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EFFECTS OF SHALLOW WATER HYDROTHERMAL VENTS ON PHYTOBENTHIC COMMUNITIES

Tutors
Prof. **Sebastiano Calvo**

Prof. **Jordi Rull Lluch**

PH.D. student
Dr. **Giancarlo Bellissimo**

Coordinator
Prof. **Sebastiano Calvo**

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Sebastiano Calvo
(Coordinator and Tutor)

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Jordi Rull Lluch
(Tutor)

“Being prepared is important, learn to wait is more important,

but take the right time is the key to life”

Arthur Schnitzler (1862-1931)

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All errors and limitations remaining in this thesis are mine alone.

Giancarlo Bellissimo
University of Palermo
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Abstract

There are high levels of uncertainty about how coastal ecosystems will be affected by rapid ocean acidification caused by anthropogenic CO_2, due to a lack of data. The few experiments to date have been short-term (<1 year) and reveal mixed responses depending on the species examined and the culture conditions used. It is difficult to carry out long-term manipulations of CO_2 levels, therefore areas with naturally high CO_2 levels are being used to help understand which species, habitats and processes are resilient to the effects of ocean acidification, and which are adversely affected. Here the effects of increasing CO_2 levels (and the associate change in seawater pH) caused by volcanic vents on phytobenthic communities are described. For it, two communities were studied in a shallow hydrothermal vent area off the coast of Panarea, in the Aeolian Islands (Tyrrhenian Sea, Italy): the community of *Cystoseira brachycarpa* and that of the epiphytes of *Posidonia oceanica* leaves. In this area, two sites were selected: one nearby to the islet of Bottaro, at about 7 m depth, within a hydrothermally active area characterized by low pH and continuous gas emissions with concentrations dominated by CO_2 and H_2S; the other nearby to the islet of Lisca Nera, also at about 7 m depth, where no hydrothermal activity were observed and characterized by a normal pH condition. Concerning the study of *C. brachycarpa* community, at the first site samples were collected along a transect from the vent outlets towards outside, seemengly corresponding to a pH gradient. The epiphytes of *P. oceanica* leaves were only studied at Bottaro, in two patched meadows exposed to different levels of gas emission. Regarding the community of *C. brachycarpa*, differences between sites and along the transect were detected, not only in the species composition and structure but also in the size and abundance *C. brachycarpa*, the dominant species of the community. The vast majority of the 101 macroalgal species studied in two periods of the year (June and October) were able to grow with a 36% decrease in species richness as the mean pH fell from 8.1 to 7.2. This fall in species richness was associated with shifts in community structure as the coverage of algae

decreased disproportionately. Calcitic calcareous species (encrusting and erected) were significantly reduced in coverage and species richness, whereas a few non-calcified species became dominant. Nearby to the vents, at mean pH 6.9, calcareous species were absent and there was a 40% fall in species richness. Under these extremely high CO_2 conditions a few species dominated the simplified *C. brachycarpa* community and a very few exhibited enhanced reproduction, although high CO_2 levels seemed to inhibit reproduction in others. Conversely, a dense canopy of fertile *C. brachycarpa* was found in the community far from vents, showing a similar composition and structure to the assemblages of literature data, as well as a greater proportion of fertile species. Concerning the community of epiphytes of *P. oceanica* leaves, no significant differences in the structure and species composition were detected between both meadows investigated. Conversely, a reduction of 60% of the mean shoot surface in the meadow closer to vents was detected.

Our data have showed that many macroalgal species are tolerant of long-term elevations in CO_2 levels but that macroalgal habitats are altered significantly as pH drops, contributing to a scant but growing body of evidence concerning the long-term effects of CO_2 emissions in marine systems. Although the hydrothermal system of Panarea has to be considered a «shallow» system, it shows many characteristics that make it similar to the «deep» oceanic systems, giving a unique opportunity for improving our knowledge on such an unexplored world by working at this easily accessible site.

Resumen

La escasa información disponible hasta el momento no permite saber con certeza cómo se verán afectados los ecosistemas costeros por la rápida acidificación del océano causada por las emisiones antropogénicas de CO_2. Los pocos experimentos realizados hasta ahora han sido a corto plazo (<1 año) y revelan respuestas mixtas dependiendo de las especies estudiadas y de las condiciones de cultivo utilizadas. Puesto que resulta difícil realizar manipulaciones de los niveles de CO_2 a largo plazo, las zonas con niveles naturalmente elevados de CO_2 se están utilizando para llevar a cabo estudios que permitan entender qué especies, hábitats y procesos son resistentes a los efectos de la acidificación de los océanos, y cuales se ven afectados negativamente. En este trabajo se describen los efectos del aumento del nivel de CO_2 en el agua de mar (y del cambio de pH asociado) causado por las surgencias hidrotermales submarinas en las comunidades fitobentónicas. Para ello, se han estudiado las comunidades de *Cystoseira brachycarpa* y de los epífitos de las hojas de *Posidonia oceanica* en un área hidrotermal poco profunda situada frente a las costas de la isla de Panarea, en el archipiélago de las Islas Eolias (Mar Tirreno, Italia). En esta zona, se escogieron dos localidades de muestreo: una próxima al islote de Bottaro, a unos 7 m de profundidad y dentro de un área hidrotermalmente activa caracterizada por un pH bajo y la emisión continua de fluidos hidrotermales ricos en gases (principalmente CO_2 y H_2S) fácilmente visibles por la existencia de burbujeo; la otra, cercana al islote de Lisca Nera, también a unos 7 m de profundidad, con valores de pH normales y donde no se apreciaba actividad hidrotermal. Además, para el estudio de la comunidad de *C. brachycarpa*, en Bottaro se escogieron cuatro puntos de muestreo distribuidos a lo largo de un transecto que se alejaba progresivamente de las surgencias. La comunidad de epífitos de las hojas de *P. oceanica* se estudió únicamente en la localidad de Bottaro, en dos praderas fragmentadas, una próxima a las surgencias y la otra alejada de ellas. Por lo que se refiere a la comunidad de *C. brachycarpa*, los resultados mostraron diferencias importantes entre las dos localidades de muestreo y a lo largo del

transecto de Bottaro, no sólo en la composición y estructura sino también en el tamaño y la abundancia de *C. brachycarpa*, la especie dominante de la comunidad. El 64% de las especies encontradas en la comunidad de *C. brachycarpa* fueron capaces de sobrevivir a un pH de 7.2. Esta disminución en el número total de especies se relaciona con ciertos cambios en la estructura de la comunidad, como una fuerte disminución en la abundancia de las algas propias del subestrato erecto. El número de especies de Corallinales (algas calcáreas constituidas por calcita) y su abundancia (recubrimiento) se redujeron significativamente, mientras que unas pocas especies no calcificadas se convirtieron en especies dominantes. Cerca de las surgencias, a un pH medio de 6,9, el número total de especies de la comunidad disminuyó un 72% y no se observaron especies del orden Corallinales. En estas condiciones, con niveles de CO_2 extremadamente elevados, la comunidad de *C. brachycarpa* se encontraba simplificada y muy poco estructurada, presentando muy pocas especies fértiles probablemente debido a los altos niveles de CO_2. Por el contrario, la comunidad de *C. brachycarpa* de las zonas más alejadas de de las surgencias presentaban una composición y estructura similares a las encontradas en los datos bibliográficos, así como una mayor proporción de especies fértiles. En cuanto a la comunidad de los epífitos de *P. oceanica*, no se encontraron diferencias significativas ni en la composición específica ni en la estructura de la comunidad. En cambio, se observó una reducción del 60% de la superficie media en los haces de hojas de *P. oceanica* en la pradera más cercana a las surgencias hidrotermales.

