave motion. In this area the formation of banquettes during the year was not observed and the biocostructions are never covered by *P. oceanica* fragments.

This area shows a maximum percentage of tubes with “sand crown” in all the seasons with values included between the 70% and 90%. The maximum percentage has been observed in Summer (100%) and Autumn (90%) while in Spring and Winter about the 70% of tubes show the crowns.

In this area the maximum number of *S. alveolata* (1883 individuals) was collected during the year. A minimum in abundance was observed in Spring (106) followed by a strong increase in Summer (872). In Autumn (556) and Winter (349) a constant decreasing in the abundances has been observed in the sampled blocks.

In this area the blocks sampled during the year do not show fractures and only in Winter the biocostructions show eroded isolated portion (5%) and very small crevices.

Samples were very compact and the tube orientations were chaotic in Summer and parallel in the other seasons.

The epibiontes community was not present in this area and the bioconstruction surface was always clean during the year.



Fig. 10: morphological features of a biocostruction of Area 3.

6.4.2 Analysis of *S. alveolata* reef associated fauna

6.4.2.1 Total faunal assemblages

A total of 361 organisms among 25 taxa was determined in the total sampling: Polychaeta 185 (11 species), Amphipoda 115 (6 species), Isopoda 40 (3 species), Decapoda 18 (4 species) and Sipuncula 4 (1 species).

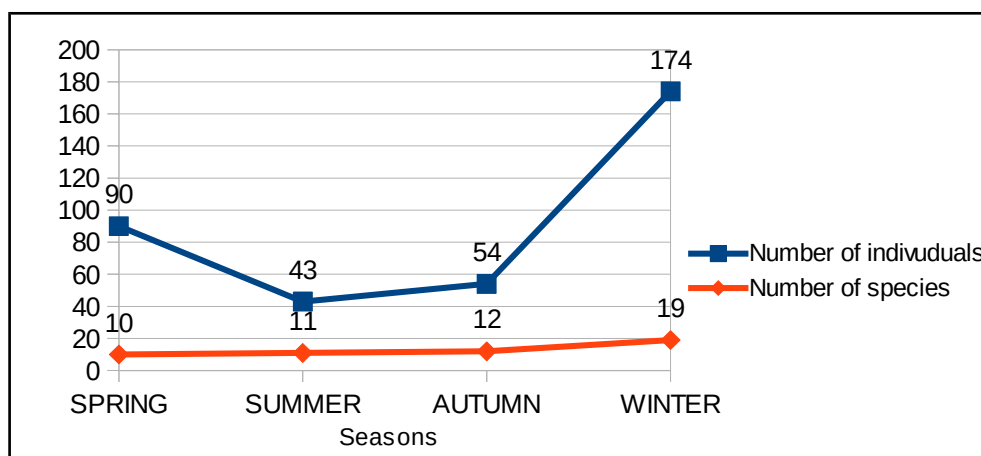


Fig 11: seasonal variation of abundances and number of species (Total sampling).

At seasonal scale, the community associated with the biocostructions shows its maximum abundance in Spring and Winter when the banquettes cover the surface of the reef (Fig.11). In particular, the largest abundance was observed in February (174 individual), followed by April (90), October (54) and August (43). The number of species undergoes a constant increase during the year and reaches their maximum in Winter (19 species).

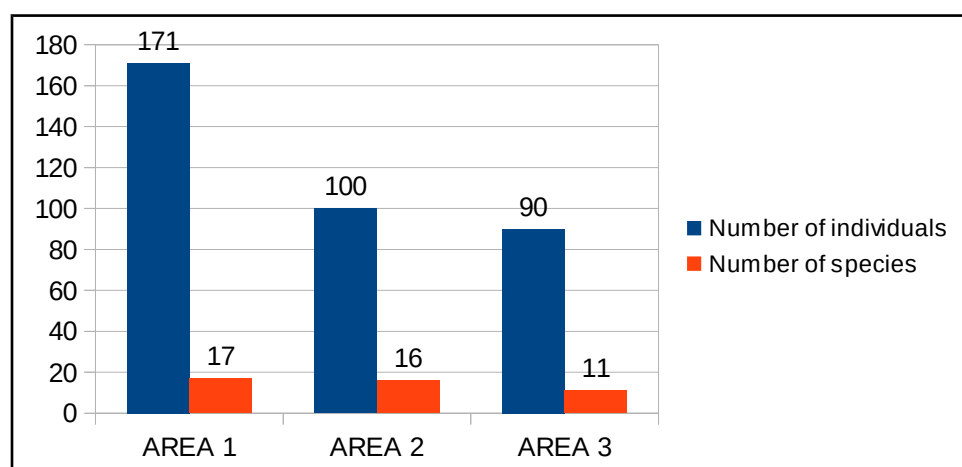


Fig 12: variation of abundances and number of species in the three areas.

The largest number of individuals was sampled in the Area 1 (170); the Area 2 (100) and Area 3 (91) shows a similar values of total abundance (Fig.12). The maximum number of species has been sampled in the Area 1 (17 species) and 2 (16 species) while a slight decrease of diversity was observed in the Area 3 (11 species).

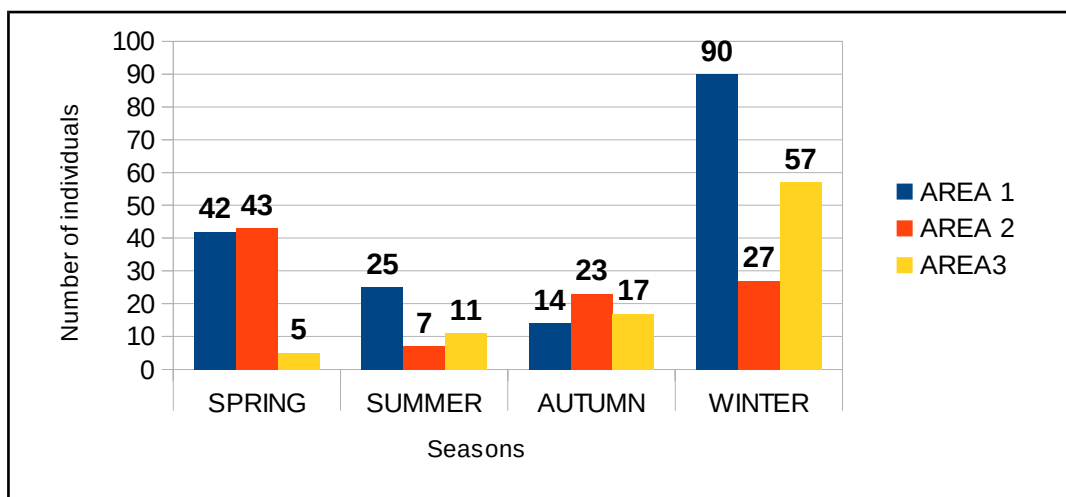


Fig 13: seasonal variation of abundances in the three Areas.

The associated faunal assemblage shows two peaks in the Area 1 in corrspondence of Spring and Winter during which the banquettes are at their greatest expansion and the *P. oceanica* fragments completely cover this reef sector (Fig.13). A similar temporal trend was observed in the Area 2.

The Area 3 undergoes a costant increase in abundances during the year and shows a minimum in Spring (5) and a maximum in Summer (58).

In all the areas an increasing trend of number of species passing from Spring to Winter was observed (Fig.14).

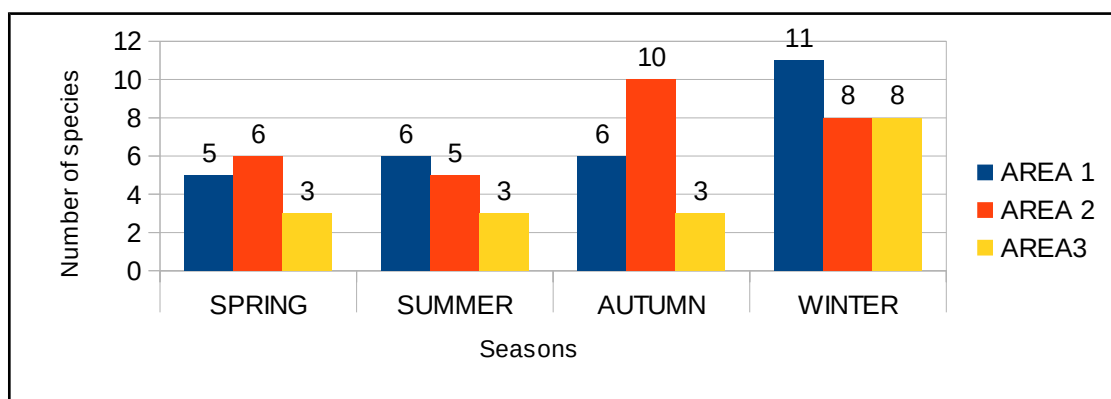


Fig 14: seasonal variation of the numbers of species in the three Areas.

The taxonomical analysis show that Polychaetes are the most rappresentative taxon both in abundance and in number of species and they are rappresentative of 51.2% of total assemblage. The Crustaceans contribute to 47.8% of the total abundance: Amphipoda 31.80% (6 species), Isopoda 11% (3 species) and Decapoda 5% (5 species) (Fig.15). The Sipuncula are represented by only one species, representing the 1% of the assemblage.

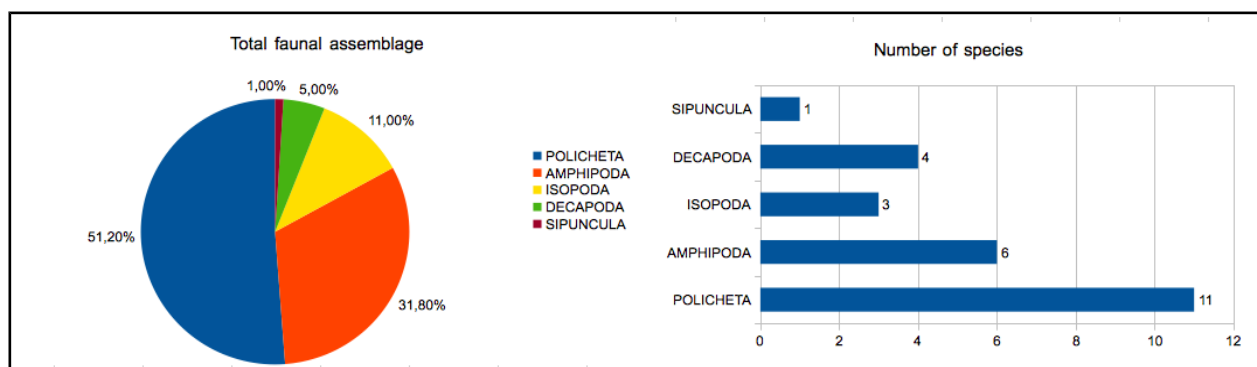


Fig 15: composition of the faunal assemblage.

At seasonal scale it has been observed that the Polychaeta, Amphipoda and Isopoda show their maximum abundances in Spring and Winter instead the Decapoda are more represented in Summer. The Sipuncula were sampled only in Autumn and Winter (Fig.16).

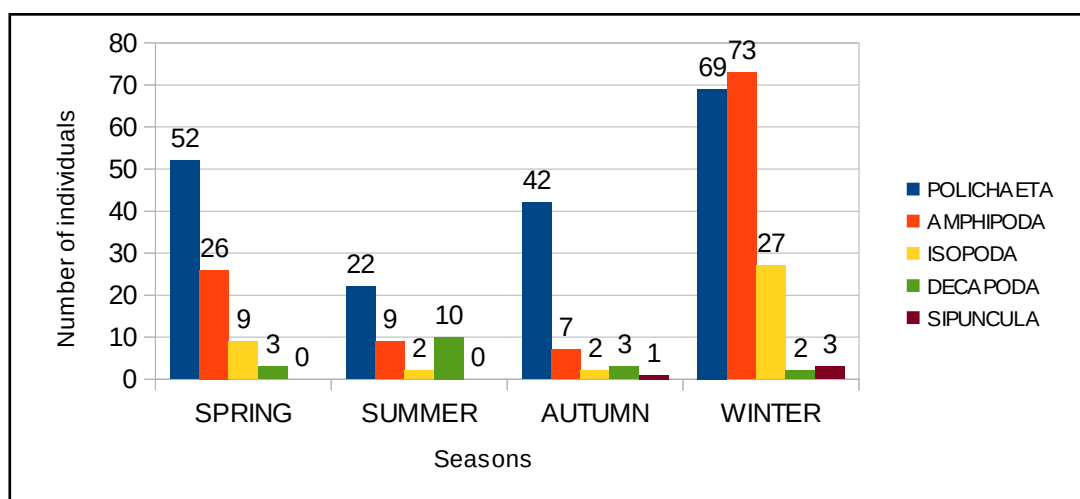


Fig 16: seasonal variation of the taxa.

The table 3 shows the total abundance of the 25 sampled species; the pool of the 10 most abundant species (in red) is representative of the 88% of the total assemblage and it is composed by 6 Polychaeta, 3 Amphipoda and 1 Isopoda.