Nuestros resultados ponen de manifiesto que, si bien muchas especies de macroalgas son capaces de tolerar a largo plazo el aumento de los niveles de CO_2 en el agua, los hábitats se alteran significativamente cuando el pH baja. Por ello, consideramos que debería realizarse un mayor número de estudios para conocer mejor el efecto de las emisiones de CO_2 a largo plazo sobre los sistemas marinos. Aunque el sistema de surgencias hidrotermales de la isla de Panarea se considera de tipo «superficial», muestra muchas características que lo relacionan con los sistemas de surgencias hidrotermales oceánicos, de tipo «profundo», ofreciendo una oportunidad única, al ser fácilmente accesible, para profundizar en el conocimiento de un mundo tan inexplorado.

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Chapter 1

Introduction

1. Introduction

During last years more and more attention has been addressed to climate change and, in particular, to ocean acidification. Surface ocean CO_2 partial pressure is expected to rise in proportion with CO_2 increase introduced into the atmosphere by human activities, causing shifts in seawater carbonate chemistry. When CO_2 dissolves, it reacts with water to form a balance of ionic and non-ionic chemical species: dissolved free carbon dioxide ($CO_2^{(aq)}$), carbonic acid (H_2CO_3), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). Dissolving CO_2 in seawater increases the hydrogen ion (H^+) concentration in the ocean, and thus decreases ocean pH and the water becomes more acidic. This decreases the carbonate ion concentration and lowers the saturation state (*Ω*) of calcium carbonate ($CaCO_3$), increasing the amounts of bicarbonate ions (Fig. 1). Moreover, this drop in CO_3^{2-} availability means organisms will be less able to deposit calcium carbonate structures and, if the reduction in CO_3^{2-} availability is severe enough, calcite dissolution can occur (Raven *et al.* 2005). According to Touratier and Goyet (2011) for the year 2001 all waters, even the deepest, have been acidified by values ranging from 0.14 to 0.05 pH unit since the beginning of the industrial era and the average pH of seawater is projected to decrease by 0.5 units (to 7.7) by the year 2100. The CO_2 increase could have a major impact on marine organisms which rely on the production of calcified tests or shells for survival, e.g. corals (Seibel and Fabry 2003), molluscs (Lindinger *et al.* 1984, Michaelidis *et al.* 2005), crustaceans (DeFur and McMahon

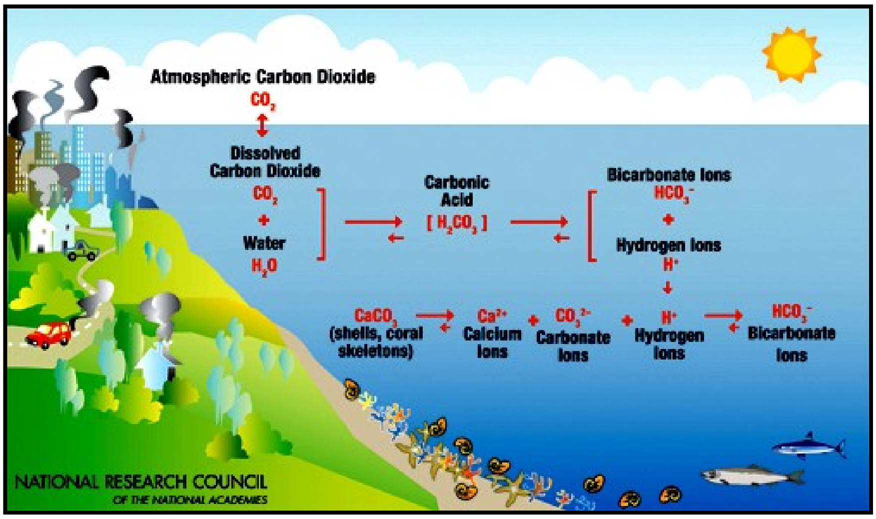


Fig. 1. Changes in seawater chemistry as a result of ocean acidification.

1984), foraminifera (Panieri *et al.* 2006) and calcified algal species (Riebesell *et al.* 2000) (Fig. 2). Laboratory and mesocosm experiments have shown that these changes in carbonate chemistry can significantly affect carbon fixation by photoautotrophs, which may cause global ecological disturbances over the coming decades (Kroeker *et al.* 2010) although there are still too few data to confirm whe ther this is the case (Hendricks and Duarte 2010).

Fig. 2. Dissolution of calcified organisms due to naturally acidified seawater: a) *Osilinus turbinata*, b) *Hexaplex trunculus*, c) *Patella caerulea*; bars = 1 cm. Figures by Hall-Spencer *et al.* (2008).

Benthic photoautotrophs exhibit mixed responses to ocean acidification, indicating that there will be changes in their settlement, competition and dominance that will have knock-on effects on coastal ecosystems (Connell and Russell 2010). However, it is very difficult to scale up the observations undertaken to date to predict the effects of increasing CO_2 emissions at the ecosystem level since most studies have been short-term (<1 year) on single or small groups of species. Some cyanobacteria grow well with CO_2 enrichment and their increased N_2 fixation may alter ocean biogeochemistry (Fu *et al.* 2008, Kranz *et al.* 2009). Some marine algae also benefit from higher CO_2 levels, enhancing their growth (Gao *et al.* 1999, Kübler *et al.* 1999, Riebesell *et al.* 2007) and calcification (Iglesias-Rodriguez *et al.* 2008), although the effects can vary between closely related species and even between strains of the same species (Langer *et al.* 2009). In general, seagrasses seem able to thrive under high CO_2 conditions (Palacios and Zimmerman 2007, Hall-Spencer *et al.* 2008), although the associated epiphytic algal coverage falls as CO_2 levels increase (Martin *et al.* 2008). Coralline algae appear to be amongst the most sensitive photoautotrophs to a rise in seawater CO_2 levels as they have a skeletal mineralogy that dissolves easily at predicted levels of calcium carbonate saturation (Gao *et al.* 1993, Martin and Gattuso 2009).

In this context, the marine hydrothermal vent areas are of great interest because the emission into sea water of thermal waters and gases causes measurable changes in the physicochemical composition of the water column, in terms of reduced pH and elevated temperature, and associated sediments (Stüben and Glasby 1999, Hannington *et al.* 2001). Hence, they provide natural laboratories to study *in situ* water acidification effects on biota (Hall-Spencer *et al.* 2008, Martin *et al.* 2008, Martin and Gattuso 2009, Cigliano *et al.* 2010, Dias *et al.* 2010, Rodolfo-Metalpa *et al.* 2010, Porzio *et al.* 2011).

To improve knowledge regarding the responses of marine ecosystems to ocean acidification, the main objective of this thesis have been to assess the effects of naturally acidified seawater on phytobenthic communities, in two periods of the year, and *Posidonia oceanica* macroalgal epiphytic assemblages in an area close to Panarea Island (Aeolian Islands, Southern Tyrrhenian Sea). In addition to this general objective, the following other aims were considered:

- to analyze the variation of the species composition and structure of the community of *Cystoseira brachycarpa* along a transect gradient forward from the vent outlets that seemingly corresponding to a pH gradient.
- to analyze the variation of the specimens size of *C. brachycarpa* along the supposed pH gradient.
- to analyze the variation of the species reproduction along the supposed pH gradient.
- to evaluate the effect of hydrothermal vents on both the community of *C. brachycarpa* and the epiphytic assemblages of *P. oceanica* leaves by comparing with those growing in an area without apparent hydrothermal activity.

1.1 Marine hydrothermal vents

Hydrothermal vent systems are found in tectonically active regions and they are linked to magmatism in a variety of geodynamic contexts, in both volcanic and non-volcanic environments (i.e., island arcs, hot-spots, Middle Ocean Ridges (MOR), seamounts, intraplate volcanism and intrusions). They occur over a wide depth range, from intertidal to the abyss. Tarasov *et al*. (2005) distinguished “shallow” and “deep” groups of hydrothermal vents on the basis of the occurrence of vent obligate taxa of a high rank (genus and family). The intensity of the relation of the faunal taxonomic groups with vents sharply changes at the depth of approximately 200 m. Based on this criterion, hydrothermal vents lying at depths from <200 m were classified as “shallow-water”, and those deeper than 200 m as “deep-sea”.

Many deep-water hot vents are located in back-arc and fore-arc zones, but they are rarely related to mid-plate hot spots [reviews in Van Dover (2000) and Bogdanov (2002)]. So far biological data have been published (Tarasov *et al*. 2005) for approximately 55 deep-water and 21 shallow-water hydrothermal vent ecosystems (Figs. 3 and 4). Most deep-water hot vents studied by biologists are situated on MOR systems. The deepest active hot vent known so far with associated fauna is the Ashadze field located at 4000-4100 m depth on the Mid-Atlantic Ridge (MAR) (Beltenev *et al*. 2003, 2004, Fabri *et al*. 2010). However, hydrothermal manifestations are known deeper: a dead field with small sulphide structures was recorded at about 5 km depths at the basement of Loihi volcano (Bogdanov 2002) and cold seeps are known even deeper; until now the deepest known chemosynthetic community is at 7326 m in the Japan Trench (Fujikura *et al*. 1999) but indirect evidence suggests that seep communities may occur in trenches at 9-10 km depths (Mironov *et al*. 2000). The major difference between shallow and deep hydrothermal vents is that deep-water vents occur far away from the coast, whether of continents or islands, whereas shallow water gas-hydrothermal systems are usually related to coastal volcanism (Figs. 3and 4).

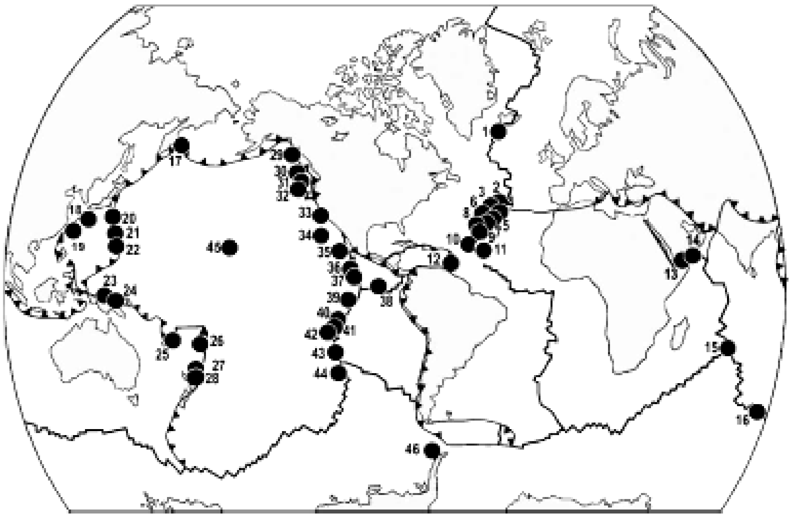


Fig. 3. Areas of deep-sea (>200 m) hydrothermal venting with known data on biota (in several cases one symbol shows more than one closely located areas). 1-Steinaholl, 2-Menez Gwen, 3-Lucky Strike, 4-Mount Saldanha, 5-Rainbow, 6-Lost City, 7-Broken Spur, 8-TAG, 9-Snake Pit, 10-Logatchev, 11-Ashadze, 12-Kick'em Jenny Volcano, Grenada, 13-Gulf of Aden, 14-Tadjoura Rift, 15-Rodryges Triple Junction (Kairei and Edmond Fields), 16-Amsterdam, St. Paul Plateau, 17-Piip's Volcano, 18-Okinawa trough (Fields Minami-Ensei Knoll, Iheya Ridge, Izena Caldron, Hatoma Knoll), 19-Daiyon Knoll, 20-Ogasawara North (Fields Myojin Knoll, Sumisi Caldera, Seamounts Suiyo, Moknyo and Kaikata), 21-Ogasawara South (Nikko Seamount), 22-Mariana Trough, North and South (Fields Daini Kasuga Seamount, Central Mariana Trough, South Mariana Ridge), 23-Manus Basin, 24-Edison Seamount, 25-North Fiji Basin, 26-Lau Basin, 27-28-Kermadec Ridge (Fields Rumble III and Rumble V, Brothers Caldera and Macauley Cone), 29-Explorer Ridge, 30-Juan de Fuca, 31-32-Gorda Ridge, 33-Guaymas Basin, 34-EPR 21°N, 35-EPR 13°N, 36-EPR 11°N, 37-EPR 9°N, 38-Galapagos Rift, 39-EPR 7°S, 40-EPR 17°, 40-21°S, 42-EPR 23°S (and Pito Seamount, Easter Microplate), 43-EPR 27-32°S, 44-Pacific-Antarctic Ridge 37°S, 45-Loihi Seamount, 46-Hook Ridge, Bransfield Strait (from Tarasov *et al.* 2005).