SPECIES	N° OF INDIVIDUALS	PERCENTAGE CONTRIBUTION	FEEDING TYPE
<i>Gammarus insensibilis</i>	70	19.39%	HERB
<i>Eulalia ornata</i>	68	18.83%	PRE-CAR
<i>Idotea baltica</i>	32	8.86%	ERB
<i>Hyale perieri</i>	29	8.03%	ERB
<i>Syllis amica</i>	28	7.75%	PRE-CAR
<i>Syllis gracilis</i>	28	7.75%	PRE-CAR
<i>Eumida sanguinea</i>	24	6.64%	PRE-CAR
<i>Nereis pelagica</i>	17	4.70%	PRE-OMN
<i>Jassa oca</i>	12	3.32%	SUSP
<i>Perinereis marioni</i>	9	2.49%	PRE-OMN
<i>Pachygrapsus marmoratus</i>	9	2.49%	PRE-OMN
<i>Dynamene edwardsi</i>	6	1.66%	DET-OMN
<i>Pilumnus hirtellus</i>	6	1.66%	PRE-OMN
<i>Arabella iricolor</i>	5	1.38%	PRE-CAR
<i>Hyale crassipes</i>	4	1.10%	HERB
<i>Golfingia elongata</i>	3	0.83%	DET-OMN
<i>Brachynotus foresti</i>	2	0.55%	PRE-OMN
<i>Sphaeroma serratum</i>	2	0.55%	DET-OMN
<i>Ampithoe ramondi</i>	1	0.27%	HERB
<i>Ceratonereis costae</i>	1	0.27%	PRE-OMN
<i>Corophium acutum</i>	1	0.27%	SUSP
<i>Eriphia verrucosa</i>	1	0.27%	PRE-OMN
<i>Nereis sp.</i>	1	0.27%	PRE-OMN
<i>Platynereis dumerilii</i>	1	0.27%	PRE- HERB
<i>Syllis sp</i>	1	0.27%	PRE-CAR

Tab. 3: species list.

The **Polychaeta** assemblage is composed only by predators species. The most abundant specie is the Phyllodocid *Eulalia ornata* Saint-Joseph, 1888 which rapresents the 18.83% of the total community. *E. ornata* was recently reported also for Mediterranean Sea, along the south-western coasts of Sicily (Sicily Channel) (Schimmenti et al. 2016). Although this intertidal species was occasionally found in crevices of hard substrates, it showed a high fidelity link with *S. alveolata* reefs (Schimmenti et al. 2016). Moreover, the Phyllodocid *Eumida sanguinea* (Örsted,1843), that shows a frequency of 6.64%, has often been sampled in association with the *S. alveolata* bioconstructions (Schimmenti et al. 2016).

The family Sillyidae shows a high abundance (15.50%) and is represented by two species common on the superficial hard substrates, *Syllis amica* Quatrefages, 1886 (7.75%) and *Syllis gracilis* Grube, 1840 (7.75%).

Among the family collected, the Nereidadae, one of the most abundant taxa among the benthic families both in marine and brackish water ecosystem (Çinar and Zeki, 2001), show the maximum number of species. The five species sampled are: *Nereis pelagica* Linnaeus, 1758 (4.70%), *Perinereis marioni* (Audouin & Milne Edwards, 1833) (2.49%), *Ceratonereis costae* (Grube, 1840) (0.27% only one individual), *Platynereis dumerilii* (Audouin & Milne Edwards, 1834) (0.27%), and *Nereis rava* Ehlers, 1868 (0.27%).

The **Amphipoda** were present with 5 species belonging to 4 genera and 3 families. The Amphipod community was mainly rapresented by *Gammarus insensibilis* Stock, 1966, the most abundant specie sampled (19.39%). These Gammarid herbivore is commonly found on lagoons and

littoral bottoms covered by macrophytal detritus and phanerogams fragments (Mancinelli and Rossi, 2002; Hans Janssen et al., 1979). *Gammarus insensibilis* resulting the dominant species associated with the *Posidonia oceanica* fragments (banquettes and suspended litter).

The family Hyalidae contributes to 9.13% of the total abundance. Two Hyalid herbivorous was collected, *Hyale perieri* (Lucas, 1849) (8.03%) and *Hyale crassipes* (Heller, 1866) (1.1%). These two species usually occur on hard and sandy substrates covered by algae.

Moreover the Jassid *Jassa ocea* (Spence Bate, 1862) (3.32%), an amphipod species with a high fidelity link with both Atlantic and Mediterranean *S. alveolata* reefs was collected (La Porta et al., 2009b; Iacofano et al., 2015; Plicanti et al., 2017).

The Class **Isopoda** is mostly represented by the cosmopolitan species *Idotea baltica* Pallas, 1772 (8.86%), the second most abundant organism collected by us inside the *P. oceanica* banquettes. *Idotea baltica* is a euryhaline crustacea occurring in subtidal and intertidal habitats of marine and brackish-water environments. This species is commonly associated with macrophytes (surface drift weed and floating debris) and represents an important member in the food web of littoral communities (Orav-Kotta & Kotta, 2004; Bulheim & Fava, 1982). Moreover this Isopod was a component of the mobile macrofauna associated with submerged detritus accumulations (SDAs) of the seagrass *Posidonia oceanica* (Gallmetzer et al., 2005).

It was also sampled the detritivores species *Dynamene edwardsii* (Lucas, 1849) (1.66%) and *Sphaeroma serratum* (Fabricius, 1787) two Isopods commonly collected on coastal hard substrates.

The **Decapoda** was mainly found inside the fractures of the *S. alveolata* blocks and was represented by 4 species of Brachyurans predators: *Pachygrapsus marmoratus* (Fabricius, 1787), *Pilumnus hirtellus* (Linnaeus, 1761), *Brachynotus foresti* Zariquiey Álvarez, 1968, *Eriphia verrucosa* (Forskål, 1775).

Three individuals of the detritivorous **Sipunculid** *Golfingia elongata* (Keferstein, 1862) was also collected inside the crevices of the blocks sampled.

Feeding analysis

The feeding analysis shows that the Predators (Pre-Car 42.5% and Pre-Omn 13.05%) are the dominant feeding group of this community followed by the Herbivorous (Fig.17). The Detritivorous and the Suspensivorous species were resulted poorly representative of the assemblage.

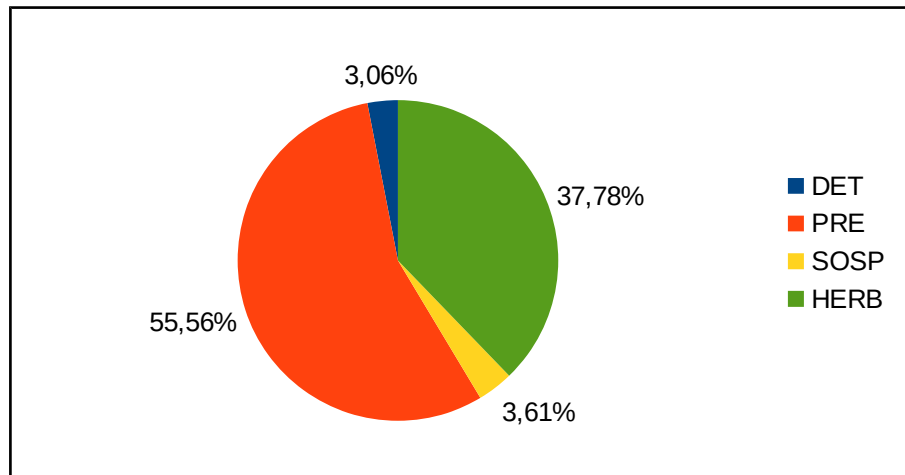


Fig. 17: abundances of the feeding groups.

At seasonal scale the Predators, mostly represented by the class Polychaetae, dominate in Spring (61,53%), Summer (73,17%) and Autumn (83,3%) and show their maximum in summer (Fig.18).

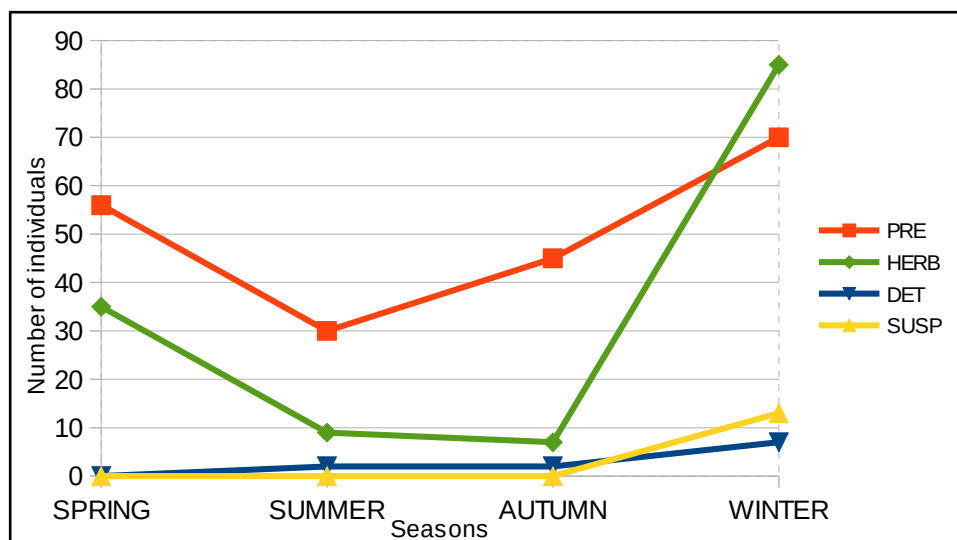


Fig. 18: seasonal variation of the feeding groups.

The Herbivorous were poorly abundant during Spring (21.95%) and Summer (12.96%) but they show a peak in Spring (38.46%) and in Summer they to represent the most abundant feeding guild (48.57%). The increase in herbivorous species has been observed in the seasons when the reef is more influenced by the presence of *P. oceanica* fragments (banquettes and litter). Detritivores and Suspensivores showed a slight increase in Summer.

6.4.2.2 Analysis of the seasonal variation in the three Areas of the reef.

Table 4 shows the spatio-temporal variation of the 25 species sampled during the year (the number of blocks corresponds to the associated areas).

SPECIES	SPRING	BLOCK	SUMMER	BLOCK	AUTUMN	BLOCK	WINTER	BLOCK
<i>Gammarus insensibilis</i>	+	1	-	-	-	-	+	1
<i>Eulalia ornata</i>	+	1-2-3	+	3	+	2-3	+	3
<i>Idotea baltica</i>	+	1	-	-	-	-	+	1
<i>Hyale perieri</i>	+	2	+	2-3	+	1-2	+	1-2
<i>Syllis amica</i>	+	2	+	1	+	2-3	+	1-2-3
<i>Syllis gracilis</i>	-	-	-	-	+	1-2	+	2-3
<i>Eumida sanguinea</i>	+	1-3	-	-	+	1-2-3	+	2-3
<i>Nereis pelagica</i>	-	-	+	1-2	+	2	+	1
<i>Jassa ocia</i>	-	-	-	-	-	-	+	1-2-3
<i>Perinereis marioni</i>	-	-	-	-	+	1	+	1-2
<i>Pachygrapsus marmoratus</i>	+	3	+	1	+	2	+	1-2
<i>Dynamene edwardsi</i>	-	-	+	3	+	1	+	1-2
<i>Pilumnus hirtellus</i>	-	-	+	1-2	+	2	-	-
<i>Arabella iricolor</i>	+	1	+	1	+	1-2	-	-
<i>Hyale crassipes</i>	+	2	-	-	-	-	+	2-3
<i>Golfingia elongata</i>	-	-	-	-	+	1	+	1
<i>Brachyotus foresti</i>	-	-	+	1			-	-
<i>Sphaeroma serratum</i>	-	-	-	-	-	-	+	1
<i>Ampithoe ramondi</i>	-	-	-	-	-	-	+	2
<i>Ceratonereis costae</i>	+	2	-	-	-	-	-	-
<i>Corophium acutum</i>	-	-	-	-	-	-	+	3
<i>Eriphia verrucosa</i>	+	2	-	-	-	-	-	-
<i>Nereis sp.</i>	-	-	-	-	-	-	+	2
<i>Platynereis dumerilii</i>	-	-	-	-	+	2	-	-

Tab. 4: spatio-temporal variation of the sampled species.

Area 1

The two dominant species in this area were the herbivorous crustaceans *Gammarus insensibilis* and *Idotea baltica* which together were representative of the 59,6 % of the total abundance (Fig.19).