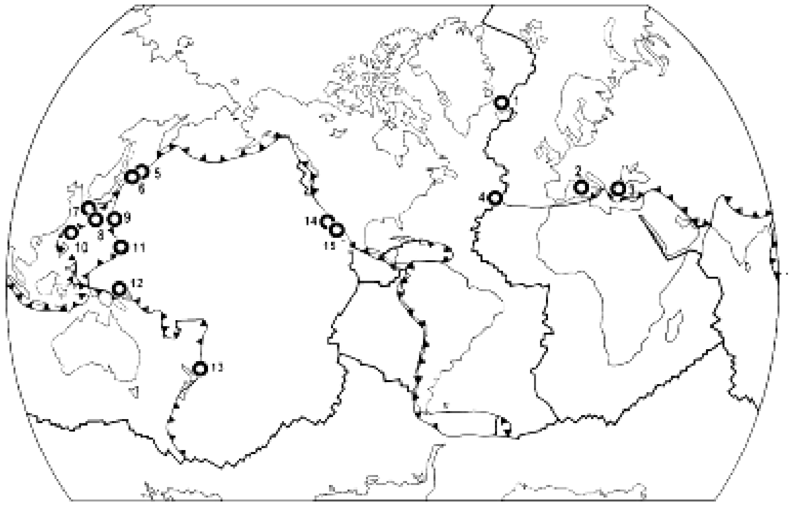


Fig. 4. Areas of shallow-water (<200 m) hydrothermal venting with known data on biota (in several cases one symbol shows more than one closely located areas). 1-Kolbeinsey, 2-Tyrrhenian Sea (Capes Palinuro and Messino, Bahia Pozzuoli, Panarea Island), 3-Aegean Sea (Islands Santorini and Milos), 4-D. João de Castro Bank, Azores, 5-Kraternaya Bight, Ushishir Island, Kuril Islands, 6-Kunashir Island, Kuril Islands, 7-Kagoshima Bay, 8-Tokora and Iwo Islands (Kita-Iwo-jima and Akuseki-jima), 9-Nishino-shima Sintoh, Ogasawara Islands, 10-Kueishan Is., Taiwan, 11-Esmeralda Bank, Mariana Islands, 12-Matupi Harbour, New Britain Island and Tutum Bay, Ambitle Island, Papua New Guinea, 13-Bay of Plenty, New Zealand, 14-White Point, Palos Verdes, California, 15-Punta Banda and Punta Mita, Baja California (from Tarasov *et al.* 2005).

Another pronounced difference between shallow and deep vent systems are differences in temperature (Figs. 5 and 6). In deepwater hydrothermal systems the temperature of the fluids can exceed 400°C, seawater penetrates deep inside the crust and the vent fluids are formed at up to 1200°C (Barriga *et al*. 1997). However, despite extreme values of temperature at deep-sea vents, most of the biota, even around the "hottest" vents, lives at temperatures between 10 and 25°C (Childress and Fisher 1992). At shallow depths the temperature of fluids is between 10 and 119°C, and temperature in the sediment can increase up to 95.8°C (Dando *et al*. 1995a, Botz *et al*. 1996, Fitzsimons *et al*. 1997, Tarasov 1999, 2002 and others).

An important feature of shallow-water vents is the presence of a gas phase (absent in the deep-sea) and much greater enrichment in O_2 compared to deep-water vents. Also in shallow-water systems a substantial role in the formation of vent fluids is played by atmospheric (meteoric) water. Among the whole variety of elements in hydrothermal fluids and surrounding seawater, most important for biological processes and formation of animal communities are the reduced compounds (H_2S, CH_4 and H_2) and metals. Deep-water fluids differ from shallow-water fluids by the extremely high concentrations of CH_4 and H_2. Moreover, at deep-water vents large sulphide structures typically form a landscape, whereas shallow depths lack these structures. In contrast, shallow-water hydrothermal vents are usually enriched in biogenic elements (first of all N, P and Si) than majority of deep-sea vents (Figs. 5 and 6).

Concerning the source of energy allowing the primary production, at deep-sea oceanic hydrothermal systems, where the light lacks, the input of energy due to the release of thermal fluids is considered to allow the production of biomass. The presence of chemosynthetic thermophilic and hyperthermophilic sulphur-oxidizing and methane-oxidizing bacteria supports the hypothesis that chemosynthesis provides a substantial primary food source for the populations of invertebrates living close to the deep vents (Karl *et al*. 1980, Jannasch and

Wirsen 1981, Ruby *et al.* 1981, Tuttle *et al.* 1983, Jannasch 1985). On the other hand, the abundance of nutrients [SiO(2-)(3), PO(3-)(4), NO(-)(3)], gases [(CO(2), CH(4), H(2), H(2)S] and other reduced compounds [C(n)H(n), SO, S(2)O(2-)(3), NH(+)(4)] in zones of shallow-water hydrothermal vents provides conditions for the use of two energy sources for primary production: sunlight (photosynthesis) and the oxidation of reduced compounds (bacterial chemosynthesis). At shallow depths chemosynthesis is a process running parallel to photosynthesis, although the role played by methane-oxidizing bacteria in primary production is low (Namsaraev 1992, Namsaraev *et al.* 1994). According to Sorokin *et al.* (1998, 2003) at shallow-water systems chemosynthesis represents between 2 and 15 mg C m^{-3} day^{-1}. In the same way, Tarasov (1999) points out that the proportion of chemosynthetic production at shallow-water vents varies from 1% (Kraternaya Bight) to 50% (Matupi Harbour). The peculiarity of chemosynthesis at shallow-water vents is that it takes place not only close to the seabed or in the plume, but also in the very superficial layer of the water, where warm vent positively buoyant fluids float. Often a peak of photosynthesis in these systems occurs below the thermal fluids, at the depth 2-5 m (Sorokin *et al.* 1993, 1994, 1998, 2003) (Fig. 5).

Both shallow-water and deep-sea hydrothermal vent systems also differ on the associated biological communities (Table 1). First of all, as noticed by many authors, among deep-sea vents species there are numerous vent-specific taxa, whilst these forms are absent or rare at shallow vents. Secondly, the biomass in deep-sea vent communities is dominated by symbiotrophic forms, whereas shallow-water vents tend to have a low biomass of a more diverse fauna with few, or no, endemic species (Fricke *et al.* 1989, Tarasov and Zhirmunsky 1989, Hashimoto *et al.* 1993, Kamenev *et al.* 1993, Tarasov *et al.* 1993, 1999, Dando *et al.* 1995c, Morri *et al.* 1999).

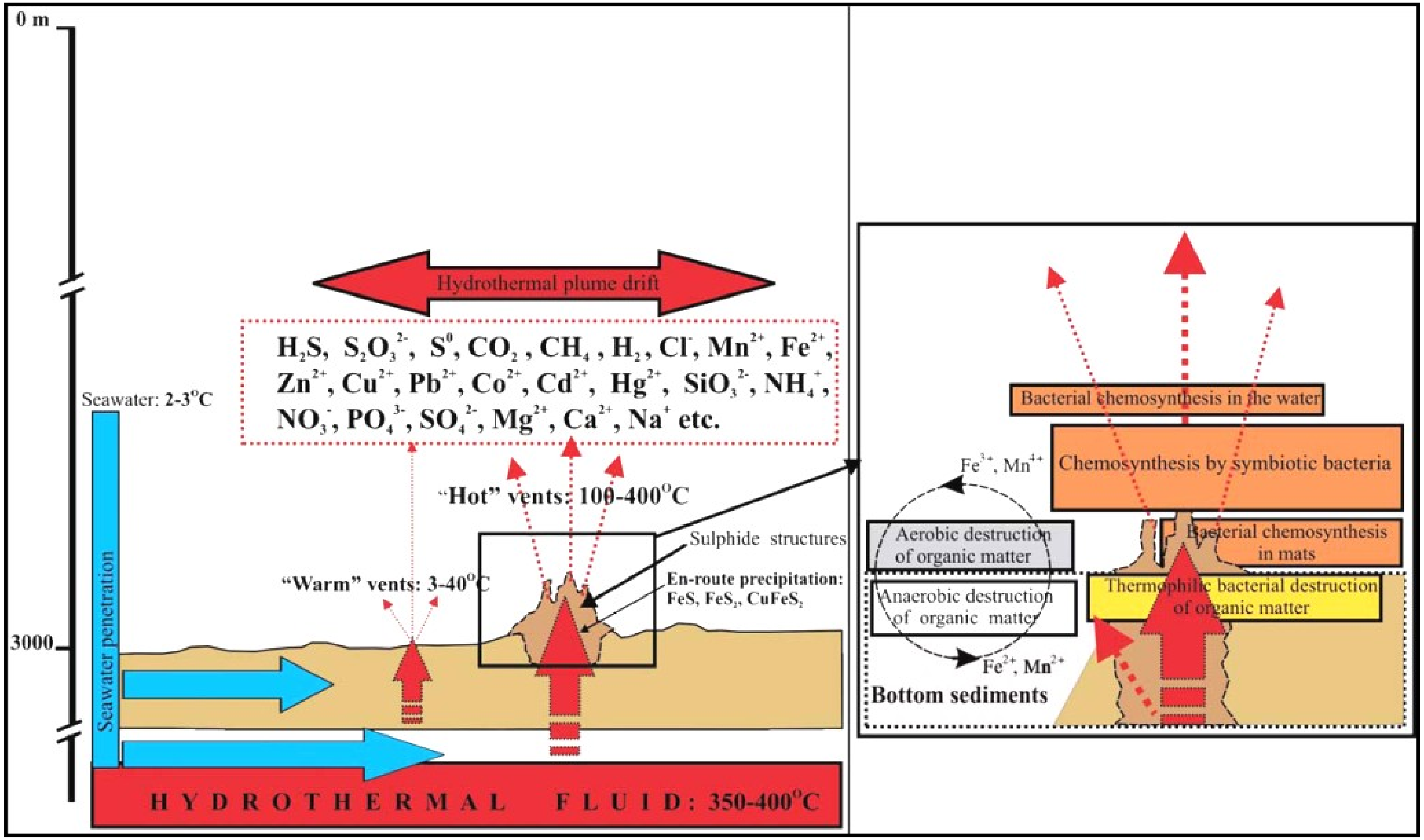


Fig. 5. Major biological and geochemical processes in deep-sea hydrothermal vent ecosystems (from Tarasov *et al*. 2005).

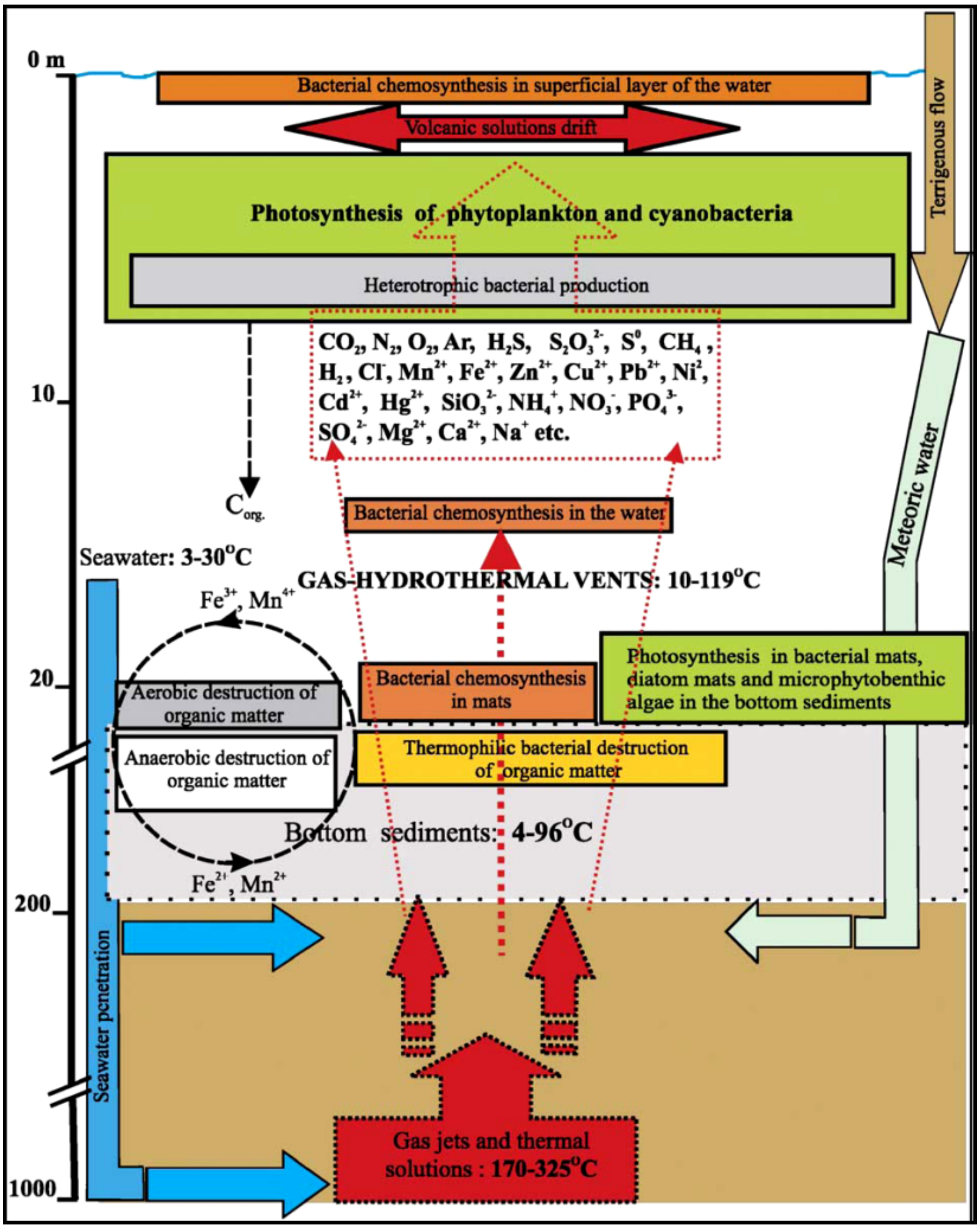


Fig. 6. Major biological and geochemical processes in coastal shallow-water hydrothermal vent ecosystems (from Tarasov *et al.* 2005).