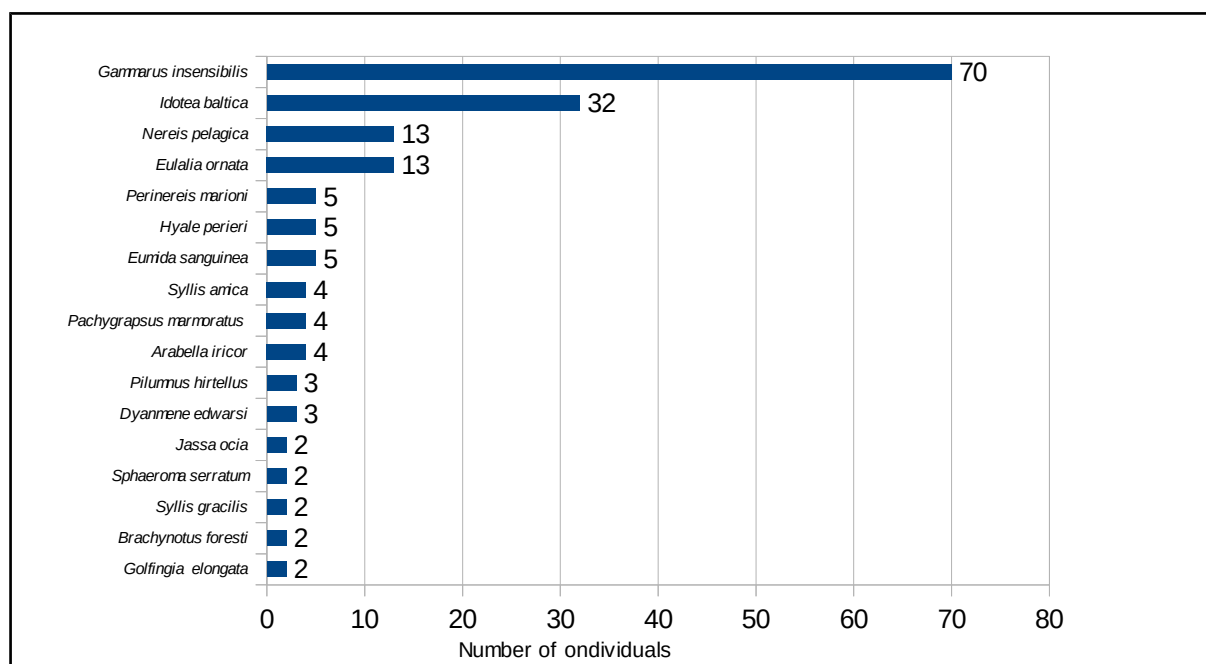


Fig. 19: species abundances in Area1.

These two species has been the most abundant in Spring and Winter, while they resulted absent in summer and autumn. The Polychaeta predators were presents with 7 species which together contribute to the 27% of the assemblage (Fig.20). In this area, four species were more representative: *Eulalia ornata*, *Eumida sanguinea*, *Nereis pelagica* and *Perinereis marioni*. While the Phyllodocids were mostly collected in Spring the two Nereids were the dominant species respectively in Summer and Autumn and in these seasons the increase of the Syllids *Syllis gracilis* and *Syllis amica* was also observed. The Sipunculid *Golfingia elongata* was found exclusively of this area.

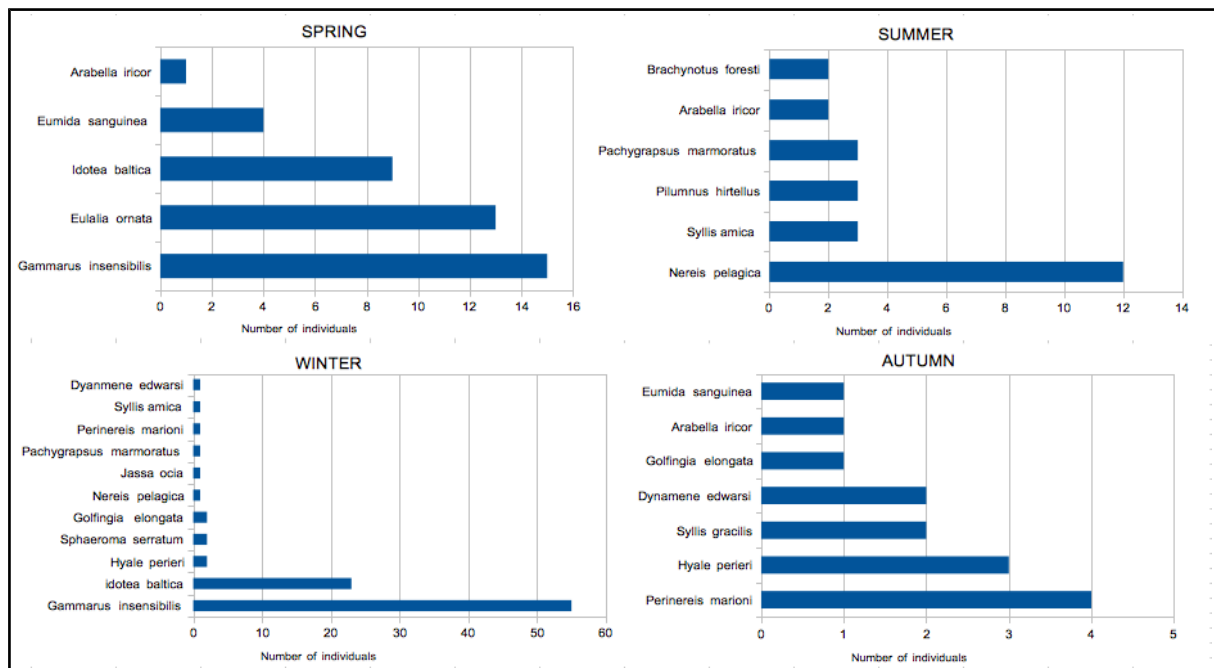


Fig. 20: seasonal abundances of the species sampled in the Area1.

Regarding to the feeding guilds abundances, Herbivores were strongly dominant in this area in Spring and Winter (Fig.21). Due to the numerical importance of *Gammarus insensibilis* and *Idotea baltica* within this trophic group, temporal and spatial patterns of Herbivores fundamentally reflect those shown by the two species. In Summer and Autumn, when the area is not affected by the presence of the banquettes, the Predators become the most abundant trophic category.

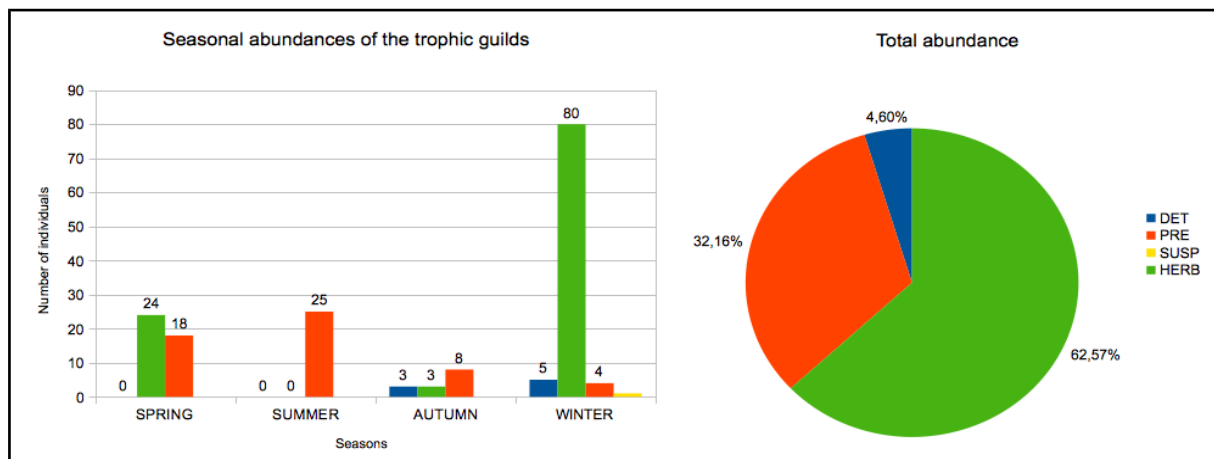


Fig. 21: seasonal variations of the feeding guilds in the Area 1.

Area 2

The Predator *Eulalia ornata* and the Herbivore *Hyale perieri* were the most abundant species in the area and they represented the 35% and the 18% of the total assemblage (Fig.22).

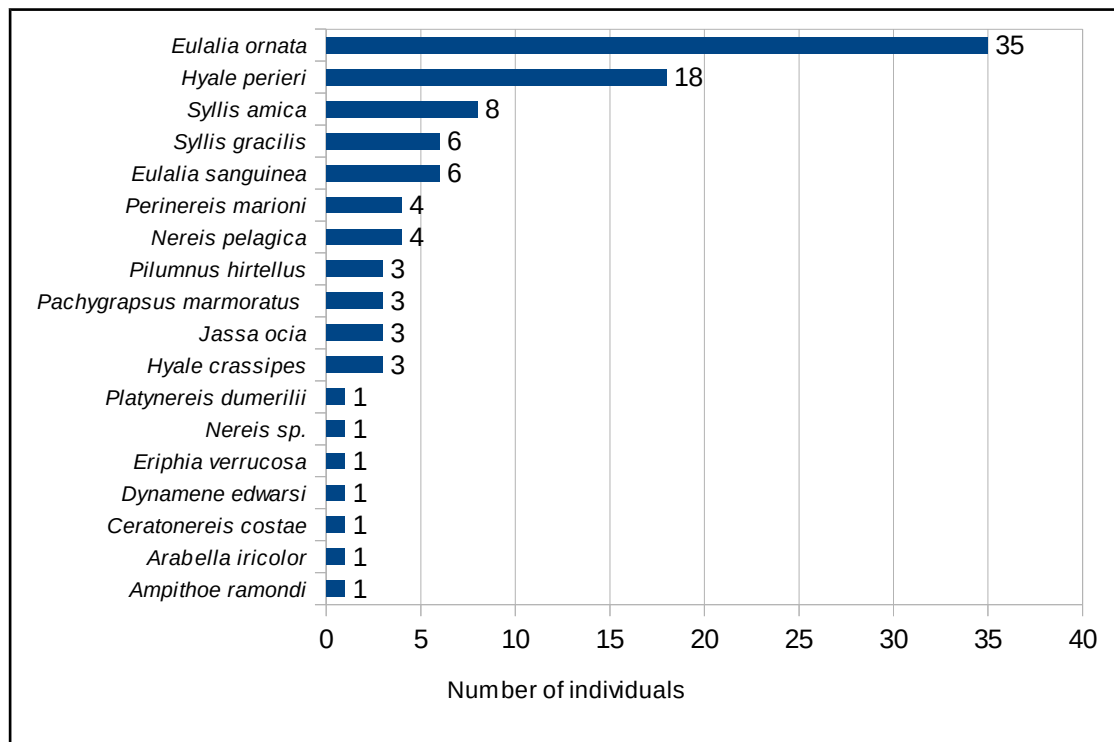


Fig. 22: species abundances in Area 2.

While the Polychete was the dominant species in Spring and Autumn the Amphipod was sampled in all the seasons and does not show a significant seasonal trend (Fig.23). In Winter an increase of the abundances of the Syllids *Syllis amica* and *Syllis gracilis* and the Nereid *Perinereis marioni* was observed in this area.

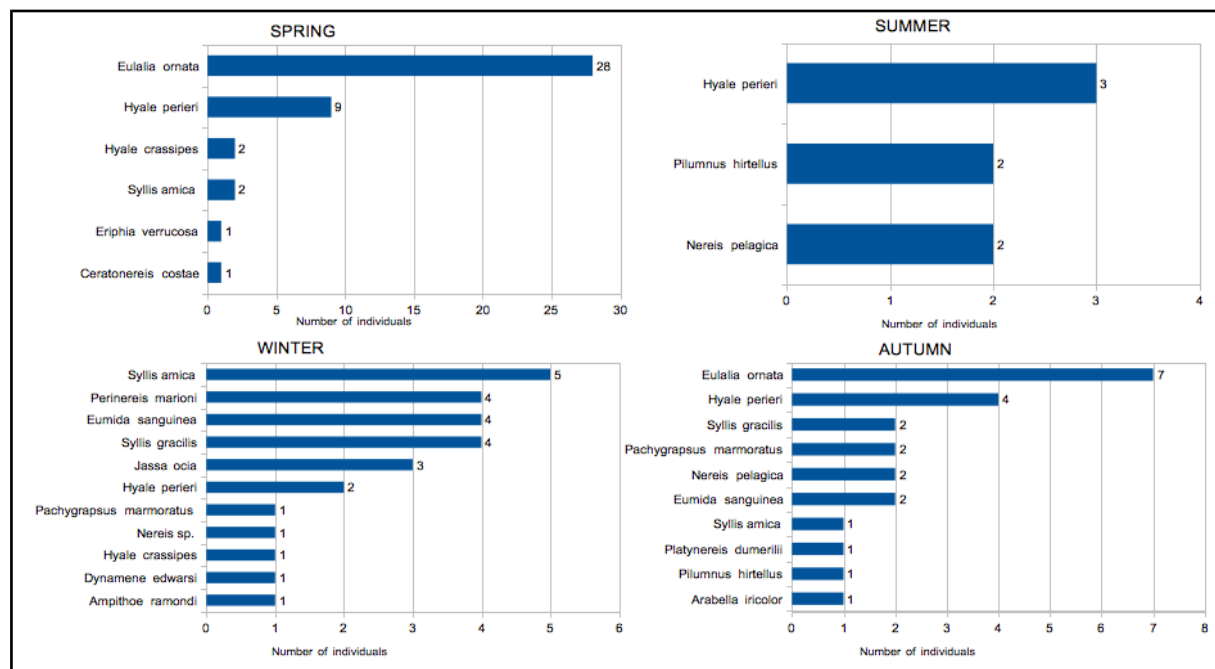


Fig. 23: seasonal abundances of the species sampled in the Area 2.

Predators feeders were the most abundant guild in all seasons (Fig.24). This guild, represented by the Polychaetes and Crustaceans Decapoda, showed a maximum in Spring followed by a minimum in Summer. The herbivores have been collected throughout the year; they reach their maximum abundance in Spring, when this area is influenced by the presence of suspended fragments of *P. oceanica*.

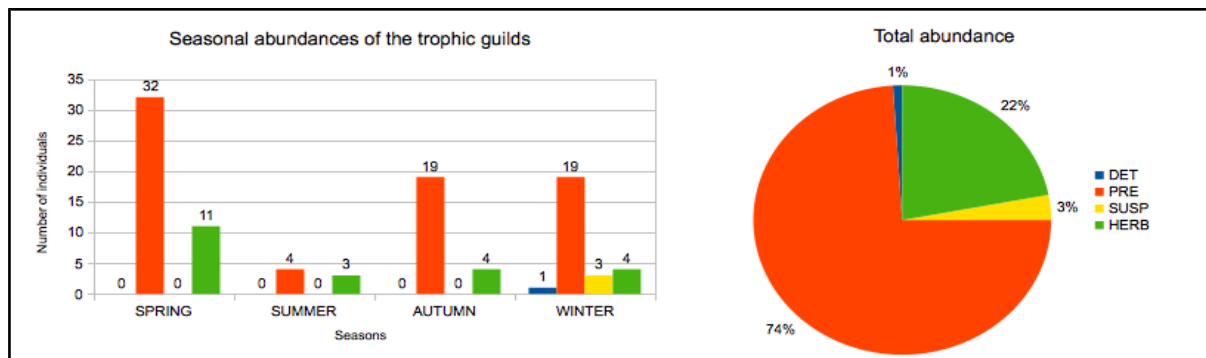


Fig. 24: seasonal variations of the feeding guilds in the Area 2.

Area 3

The analysis of the community showed that Area 3 undergoes to a continuous increase in the number of individuals during the year: while passing from Spring to Summer the variation of the abundances was progressive, in Winter a strong increase of the number of species and the number of individuals was observed (Fig.26).

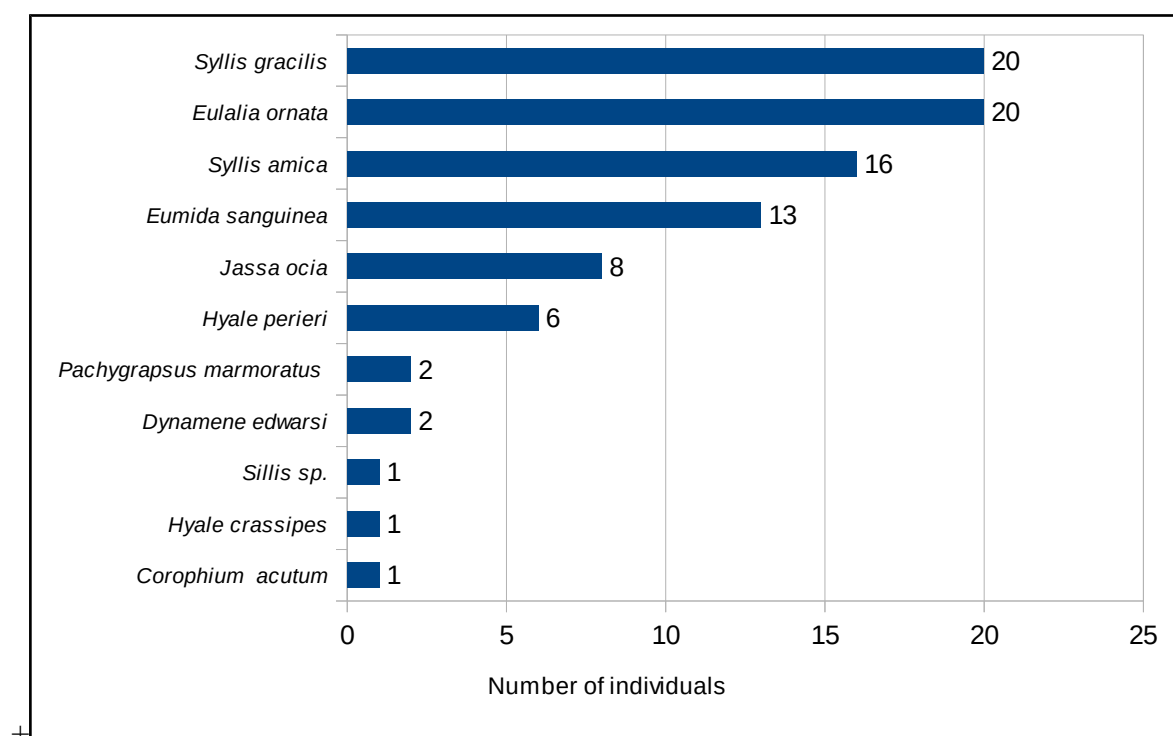


Fig. 25: species abundances in Area 3.

These variations were mainly linked to the increase of the Sillids Polychaetae. The family Sillidae (40% of total community) was represented by the two most abundant species *Syllis amica* and *Syllis gracilis* (Fig.25), these species showed their maximum abundances in this area. In winter the increase of the Amphipods *Jassa oca* was also observed.

The Phyllodocid *Eulalia ornata* and *Eumida sanguinea*, representative together of the 36,7% of the total assemblage, were collected in all the seasons.

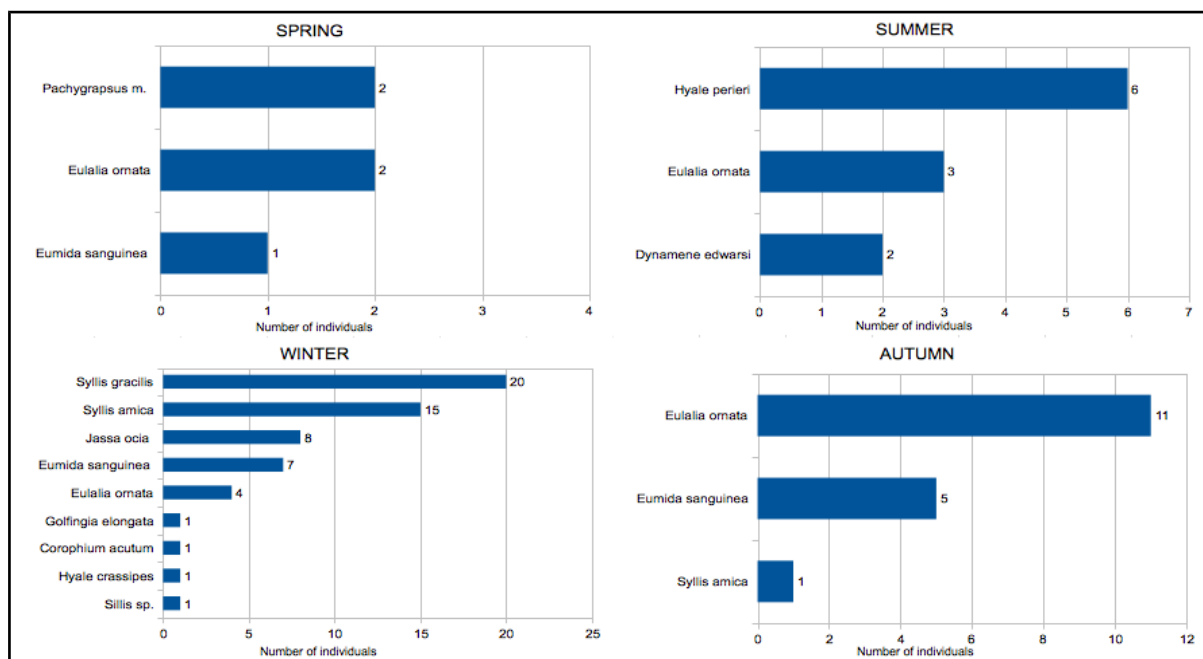


Fig. 26: seasonal abundances of the species sampled in the Area 3.

The feeding analysis shows that the Predators dominate this area and has been observed that they undergo a continuous increase during the year and reach their maximum in Winter (Fig.27). The Herbivores are represented only by the Amphipods *Hyale perieri* and they are mostly sampled in Summer.

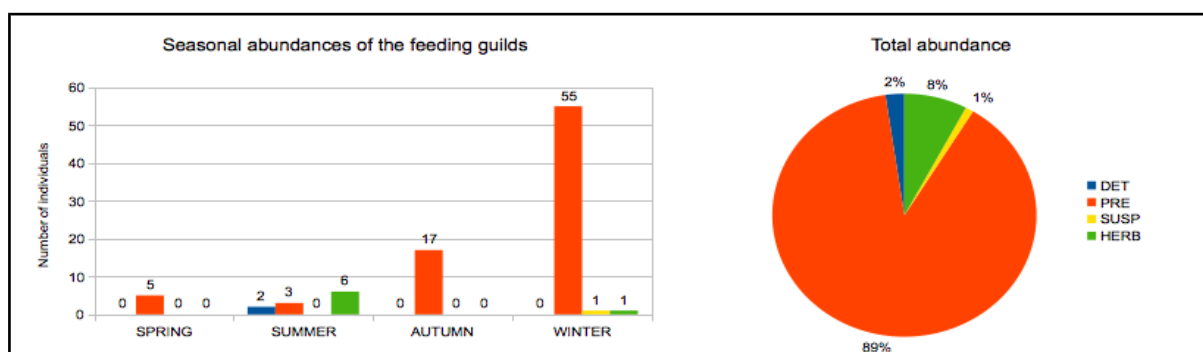


Fig. 27: seasonal variations of the feeding guilds in the Area 3.

6.4.2.3 Analysis of the benthic communities in the substrates associated at the *S. alveolata* reef.

In this paragraph the seasonal variations of the species collected within the sediments sampled near the *S. alveolata* reef has been described. In Winter and Spring the area in which this substrate was collected is affected by the presence of *P. oceanica* fragments and only in these seasons has been observed the presence and the extraordinary abundance of crustaceans *Gammarus insensibilis* and *Idotea baltica*. Since these species have not been collected in the sediment but only in the *P. oceanica* fragments that cover it, these taxa have not been used in the analysis of this community.

A total of 102 organisms among 15 taxa were determined in the total sampling: Polychaeta 69 (11 species), Amphipoda 5 (1 species), Isopoda 25 (2 species) and Decapoda 3 (2 species) (Fig.29). In addition 88 individuals of *Gammarus insensibilis* and 59 individuals of *Idotea baltica* were collected, the seasonal trend of the abundances of these two species is described in Figure 28.

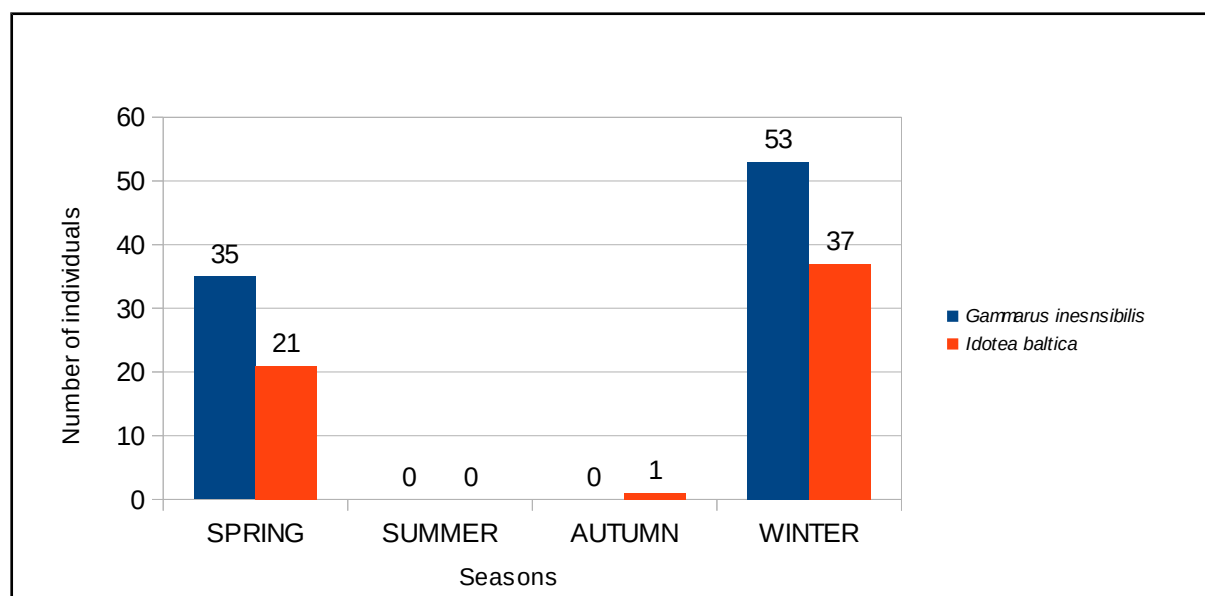


Fig. 28: seasonal variations of *G. insensibilis* and *I. baltica* (sediments).