Microbial mats, which cover the substratum on the seafloor near the vents opening, represent a common feature of deep-sea and shallow-water hydrothermal ecosystems (Figs. 5 and 6) (Jannasch 1985, Jacq *et al*. 1989, Taylor and Wirsen 1997). The mats at deep-sea vents are often dominated by filamentous colourless sulphur bacteria *Beggiatoa* Trevisan, *Thiotrix* Winogradsky, *Thiovulvum* Hinze and *Thiomicrospira* Kuenen and Veldkamp (Jannasch and Wirsen 1981, Gundersen *et al*. 1992, 1995, Tarasov *et al*. 1999). These mats can be thick (>1 cm) and are characterized by a high rate of CO_2 assimilation (Tarasov *et al*. 2005). On the other hand, at shallow-water venting microorganisms form mats on the seabed that consist of bacteria of various physiological groups and microalgae, as well as the products of their metabolism and sedimentary particles. These mats can reach the thickness of 30 cm and they often have a more complex nature than in deep waters. Three main types of mats can be distinguished at shallow vents: 1) diatom, 2) algae-bacterial and 3) bacterial mats. The diatom mats develop around vents lacking hydrogen sulphide. They are often built by filamentous diatoms of the genera *Melosira* C. Agardh and *Thalassiosira* Cleve and can be up to 30 cm thick (Tarasov 1999, 2002). In the algae-bacterial mats the diatoms are associated with various groups of chemosynthetic microorganisms that either reduce or oxidize sulphur compounds: thionic bacteria, purple, green and colourless sulphur bacteria. These associations develop at temperatures up to 55-60°C. Both the synthesis and the destruction of organic matter in these systems are related to the sulphur cycle (Starynin *et al*. 1989, Nesterov *et al*. 1991, Tarasov *et al*., 1990, 1991, Tarasov 1999, 2002). The bacterial mats *per se* are composed of either thiobacteria of the genera *Thiobacillus* Beijerinck, *Thiomicrospira* and *Thiosphaera* Robertson and Kuenen (up to 10^6 cell ml^{-1}), or filamentous colourless sulphur bacteria such as *Thiothrix* or *Beggiatoa*. The major biogeochemical processes in these mats are the oxidation of reduced sulphur compounds (hydrogen sulphide or thiosulphate) to elemental sulphur, thiosulphate or sulphate and organic matter synthesis (Dubinina 1989, Namsaraev *et al*. 1991, Nesterov *et al*. 1991, Sorokin 1991). The major components of fresh mats were sulphur (up to 50-80% of the total dry weight) and silica, the composition varying with time and with site. In addition, the mats concentrated heavy metals, including Hg (up to 1.1 mg g^{-1} dry weight) (Dando *et al*. 2000).

Table 1. Major features of shallow and deep-water hydrothermal communities and environments (from Tarasov *et al.* 2005).

	Shallow-water zone	**Deep-water zone**
Depth and geological setting	Located at depths <200 m.	Located at depths >200 m.
	Mostly related to coastal volcanism, often in volcanic island arc systems.	In zones of spreading on Mid-Ocean Ridges or in back-arc and fore-arc zones; some are related to mid-plate hot spots.
Environment	Temperature of fluids increased, maximum values <120.	Temperature of fluids increased or high, maximum values >400.
	High concentration of reduced substances (H_2S, $S_2O_3^{2-}$, S°), nutrients (SiO_3^{2-}, NH_4^+, NO_3^-, PO_4^{3-}, SO_4^{2-}) and metals (Fe, Mg, Mn, Zn, Cu, Pb, Cd, Ni etc.).	High concentration of reduced substances (H_2S, $S_2O_3^{2-}$, S°) and metals (Fe, Mn, Zn, Cu, Pb, Cd, Ni etc.). Presence of nutrients (SiO_3^{2-}, NH_4^+, NO_3^- etc.).
	Gas phase present in dissolved or free form (CO_2, N_2, H_2, CH_4, ${}_nH_n$).	Gas phase present in dissolved form (CO_2, N_2, H_2, CH_4). Concentrations of H_2, H_2S and H_4 rich extremely high values.
	A substantial role in the formation of vent fluids is played by atmospheric (meteoric) water.	
	Alkalinity: from low to normal.	Alkalinity: low.
	Habitat conditions in the water and in sediments altered compared to the background; alteration most pronounced in semi-isolated bights. Volcanic fluids float on the surface andform stratification in the water.	Habitat conditions significantly altered on the seafloor and in plumes.
	Large mineral structures are usually lacking.	Large mineral structures common.
Energy source	Two principal sources: organic matter derived from photosynthesis and chemosynthesis.	Two principal sources: organic matter derived from chemosynthesis and photosynthesis.
		Chemosynthetically produced organic plays major role.
	Photosynthetically produced organic plays major role.	Role of photosynthetically produced organic is not fully known.
	Organic matter inflows with meteoric waters and terrigenous material.	–
Features of primary production	Maximum for coastal marine ecosystems rate of photosynthesis in the water was recorded: 3.2 g C m^{-3} day^{-1}.	No photosynthesis.
	Ratio of chemosynthesis in autotrophic processes varies from 1% to 50%.	–
	Rate of chemosynthesis in venting fluids from 2 to 15 mg C m^{-3} day^{-1}.	Average bacterial production in the plume is 244 mg C m^{-2} day^{-1}.
	–	Net bacterial production on an “average field”: 275 mg C m^{-2} day^{-1}.
Plankton	Diversity in pelagic communities (bacterio-, phyto, holo- and zooplankton) is low compared to background.	Little data (but phytoplankton lacking).
	Abundances and biomass high.	Abundance of bacterioplankton increased in the plume. Abundance of background pelagic organisms (especially gelatinous organisms) can be also increased, though, with no proven link to hydrothermalism.