The Polychaetae was the dominant taxa in both the number of species and the number of individuals and was representative of 68% of the this assemblage (Fig.29). The Isopods (25%) were present with 25 individuals and only 2 species. The Amphipods (3%) and Decapods (5%) were poorly representative of this community.

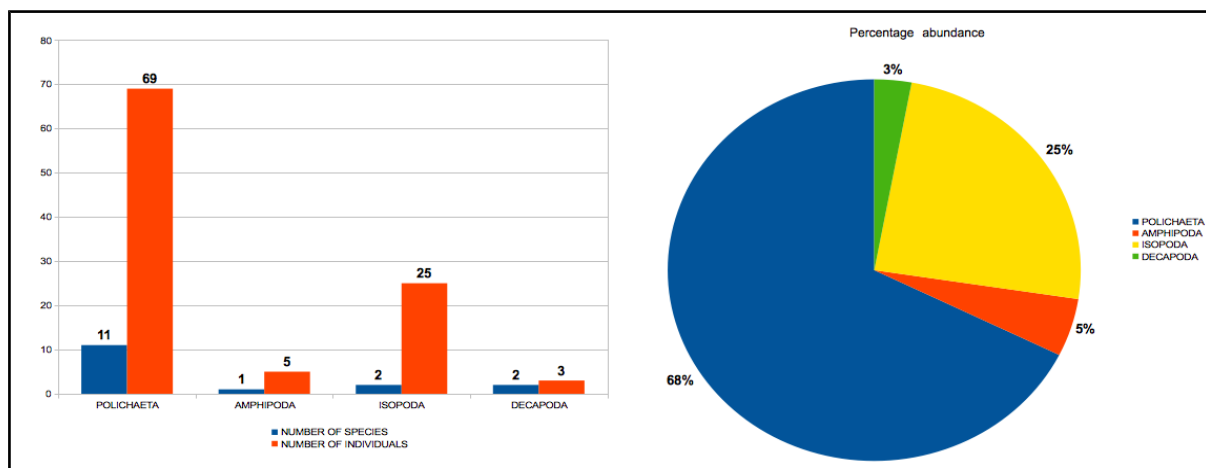


Fig. 29: abundance and diversity of the taxa sampled in the sediments.

Both the number of species and the number of individuals have shown their maximum values in Spring and Winter and their minimum values in Summer and Autumn (Fig.30).

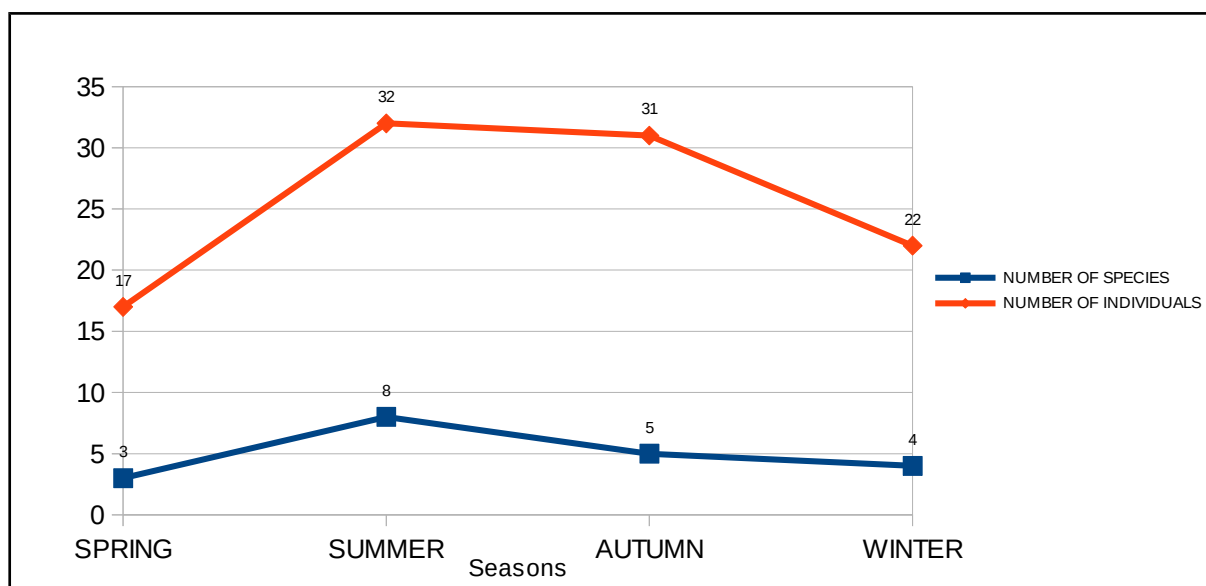


Fig. 30: seasonal variation of the abundance and diversity in the sediment.

Unlike the seasonal variations observed in the areas already analyzed, in this assemblage the peaks of abundances coincided with the seasons in which the *P. oceanica*. fragments are absent.

Community analysis showed that the class Polychaetae do not show a particular seasonal trend and the number of individuals collected was higher in Summer and Winter and lower in Autumn and Spring (Fig.31). The Isopods dominate in Autumn and were absent in Spring and Winter.

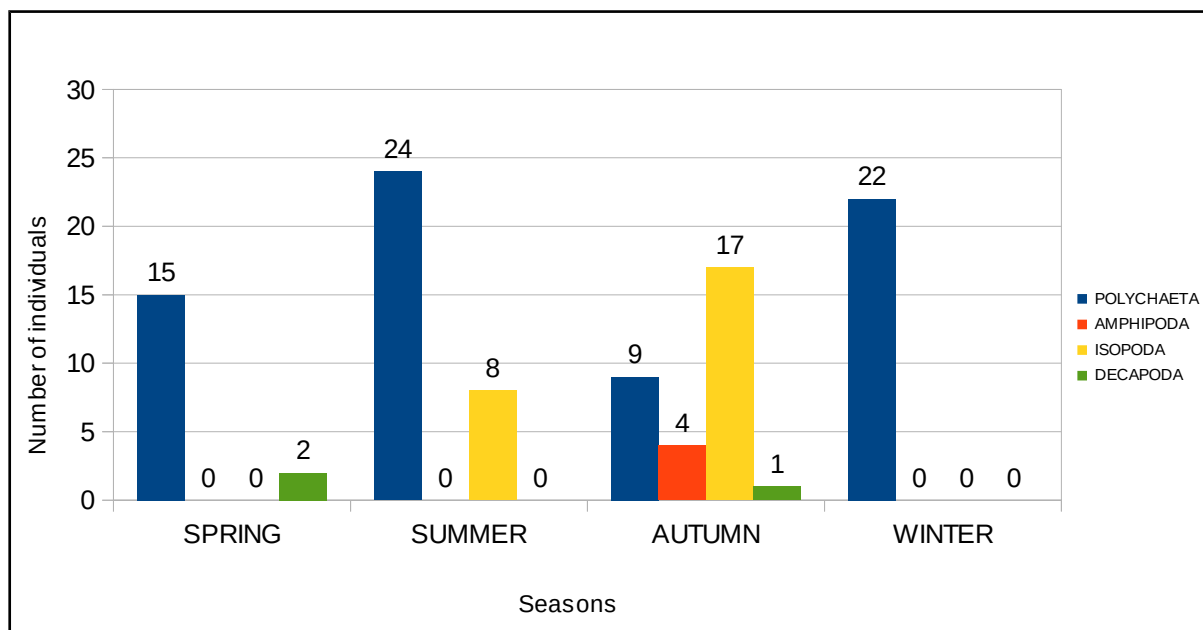


Fig. 31: seasonal variation of the taxa sampled in the sediments.

Table 5 shows the total abundance of the 15 species sampled in the sediment:

SPECIES	Nº OF INDIVIDUALS	PERCENTAGE CONTRIBUTION	FEEDING TYPE
<i>Scolelepis</i> sp.	25	24.50%	DEP
<i>Eurydice affinis</i>	17	16.66%	PRE
<i>Nereis pelagica</i>	17	16.66%	PRE
<i>Sphaeroma serratum</i>	8	7.84%	DET
<i>Timarete filigera</i>	8	7.84%	DEP
<i>Eteone picta</i>	7	6.86%	PRE
<i>Glycera tridactyla</i>	5	4.90%	PRE
<i>Hyale perieri</i>	4	3.92%	HERB
<i>Capitella capitata</i>	3	2.94%	DEP
<i>Portunus latipes</i>	2	1.96%	PRE
<i>Scoletoma emandibulata mabiti</i>	2	1.96%	PRE
<i>Arabella iricolor</i>	1	0.98%	PRE
<i>Paraonidae</i> IND	1	0.98%	DEP
<i>Protodirillea kefersteini</i>	1	0.98%	PRE
<i>Upogebia deltaura</i>	1	0.98%	SUSP

Tab. 5: species list.

The Class **Polychaetae** was most represented by the deposit feeder Spionid *Scolelepis* sp.; this sedentary worm uses its two long palps to collect food particles. It was observed that some species of the genus *Scolelepis* (such as *S. fuliginosa*, *S. squamata*, *S. tridentata*) were ecologically favored by the presence of organic input in the sediments (Hiscock et al., 2004.).

Also *Capitella capitata* (Fabricius, 1780) is a worm particularly resistant to the presence of high percentages of organic material in the substrates and is also a common species in areas that have

suffered an anthropogenic impact .(Hiscock et al., 2004).

The family Nereididae was present with only one species, *Nereis pelagica*; this shallow water predator was commonly collected on hard substrates colonized by photophilic algae. This species was found to be particularly sensible to hypoxia (Diaz & Rosenberg, 1995).

The deposit feeder *Timarete filigera* (Della Chiaje, 1828) belonging to the family Cirratulidae, was a species commonly sampled on coastal substrates with sandy or muddy components.

The **Isopods** community was composed by only two species: the predator *Eurydice affinis* Hansen, 1905 and the detritivorous *Sphaeroma serratum* (Fabricius, 1787). *E. affinis*, the second species in order of abundance, was a common intertidal crustacea of sandy beaches. The seasonal variations in the abundances and spatial distribution of this species were directly influenced by the tidal and circadian rhythms (Jones & Hobbins, 1985; Macquart-Moulin, 1977). The Sphaeromatid *S. serratum*, as the *Idotea baltica*, was a component of the mobile macrofauna associated with Submerged Detritus Accumulations (SDAs) of the seagrass *P. oceanica* (I. Gallmetzer et al., 2005).

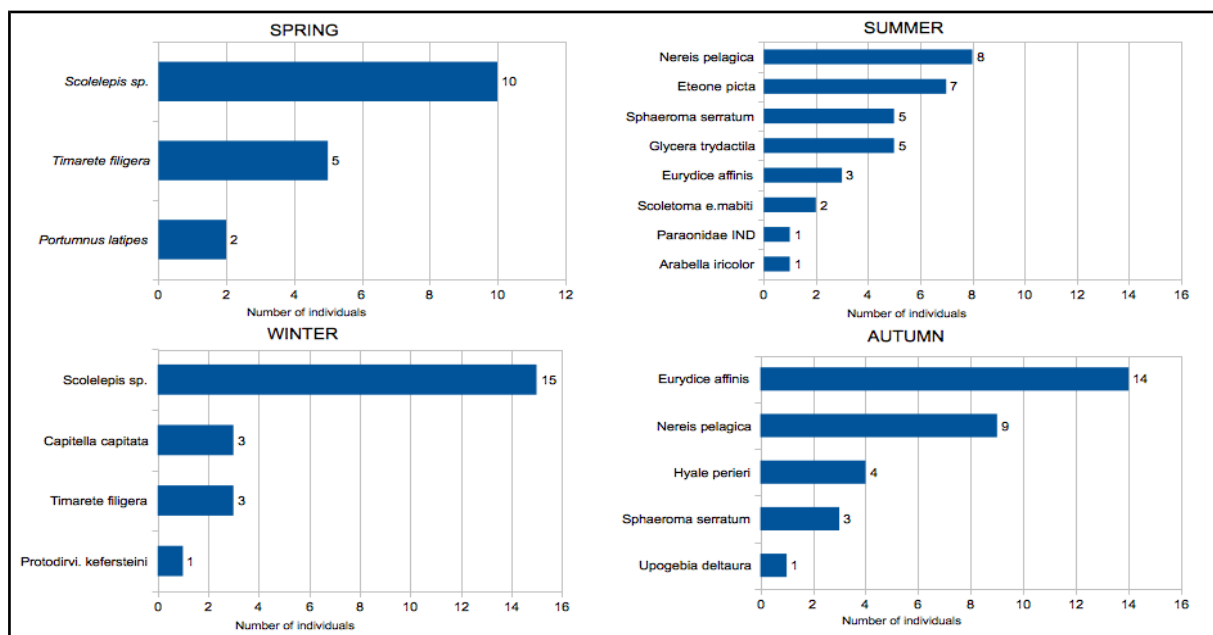


Fig. 32: seasonal abundances of the species sampled in the sediment.

Also in this community a relationship has been observed between its composition and the seasonal presence of *P. oceanica* leaf litter residues. In fact, both the seasonal analysis of the species abundances (Fig.32) and the trophic analysis (Fig.33) showed the presence of two different faunistic assemblages during the year: while in Spring and Winter (presence of fragments) the associated community was dominated by the deposit feeders *Scolecipis sp* and *Timarete filigera*, in Summer

and Autumn (absence of fragments) the community is mainly represented by the two predators, *Nereis pelagica* and *Eurydice affinis* (Some individuals of *Nereis pelagica* in the Heteronereis stage were collected in August). In these seasons the increase of the Isopod *Sphaeroma serratum* and the presence of Polychaete *Eteone picta* (Quatrefages, 1886) was also observed.

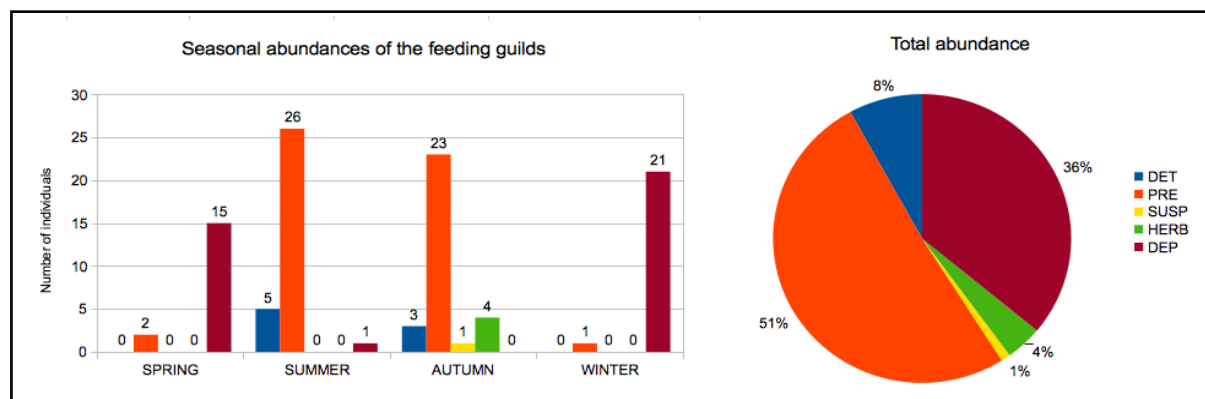


Fig. 33: seasonal variations of the feeding guilds in the sediment.

6.5 Discussion

In this study, for the first time, the effects of *P. oceanica* leaf litter (fragments and banquettes) on the *S. alveolata* biocostructions were analyzed and described.

The cyclical covering of some areas of the reef (Area 1 and 2), observed in Winter and Spring, has clear negative effects on the quality of the biocostructions and involves a clear change in the composition of the associated fauna. Moreover the effects of *P. oceanica* residue have also been observed in the macrozoobenthonic assemblage associated with sandy sediments adjacent to the reef.

Area 1, in which the presence of *P. oceanica* banquettes was observed, was the most damaged. In the blocks sampled in this area, the minimum number of individuals of *S. alveolata* has been collected in all the seasons and in particular the density of individuals undergoes a strong decrease in spring and winter.

From the temporal analysis of the morphological characteristics it was supposed that the decrease of quality of the bioconstruction, mainly observed when the *P. oceanica* fragments are most abundant, can be linked to a phase of destruction of this reef portion (Gruet, 1982). This thesis is also confirmed by the high number of associated species and individuals sampled in this area (maximum abundance and specific richness in the analyzed areas). Many studies observed that the biodiversity of the associated benthic macrofauna decreases in areas with high densities of the *S. alveolata* individuals, and they have emphasize that species richness is higher in degraded reef

zones (Gruet 1971, 1982; Porras et al, 1996; Dias & Paula 2001; Dubois, 2002, 2006; La Porta & Nicoletti 2009; Schlund et al, 2016). Moreover, two different community structures and species compositions have been observed related at the presence/absence of *P. oceanica* banquettes. In the months in which the bioconstructions are covered by plant debris the community is dominated by the herbivores *Gammarus insensibilis* and *Idotea baltica*, two important members of the seagrass detritus chains that are commonly found in *P. oceanica* leaf litter (Janssen et al., 1979; Bulheim & Fava, 1982; Mazzella et al., 1992; Mancinelli & Rossi, 2002; Orav-Kotta & Kotta, 2004; Gallmetzer et al., 2005).

In Summer and Autumn, when the reef is clean, the community is most represented by species already sampled in association with *S. alveolata* reefs and also common on shallow water hard substrates colonized by photophilic algae such as the Polychaetes *Nereis pelagica* and *Perinereis, marionii* and the Amphipod *Hyale perieri* (Dubuis, 2002; La Porta & Nicoletti, 2009).

The degradation status of this area is also highlighted by the presence of green algae, serpulids and mussels that partially cover the surfaces of bioconstructions. The epibionts, especially the green algae like *Ulva* spp., alter *S. alveolata* population structure, causing a reduction in new recruits that may cause significant damage to the reef structure over the long run (Dubois 2006). In addition, the presence of the suspension feeders *Mytilaster minimus* and *Pomatocerus lamarkii*, epibionts commonly observed on this substrates (Nicoletti et al., 2001; Dubois 2002, 2006; La Porta & Nicoletti, 2009), reveals the low quality of the bioconstructions. Porras et al. (1996) suggest that in areas with low *S. alveolata* density, the colonization by other suspensivorous species (epibionts) is favored because the presence of empty tubes and fractures that facilitate the larval settlement. Indeed the colonization is disadvantaged in high-density areas since the *S. alveolata* feeds on the newly settling larvae (Andrés et al., 1993)

Concerning the Area 2, the decrease of the associated fauna and the absence of green algae, the increase of density in *S. alveolata* individuals and the improvement of the morphological conditions could testify a better quality of this portions of the reef. Also in this area the negative effects, caused by the cyclic presence of resuspended *P. oceanica* fragments (linked to the presence of the banquettes in Area 1), result evident. In fact, in Spring and Winter (maximum presence of *P. oceanica* leaf litters) a strong decline was recorded in *S. alveolata* population and an increase in epibionts (*Mytilaster minimus* and *Pomatoceros lamarkii*) was observed on the surface of bioconstructions. The analysis of the associated fauna showed the dominance of the Polychaetae class most represented by *Eulalia ornata*, *Syllis amica*, *Syllig gracilis* and *Eumida sanguinea*. These predators species were previously listed among the *S. alveolata* reef-associated fauna (Dubuis, 2002; La Porta & Nicoletti, 2009, Schlund et al., 2016) but the Phyllodocid *Eulalia ornata*, one of

the most abundant species in the biocostructions of the Eastern Atlantic, was only recently reported in Italian Waters (Sicily Channel) in association with *S. alveolata* (Scimmenti et al., 2016). This work increases the knowledge of this species and represents the first segnalation of this Polychaete in the Tyrrhenian Sea.

Higher quality bioconstructions were observed in Area 3 (lower specie richness, absence of epibionts, good morphological conditions and maximum density of *S. alveolata*) classifying this portion of the reef in the growth phase (Gruet 1971, 1986). The associated fauna, dominated by Sillids and *E. ornata*, were comparable with those observed in the Area 2 and showed a dominance of the Polychaetes predators. In this area the presence of fragments of *P. oceanica* was not observed and the biocostructions are located in the portion of the breakwater most exposed to the waves action and probably the hydrodynamic regime represented the main factor influencing the biocostructions developments. The reefs situated in the most exposed coastal areas generally show a high percentage of *S. alveolata*, because wave action supplies food, sediment for tubes costruction and cleans the surface of biocostructions (Dias & Paula, 2001; La Porta & Nicoletti, 2009). Probably the decrease in the density of *S. alveolata*, recorded in Spring and in Winter, was linked to the adverse marine conditions that characterize these seasons: the action of strong waves can also damage or even destroy the reefs (Gruet, 1982; Dias & Paula, 2001).

Finally, the effects of the cyclic presence of *P. oceanica* fragments and banquettes were observed in the fauna associated with the sandy sediments surrounding the reef. In Winter and Spring a very high number of individuals of *Gammarus insensibilis* and *Idotea baltica* have been sampled in the accumulation of *P. oceanica* leaf debris that covers the seabed. In these seasons the faunal assemblage shows the dominance of the deposit feeder *Scolecopsis sp.* The increase of this species was probably favored by the presence of *P. oceanica* detritus in decomposition. In fact it was observed that some species of the genus *Scolecopsis* (such as *S. fuliginosa*, *S. squamata*, *S. tridentata*) was ecologically favored by the presence of organic input in the sediments (Hiscock et al., 2004). In Summer and Autumn, when the seabed was clean, the communities showed an increase of the number of species and individuals with a drastical change in the benthic assemblage. In this seasons the most abundant species were the predator *Eurydice affinis*, a common intertidal Isopod of sandy beaches, and the Polychaeta *Nereis pelagica* which was also collected in the neighboring bioconstructions of *S. alveolata*.

6.6 Conclusions

The honeycomb worm *Sabellaria alveolata* is an important ecosystem engineer (Commito et al., 2005) and its reefs are subject to various disturbances causing changes both in the morphological features of the biocostructions and in richness and composition of the associated fauna (Gruet, 1982; Dubois et al., 2002, 2006; Plicanti et al., 2016).

Our results demonstrate that the presence of supra and meso-littoral deposit of *P. oceanica* leaf litter (banquettes and resuspended fragments) alter the *S. alveolata* population structure both causing a significant decrease of the quality of the biocostructions and promoting the increase of epibionts.

Moreover the seagrass litter affects the species assemblage associated with the *S. alveolata* bioconstructions and also the other associated with the sediments surrounding these structures.

This research has increase the knowledge of these biocostructions also by the segnalation and description of some new species associaed at the *S.alveolata* reefs of the Tyrrenian sea.

7. Photographic collection

Rhizoma stratum:

Platynereis dumerilii (Audouin & Milne Edwards, 1834)

Class: Polychaeta

Order: Phyllodocida

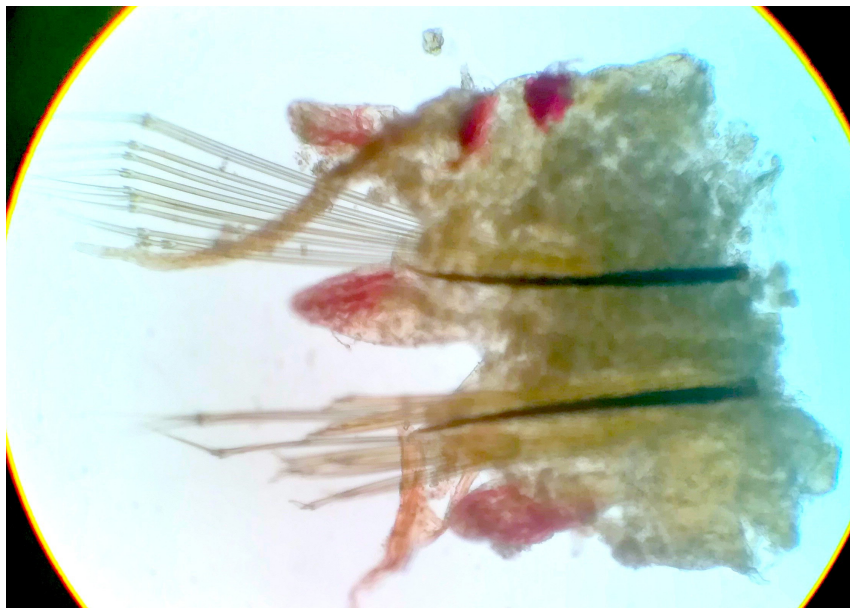
Family: Nereididae



Total body



Head



Anterior parapodia



Posterior homogomph
falciger

Nereis rava Ehlers, 1868

Class: Polychaeta
Order: Phyllodocida
Family: Nereididae



Anterior end



Anterior parapodia

Psamathe fusca Johnston, 1836
ex *Kefersteinia cirrhata* (Keferstein, 1862)

Class: Polychaeta
Order: Phyllodocida
Family: Hesionidae



Anterior end



Median parapodia

***Ericthonius punctatus* (Spence Bate, 1857)**

Class: Malacostraca

Order: Amphipoda

Family: Ischyroceridae



Male and Female



Gnathopod 2 (Male)



Pereiopod 3



Pereiopod 7 (Basis)

***Leptocheirus guttatus* (Grube, 1864)**

Class: Malacostraca

Order: Amphipoda

Family: Corophiidae



Male = Female



Urosome

***Chondrochelia savignyi* (Kroyer, 1842)**

Class: Malacostraca

Order: Tanaidacea

Family: Leptocheliidae



Head (Female)



Chelipeds

Callochiton septemvalvis (Montagu 1803)