Table 1 *(continued)*

Plankton	Obligata taxa lack.	Obligate taxa lacking in the pelagic zone, but present in the bentho-pelagic.
Thermophilic microorganisms	Hyperthermophilic, extreme- and mesothermophilic archaea and eubacteria are present. Play important role in organic matter destruction; rates of sulphur reduction very high: up to 3.2 g S^{2-} m^{-2} day^{-1}.	Hyperthermophilic, extreme- and mesothermophilic archaea and eubacteria are present and play an important role to carbon and sulphur cycling.
Growth of mats	Mats of diverse types are present: diatom, algae-diatom and bacterial. Rate of primary production in the mats from 600 to 3700 mg m^{-2} day^{-1}.	Only bacterial mats and fouling develop. Bacterial production in the mats from 2.1 to 27.0 mg C m^{-2} day^{-1}.
Features of spatial community structure	Vent is the key parameter controlling the spatial distribution of organisms. Control of vents on the distribution of meio- and macrofauna is indirect (via the development of mats, around them macrofauna aggregates). Communities have no well pronounced concentric or vertical structure.	Vent is the key parameter controlling the spatial distribution of organisms. Control of vents on the distribution of meio- and macrofauna is direct. (Access to reduced substances in the fluid to symbiotrophic organisms has a major structuring role). Communities have concentric or vertical structure related to temperature zones.
Biomass	Biomass of macrofauna up to several kg m^{-2}.	Biomass of macrofauna reaches several tens of kg m^{-2}.
Meiofauna	Species diversity and abundance in vent communities can be higher than in the background.	Species diversity and abundance is lower than in the background.
Symbiotrophs	Biomass is dominated by non-symbiotrophic species (suspension-feeders, deposit-feeders and grazers). Variety of symbiotrophs is low.	Biomass is dominated by symbiotrophic species. Variety of symbiotrophs is high.
Physiological adaptations	Physiological adaptations to hydrothermal environment unknown.	Physiological adaptations develop to high concentration of sulphides, methane, metals and a high temperature.
Obligate taxa	Obligate species absent or only a single species present. Rank of obligate taxa does not exceed a species.	Obligate species comprise bulk of the fauna. Rank of obligate taxa up to a family level.
Biogeography	Specific taxonomic structure of vent communities does not repeat within large geographic regions. Ratio of species with a pointlike range (endemics of small areas) is low. There are no significant differences between the vent and non-vent biogeography.	Specific taxonomic structure of vent communities repeats within large geographic regions. Ratio of species with a “point” range is high. There are no significant differences between the vent and non-vent biogeography.

1.1.1 Hydrothermalism in the Mediterranean Sea

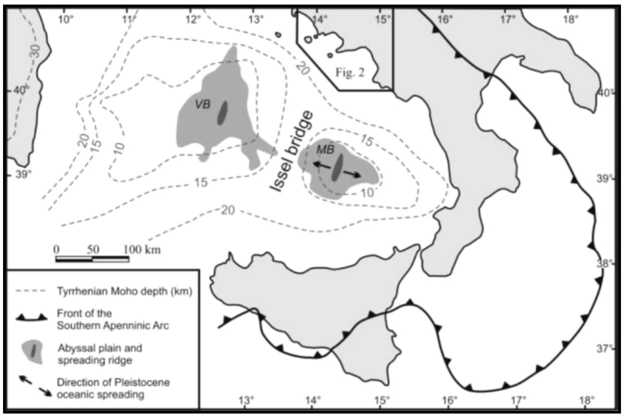


Fig. 7. Sketch of the southern Tyrrhenian Sea, after Sartori (2003). VB, Vavilov basin; MB, Marsili basin. Spreading direction of the Marsili basin (2-0 Ma) is after Marani (2004), and closely matches the coeval extension of detachment faults on the Campania margin. Southern Apenninic Arc = Calabrian Arc.

The subduction of the African plate below Europe has resulted in the formation of the Mediterranean Ridge and deep subduction basins as well as active volcanic arcs in the Tyrrhenian and Aegean Seas. Volcanic arc hydrothermal systems release large volumes of gas, because of both the degassing of the subducted slab and the mantle, and the decomposition of carbonates in overlying marine sediments. Since most of the known venting in the Mediterranean is from shallow vents, the majority of the outlets are of the gasohydrothermal type emitting large volumes of carbon dioxide (Dando *et al.* 1999). The present shape of the Tyrrhenian and Aegean Seas has resulted from lithospheric extension which continues today (Makris and Stobbe 1984, Bonasia *et al.* 1985, Bassi and Sabadini 1994). In the Tyrrhenian Sea, the Marsili Basin is believed to have opened at a rate of 3-4 cm y^{-1} and subsided at a rate of 0.7 cm y^{-1} (Fig. 7). There are seamounts with hydrothermal deposits where hydrothermalism may still be active (Uchupi and Ballard 1989, Sborshchikov and Al'mukhamedov 1992, Eckhardt *et al.* 1997). In the eastern Mediterranean the Sea is tectonically bounded to the north by the active continental margins defined by the Calabrian, Hellenic and Cyprus-Antalya Arcs. Active volcanism in both the Aegean and the Tyrrhenian Seas began in the Oligocene (Bellon *et al.* 1979, Savelli 1988) and has continued episodically until the present time with a long historical record of catastrophic impacts on local populations. Currently the volcanoes that are the most active are Etna, Vulcano, Stromboli and Vesuvius in Italy and Santorini and Nisiros in Greece.

1.1.1.1 Current locations of hydrothermal venting

Submarine hydrothermal venting in the Mediterranean has mostly been described from shallow water (<200 m depth). Bubble plumes in shallow water may be seen as steams of bubbles breaking the surface, even from depths of 100 m (Dando *et al.* 1995a) and are clearly visible to divers and ROV's (Italiano and Nuccio 1991, Calanchi *et al.* 1995, Dando *et al.* 1995a). However, to date, there has been little systematic mapping of hydrothermal fields carried out in the Mediterranean.

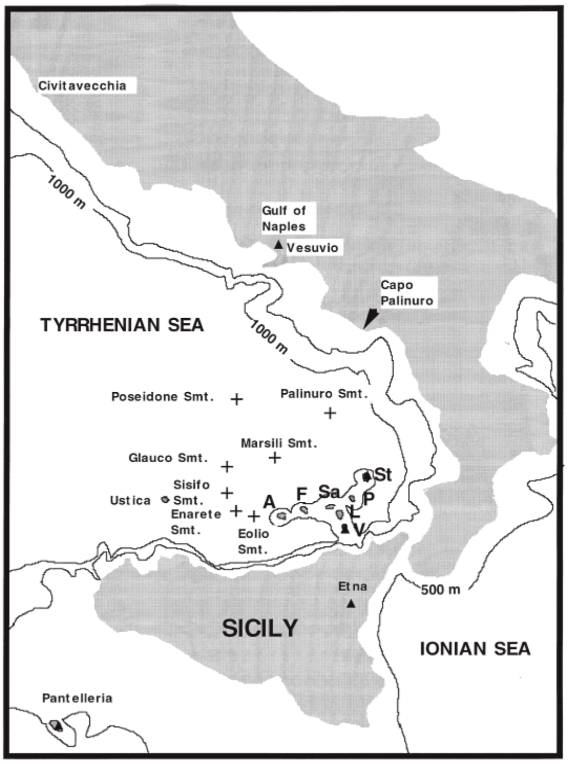


Fig. 8. Areas of hydrothermalism in the Tyrrhenian Sea. (▲) active volcano. Aeolian islands: A: Alicudi, F: Filicudi, L: Lipari, P: Panarea, Sa: Salina, St: Stromboli, V: Vucano (from Dando *et al.* 1999).