Class: Polyplacophora

Order: Chitonida

Family: Callochitonidae



Cromatics patterns



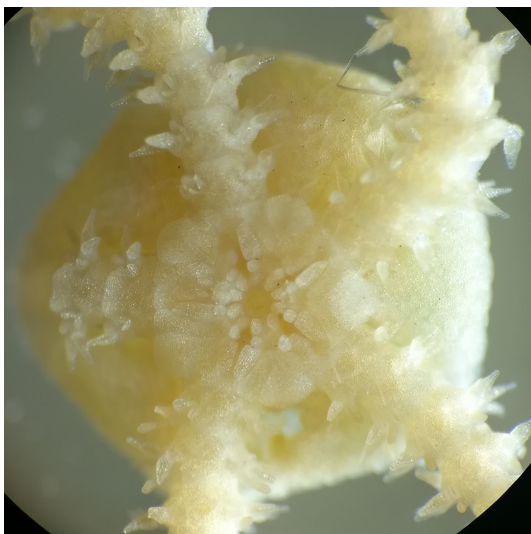
Total red pattern

Amphipholis squamata (Delle Chiaje, 1828)

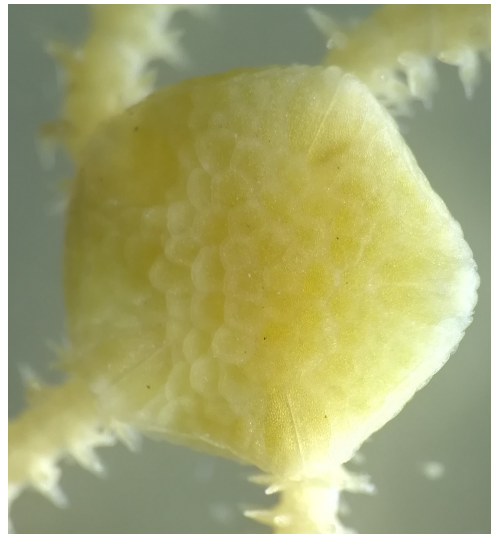
Class: Ophiuroidea

Order: Ophiurida

Family: Amphiuridae



Central disc (oral surface)



Central disc (aboral surface)

Leafs stratum

Hippolyte inermis Leach, 1816

Class: Malacostraca

Order: Decapoda

Family: Hippolytidae



Male



Rostrum

Siriella clausii G.O. Sars, 1877

Class: Malacostraca

Order: Mysida

Family: Mysidae



Lateral view



Telson

Photis longicaudata (Spence Bate & Westwood, 1862)

Class: Malacostraca

Order: Amphipoda

Family: Photidae



Male



Gnathopod 2 (male)



Head

***Stenosoma* CONF. *appendiculatum* (Risso, 1816)**

Class: Malacostraca

Order: Isopoda

Family: Idoteidae



Adult



Juvenile (?)

***Gnathia* CONF. *vorax* (Lucas, 1849)**

Class: Malacostraca

Order: Isopoda

Family: Gnathiidae



Male



Head

Sands pools

Aponuphis brementi (Fauvel, 1916)

Class: Polychaeta

Order: Eunicida

Family: Onuphidae



Anterior end (dorsal side)



Anterior end (ventral side)



Compound falciger (second parapodium)

Pseudomystides limbata (Saint-Joseph, 1888))

Class: Polychaeta

Order: Phyllodocida

Family: Phyllodocidae



Anterior end



Head



Dorsal cirrus

***Gammarella fucicola* (Leach, 1814))**

Class: Malacostraca
Order: Amphipoda
Family: Nuuanuidae



Male



Urosome

***Maera grossimana* (Montagu, 1808)**

Class: Malacostraca
Order: Amphipoda
Family: Maeridae



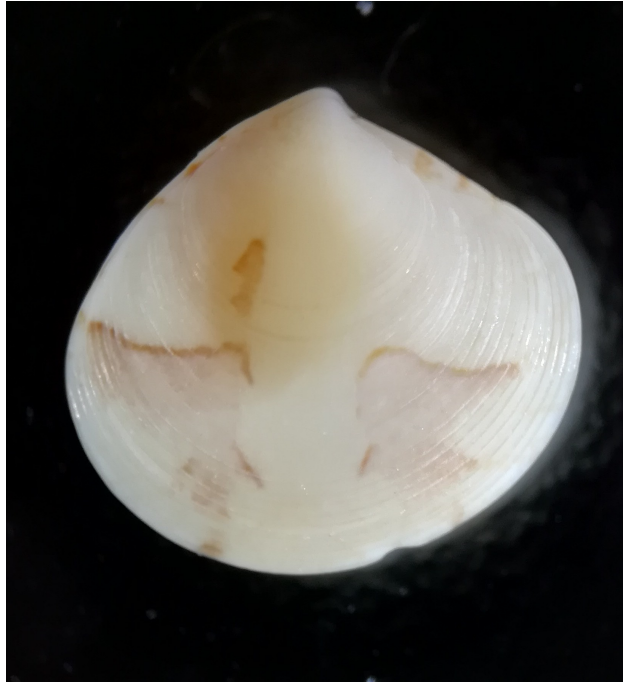
Male



Gnathopod 2 (male)

Gouldia minima (Montagu, 1803)

Class: Bivalvia
Order: Venerida
Family: Veneridae



Ebalia edwardsii Costa, 1838

Class: Malacostraca
Order: Decapoda
Family: Leucosiidae



Species sampled on *Sabellaria alveolata* biocostructions.

Sabellaria alveolata (Linnaeus, 1767)

Class: Polychaeta

Family: Sabellariidae



Ventral side



Operculum

***Idotea balthica* (Pallas, 1772)**

Class: Malacrostaca

Order: Isopoda

Family: Idoteidae



Different chromatics patterns



Head

***Eurydice* CONF. *affinis* Hansen, 1905**

Class: Malacrostaca

Order: Isopoda

Family: Cirolanidae



Dorsal chromatic pattern



Lateral view

Gammarus insensibilis Stock, 1966

Class: Malacrostaca

Order: Anhipoda

Family: Gammaridae



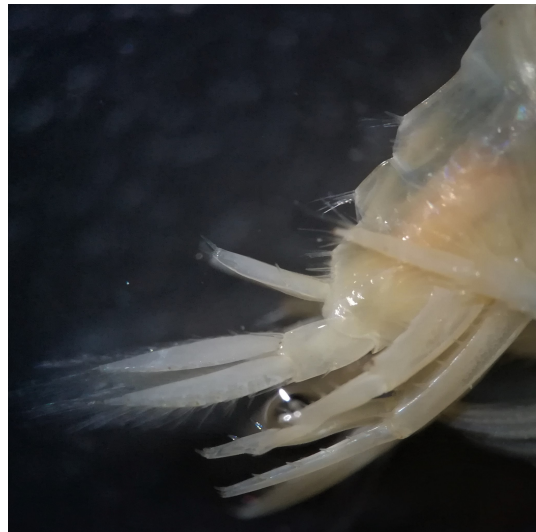
Adult



Adult



Head



Urosome

Jassa ocia Spence Bate, 1862

Class: Malacrostaca
Order: Anhipoda
Family: Ischyroceridae



Adult (male)



Head



Urosome



Gnathopods

Nereis pelagica Linnaeus, 1758

Class: Polychaeta
Order: Phyllodocida
Family: Nereididae



Anterior end



Anterior end
(Heteronereis?)



Pharynx (ventral side)



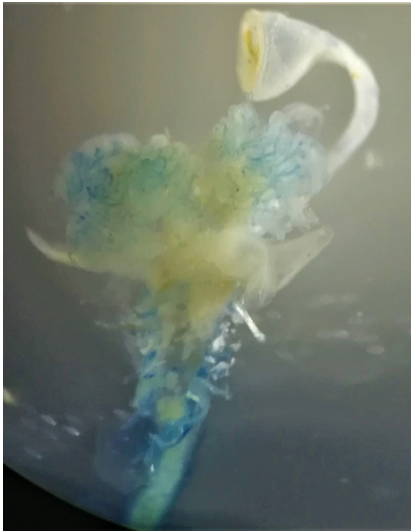
Pharynx (dorsal side)

Pomatoceros lamarckii Quatrefages, 1866

Class: Polychaeta

Order: Sabellida

Family: Serpulidae



Anterior end



Operculum

Scolelepis sp.

Class: Polychaeta

Order: Spionida

Family: Spionidae



Lateral view



Anterior end

Overall conclusions

A total of 290 taxa and 2.829 organisms (plus 3.970 *S. alveolata* individuals) were studied in this work. These included Polychaeta 1.088 (130 species), Amphipoda 704 (52 species), Isopoda 199 (14 species), Decapoda 116 (19 species), Tanaidacea 51 (3 species), Mysida 41 (1 species), Gasteropoda 100 (20 species), Bivalvia 262 (23 species), Echinodermata 57 (11 species) and Sipuncula 20 (4 species). The remaining 161 individuals were from taxa less representative of the Macrozoobenthonic communities, such as Oligochaeta, Nematoda and Chaetognata. Only 12.9% of these organisms could not identified at the species level.

The study of benthic communities has also allowed the determination of ecological quality in the study area through the use of the AMBI and M-AMBI indices. During all seasons, the quality of macroinvertebrate assemblages was high, and the area was classified as ‘slightly disturbed’.

Moreover, during the taxonomic identification phase, four alien organisms associated with *P. oceanica* were reported (*Caprella scaura*, *Parantura japonica*, *Mesanthura* sp. and *Paracerceis sculpta*). Among these, the Isopod *Mesanthura* sp. was recorded for the first time in the northern Tyrrhenian Sea. The rare Polychaeta Sabellid *Acromegalomma messapicum* was observed for the first time in the Tyrrhenian Sea, making this the second report of this species ever. This find added some useful morphological and biological information to the original description of this species. The discovery of these species highlights the importance of *P. oceanica* meadows as a biodiversity hotspot and emphasizes the ability of this plant to create various ecological niches useful for the colonization and sustenance of rare and alien species.

The experimental investigations conducted on *P. oceanica* meadows have confirmed a role for seagrass in the particle sedimentary process. This study also showed how this interaction has a direct effect on the structure of fauna assemblage. Proceeding from the bottom toward the leaves, a vertical gradient of stability was clearly observed. The leaf stratum fauna is the most variable and it is strongly dependent on the growth of leaves. Thus, the population of rhizomes is more susceptible to sedimentary dynamic regimes associated with particles, which cause a shift in the trophic categories despite populations in the sand pool remaining quite stable during the year. The capacity of a *P. oceanica* meadow in particle retention, especially during the maximum growth of leaves, favours the accumulation of organic matter and sediment. This contributes to ‘matte’ accretion and provides a habitat and food for benthic species that live in the rhizome-matte stratum.

Finally, our results demonstrate that the presence of supra and meso-littoral deposits of *P. oceanica* leaf litter (banquettes and resuspended fragments) alter the *S. alveolata* population structure, causing a significant decrease in the quality of the bioconstructions and increasing the population of epibionts. The seagrass litter affects both the species assemblage associated with the *S. alveolata* bioconstructions and the communities associated with the sediments surrounding these structures.

9. Literature references

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ANNEX 1

Species list (*Posidonia oceanica*)

Taxa	Autumn	Winter	Spring	Summer
<i>Achelia</i> sp.	-	-	+	+
<i>Acheus cranci</i>	-	-	+	-
<i>Adyte pellucida</i>	-	+	-	-
<i>Alpheus</i> sp.	-	-	+	+
<i>Alvania cimex</i>	+	-	-	-
<i>Alvania discors</i>	+	-	-	+
<i>Alvania lineata</i>	+	-	-	-
<i>Alvania</i> sp.	-	-	+	+
<i>Ampelisca rubella</i>	-	-	+	-
<i>Ampelisca diadema</i>	+	-	-	-
<i>Ampelisca</i> sp.	-	-	+	+
<i>Amphipoda</i> IND	-	+	+	+
<i>Amphipolis squamata</i>	+	+	+	+
<i>Amphithoe helleri</i>	-	-	+	+
<i>Amphiura apicula</i>	-	-	-	+
<i>Amphiura chiajei</i>	-	+	-	-
<i>Ampipholis squamata</i>	-	-	-	+
<i>Ampithoe ramondi</i>	-	-	+	+
<i>Ampithoe</i> sp.	-	-	+	+
<i>Anapagurus</i> sp.	-	-	+	-
<i>Amphipoda</i> IND	+	-	+	+
<i>Anthuridae</i> IND	-	-	+	+
<i>Aora spinicornis</i>	+	+	-	+
<i>Aphelochaeta</i> sp.	-	-	-	+
<i>Aphelochaeta filiformis</i>	+	-	-	-
<i>Aphelochaeta multibranchis</i>	+	-	-	-
<i>Apherusa chireghinii</i>	-	+	+	+
<i>Aphroditidae</i> IND	+	-	-	-
<i>Aponuphis brementi</i>	+	+	+	+
<i>Apseudes</i> sp.	+	-	+	+

<i>Arabella geniculata</i>	+	-	-	+
<i>Arabella iricolor</i>	-	-	+	-
<i>Arca noae</i>	-	+	-	-
<i>Aricidea</i> sp.	-	-	+	-
<i>Armandia cirrhosa</i>	-	-	+	-
<i>Aspidosiphon muelleri</i>	+	-	+	+
<i>Asterina gibbosa</i>	-	-	-	+
<i>Asterina panceri</i>	-	-	+	-
<i>Asterina</i> sp.	-	+	-	+
<i>Athylus guttatus</i>	-	-	+	-
<i>Barbatia barbata</i>	-	-	+	-
<i>Bittium reticulatum</i>	+	-	-	+
<i>Bivalvia</i> IND	+	-	-	-
<i>Branchiomma bombyx</i>	+	+	+	-
<i>Branchiomma</i> sp.	-	-	-	+
<i>Branchiostoma lanceolatum</i>	+	-	-	-
<i>Calcinus tubularis</i>	-	-	-	+
<i>Callochiton septemvalvis</i>	-	+	+	+
<i>Caprella achantifera</i>	-	-	+	+
<i>Caprella danilevskii</i>	-	-	+	-
<i>Caprella scaura</i>	-	-	+	-
<i>Caulleriella alata</i>	+	-	+	-
<i>Caulleriella</i> sp.	-	-	-	+
<i>Cerithiopsis tubercularis</i>	+	-	-	-
<i>Cestopagurus timidus</i>	-	-	+	-
<i>Chaetognata</i> IND	-	-	+	+
<i>Chaetozone</i> sp.	-	-	+	+
<i>Chiton olivaceus</i>	+	-	-	-
<i>Chlamys varia</i>	-	-	+	-
<i>Chondrochelia savignyi</i>	+	+	+	+
<i>Chone duneri</i>	+	-	-	-
<i>Chone</i> sp.	-	-	-	+
<i>Chrysopetalium debile</i>	-	-	+	-
<i>Cirratulidae</i> IND	+	-	-	+

<i>Cirratulus cirratus</i>	-	-	+	-
<i>Cirriformia tentaculata</i>	+	-	+	-
<i>Cumacea</i> IND	-	+	+	-
<i>Cymodoce henseni</i>	+	+	+	+
<i>Decapoda</i> IND	+	-	-	-
<i>Dexamine spiniventris</i>	+	-	+	-
<i>Dexamine spinosa</i>	+	-	+	+
<i>Dexamine thea</i>	-	-	-	+
<i>Diadematidae</i> juv.	-	-	+	-
<i>Dialychone collaris</i>	-	+	+	-
<i>Diopatra</i> sp.	+	+	-	-
<i>Dodecearia concharum</i>	-	-	+	-
<i>Donax trunculus</i>	+	-	-	-
<i>Dorvillea</i> sp.	+	-	-	+
<i>Dynamene edwardsi</i>	-	-	+	-
<i>Ebalia edwardsii</i>	-	-	+	-
<i>Elasmopus brasiliensis</i>	+	-	-	-
<i>Elasmopus poecilomanus</i>	-	-	-	+
<i>Elasmopus</i> sp.	+	+	+	-
<i>Enoplus meridionalis</i>	-	-	+	+
<i>Erichthonius punctatus</i>	+	+	+	+
<i>Eriopisa coeca</i>	-	-	+	+
<i>Eulalia</i> sp.	-	-	-	+
<i>Eunice pennata</i>	+	+	-	-
<i>Eunice vittata</i>	+	+	-	+
<i>Eunicida</i> IND	-	+	-	-
<i>Eupolymia nebulosa</i>	-	-	+	+
<i>Eurydice</i> sp.	-	-	-	+
<i>Eurysillys tuberculata</i>	-	+	+	+
<i>Exogone</i> spp.	-	-	+	+
<i>Fabricidae</i> IND	-	-	+	-
<i>Gammarella fucicola</i>	-	+	+	+
<i>Gammaropsis maculata</i>	+	-	+	-
<i>Gammaropsis</i> sp.	-	-	-	+

<i>Genocidaris maculata</i>	+	-	-	-
<i>Gibberula miliaria</i>	-	+	-	-
<i>Glans trapezia</i>	+	+	+	+
<i>Glycera alba</i>	+	-	-	+
<i>Glycera fallax</i>	+	-	+	+
<i>Glycera</i> IND	-	-	-	+
<i>Glycera lapidum</i>	-	-	+	+
<i>Glycera trydactila</i>	-	-	-	+
<i>Glycera unicornis</i>	-	-	-	+
<i>Gnathia</i> conf. <i>vorax</i>	-	+	+	+
<i>Golfingia elongata</i>	+	-	-	-
<i>Golfingia vulgaris</i>	-	-	+	+
<i>Goniada emerita</i>	-	-	+	-
<i>Goniadella</i> sp.	-	-	+	+
<i>Gouldia minima</i>	-	+	+	+
<i>Harmothoe reticulata</i>	+	+	+	+
<i>Hiatella arctica</i>	-	-	+	+
<i>Hippolyte inermis</i>	-	+	+	+
<i>Holothuria helleri</i>	-	+	+	-
<i>Hyale schmidtii</i>	+	-	+	+
<i>Hydroides helmatus</i>	-	+	-	-
<i>Hydroides nigra</i>	-	-	-	+
<i>Hippolyte helmata</i>	+	-	-	-
<i>Idunella</i> sp.	-	-	+	-
<i>Iphimedia</i> sp.	-	-	-	+
<i>Ischnochiton rissoi</i>	+	-	-	-
<i>Iscnochyton septemvalvis</i>	+	-	-	-
<i>Isopoda</i> IND	-	-	+	-
<i>Jujubinus striatus</i>	-	-	-	+
<i>Kefersteina cirrhata</i> (<i>Psamathe fusca</i>)	+	+	+	+
<i>Lepadogaster lepadogaster</i>	-	-	-	+
<i>Lepidonotus clava</i>	-	-	-	+
<i>Leptocheirus guttatus</i>	+	+	+	+
<i>Leucothoe</i> sp.	-	-	+	-

<i>Lilljeborgia dellavallei</i>	+	+	+	+
<i>Limnoria</i> conf. <i>mazzellae</i>	+	-	+	+
<i>Lucinella divaricata</i>	+	+	-	-
<i>Lumbrinereis coccinea</i>	+	-	+	-
<i>Lysianassa costae</i>	-	-	+	-
<i>Lysianassidae</i> IND	+	-	-	-
<i>Lysidice collaris</i>	+	+	+	-
<i>Lysidice ninetta</i>	+	-	-	-
<i>Macropodia</i> sp.	+	-	-	-
<i>Mactra corallina</i>	+	-	-	-
<i>Maera grossimana</i>	+	-	+	+
<i>Maldanidae</i> IND	-	+	-	+
<i>Acromegalomma messapicum</i>	+	+	+	+
<i>Melita palmata</i>	-	-	-	+
<i>Melita</i> sp.	-	-	+	-
<i>Mesanthura</i> sp.	+	+	+	+
<i>Microdeutopus chelifer</i>	+	-	+	+
<i>Microdeutopus</i> sp.	+	+	-	-
<i>Modiolus barbatus</i>	+	-	-	-
<i>Moerella donacina</i>	+	+	-	+
<i>Monoculodes acutipes</i>	-	-	-	+
<i>Monticellina dorsobranchialis</i>	+	-	+	+
<i>Muricopsis</i> sp.	-	-	+	+
<i>Musculus costulatus</i>	+	+	+	-
<i>Nassarius incrassatus</i>	-	-	+	-
<i>Neanthes caudata</i>	-	-	-	+
<i>Nematalycidae</i> IND	-	-	+	-
<i>Nematoda</i> IND	+	+	+	+
<i>Nematonereis unicornis</i>	-	+	-	-
<i>Nemertino</i> IND	-	-	+	-
<i>Nereididae</i> sp.	+	-	-	-
<i>Nereis rava</i>	+	+	-	+
<i>Nereis</i> sp.	-	+	+	-
<i>Notomastus latericeus</i>	+	+	+	+

<i>Notomastus lineatus</i>	-	-	+	-
<i>Ocnus syracusanus</i>	-	+	-	-
<i>Onuphiidae</i> IND	+	-	-	-
<i>Ophelia</i> conf. <i>limacina</i>	-	-	-	+
<i>Ophelia</i> conf. <i>neglecta</i>	-	+	-	-
<i>Ophiothrix quinquemaculata</i>	-	-	-	+
<i>Paracerceis sculpta</i>	-	-	+	+
<i>Paguristes syrtensis</i>	-	-	+	-
<i>Pagurus anachoretus</i>	-	+	-	-
<i>Palliolum tigerinum</i>	-	-	-	+
<i>Pantopoda</i> IND	-	-	+	-
<i>Papillicardium papillosum</i>	+	-	-	-
<i>Paranthura japonica</i>	-	-	+	+
<i>Parapionosyllis elegans</i>	+	-	-	-
<i>Paraprionospio multibranchiata</i>	-	-	+	-
<i>Parasabella langerhansi</i>	-	-	+	+
<i>Parvicardium</i> sp.	-	-	+	-
<i>Pholoe inornata</i>	-	+	-	-
<i>Photis longicaudata</i>	-	+	+	+
<i>Phyllodocidae</i> IND	+	-	+	+
<i>Pilumnus hirtellus</i>	+	-	+	+
<i>Piromis eruca</i>	-	+	+	+
<i>Pisidia bluteli</i>	-	-	-	+
<i>Pista maculata</i>	+	-	-	-
<i>Pistella unibranchia</i>	-	-	+	+
<i>Plagiocardium papillosum</i>	+	-	-	-
<i>Plagiocardium</i> sp.	-	-	-	+
<i>Platynereis</i> conf. <i>coccinea</i>	-	-	-	+
<i>Platynereis dumerilii</i>	+	+	+	+
<i>Polycaeta</i> IND	+	+	+	+
<i>Polydora agasszyi</i>	-	-	-	+
<i>Polyophtalmus pictus</i>	+	-	+	-
<i>Pontocrates arenarius</i>	+	-	-	-
<i>Pontogenia chrysocoma</i>	+	-	+	-

<i>Prionospio</i> sp.	+	-	-	-
<i>Processa edulis</i>	-	-	+	-
<i>Prothiostomum</i> sp.	-	-	+	-
<i>Protodorvillea kefersteini</i>	+	+	+	+
<i>Pseudomystides limbata</i>	+	-	+	+
<i>Pterocirrus</i> sp.	-	-	+	+
<i>Pusillina</i> sp.	-	-	+	+
<i>Quadrimaera inaequipes</i>	+	+	+	+
<i>Rissoa auriscalpium</i>	-	-	-	+
<i>Rissoa ventricosa</i>	-	-	+	+
<i>Rissoa</i> sp.	+	+	+	+
<i>Rissoa violacea</i>	+	-	-	+
<i>Rissoidae</i> IND	-	-	+	-
<i>Saballidae</i> IND	+	+	+	+
<i>Sabellaria spinulosa</i>	+	-	+	-
<i>Scolecopsis</i> sp.	-	-	-	+
<i>Scoloplos typicus</i>	-	-	-	+
<i>Serpula concharum</i>	-	-	+	+
<i>Serpula vermicularis</i>	-	-	+	+
<i>Sipuncula</i> IND	-	-	+	-
<i>Sirpus zariquieyi</i>	+	+	+	-
<i>Spaerosyllis</i> conf. <i>hystrix</i>	+	+	+	+
<i>Sphaerosyllis</i> conf. <i>pirifera</i>	-	+	-	-
<i>Sphaerosyllis</i> spp.	-	-	+	+
<i>Spio</i> sp.	-	-	+	-
<i>Spionidae</i> IND	-	-	-	+
<i>Stenosoma appendiculatum</i>	-	+	+	+
<i>Striarca lactea</i>	+	+	+	+
<i>Sycon raphanus</i>	-	-	+	-
<i>Syllis rosea</i>	-	-	+	-
<i>Syllis garciai</i>	-	+	-	+
<i>Syllis gracilis</i>	-	-	-	+
<i>Syllis prolifera</i>	-	-	-	+
<i>Syllis spongicola</i>	+	+	-	+
<i>Syllis</i> spp.	+	+	+	+
<i>Syriella clausii</i>	-	+	+	+
<i>Tanais</i> sp.	-	-	+	+
<i>Tectura virginea</i>	-	-	+	+

<i>Terebellidae</i> IND	-	-	-	+
<i>Thelepus cincinnatus</i>	-	-	+	-
<i>Timarete filigera</i>	-	-	+	-
<i>Tricolia pullus pullus</i>	-	-	+	-
<i>Tricolia speciosa</i>	+	-	+	+
<i>Tritaeta gibbosa</i>	-	-	-	+
<i>Urothoe elegans</i>	-	-	+	-
<i>Urothoe</i> sp.	+	-	-	-
<i>Venericardia antiquata</i>	-	-	+	+
<i>Venus casina</i>	-	+	-	-
<i>Venus verrucosa</i>	+	+	-	+
<i>Xaiva biguttata</i>	-	-	-	+