Detailed studies have been published only for the island of Milos in the Aegean (Dando *et al.* 1995a, 1995b) and for Panarea and the islets of the submerged caldera to the east (Italiano and Nuccio 1991) and for the submarine caves at Capo Palinuro (Alvisi *et al.* 1994) both in the Tyrrhenian Sea (Fig. 8). Hydrothermal venting in the Tyrrhenian Sea is found today at the seabeds of Vulcano Island (that is now in a state of solphataric activity), Stromboli (that erupts with regular low energy blasts), Panarea Island and nearby islets, Capo Palinuro and in the Bay of Naples (Fig. 8). Reported maximum temperatures for the submarine vents are 103°C for the shallow vents at Vulcano Island, 53°C at Panarea Island and 24°C in the Grotta Azzurra, Capo Palinuro (Dando *et al.* 1999 and references therein).

In the Aegean Sea, major hydrothermal vent systems are found along the Volcanic Arc at Euboea, Methana and Sousaki, Milos, Santorini, Kos, Yali and Nisiros (Fig. 9). Geothermal areas are also found elsewhere around the edge of the Aegean, including the regions around the Aridea, Antemus, Volvi -Langada, Strymon, Nestos-Xanthi and Alexandroupoli basins in the north, Lesbos in the east and the Gulf of Maliakos and Sperchios basins in the west.

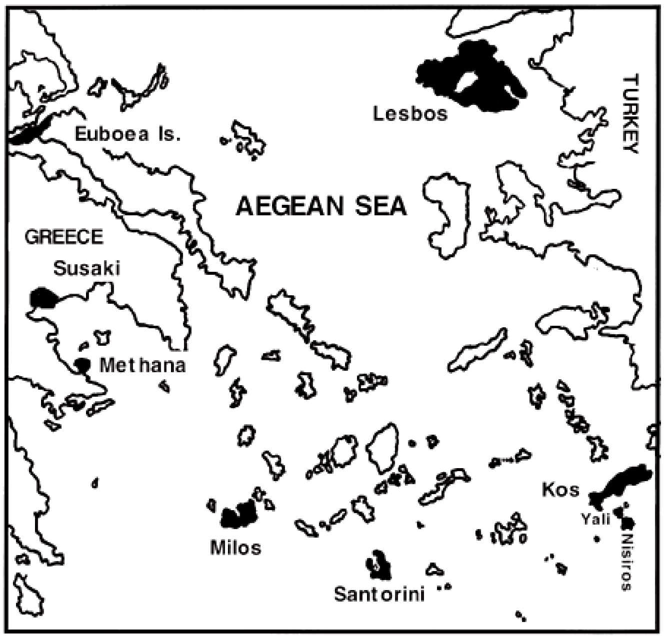


Fig. 9. Major hydrothermal areas (shaded) in the Aegean Sea (from Dando *et al.* 1999).

The maximum recorded temperatures at the fluid outlets of submarine vents in the Aegean are 35°C off Methana, more than 119°C south of Milos, 40°C at Nea Kameni (Santorini), 46°C for shallow vents off Kos and 33°C for those off Yali (Dando *et al.* 1999 and references therein).

However, higher temperatures must exist offshore, particularly in areas where venting occurs directly from faults in the rocks, where there is likely to be less sub-surface dilution with overlying seawater. Venting is found in hydrothermal areas along geological faults, particularly where these intersect. Hot fumarolic gases consist mainly of water vapour, while at lower temperature fumaroles contained mostly H_2O; thus, for example, the gases emitted from 6 fumaroles at Vulcano consisted of 88-98% by volume of steam at temperatures of 208-640°C (Le Cloarec *et al.* 1994) whereas according to Italiano and Nuccio (1991) the lower temperature fumaroles of Panarea contained 93% H_2O. As the gases are cooled near the seabed, the steam condenses and can significantly dilute the salinity of the venting water. In the majority of analyses of gases from submarine hydrothermal vents reported from the Mediterranean the major gas component has been CO_2 (Table 2). At most sites this CO_2 is believed to be derived from both dissociation of marine carbonates and degassing of the subducted slab and magma (Botz *et al.* 1996, Calanchi *et al.* 1995, Dando *et al.* 1995a, Italiano and Nuccio 1991). Amongst the other gases, hydrogen sulphide has been reported as occurring at concentrations of up to 6.5% by volume in the Calabrian Arc (Italiano and Nuccio 1991) and 8.1% in the Hellenic Volcanic Arc (Dando *et al*. 1995a). Hydrogen and methane can be other important components (Calanchi *et al*. 1995, Dando *et al*. 1995a).

1.1.1.2 Flora and vegetation at shallow vents

The direct effect of venting on the macrobiota is to exclude many of the less tolerant local species (Dando *et al*. 1995c, Fitzsimons *et al*. 1997). For example seagrasses are absent from the neighbourhood of vents outlets, algal distributions are changed and many common infaunal species are excluded from the sediments surrounding the vents. In the vicinity of both the Milos and Vulcano vents *Posidonia oceanica* (Linnaeus) Delile is replaced by *Cymodocea nodosa* (Ucria) Ascherson (Dando *et al*. 1995a, Giaccone 1969), which is a more tolerant species (Mazzella and Buia 1986), but still unable to withstand conditions in the immediate vicinity of acidic and sulphidic vents (Aliani *et al*. 1998). Similar effects of venting on *P. oceanica* were noticed at Panarea in the Tyrrhenian Sea (Acunto *et al*. 1996, Vizzini *et al*. 2010). On the other hand, Hall-Spencer *et al.* (2008) recently pointed out the positive effect of vents on the growth performance of *P. oceanica* meadows.

Little is known about the marine benthic algae of hydrothermally active areas of the Mediterranean Sea. Floristic observations on submarine fumarolic emissions were carried out in the Aeolian and Cyclades archipelagos (Acunto *et al*. 1997, Sartoni and De Biasi 1999, Cocito *et al*. 2000). The effect of vents on marine vegetation was previously studied by Giaccone (1969) and Acunto and Rindi (1997) off Vulcano Island and by Acunto *et al*. (1996) off Panarea Island, both in the Aeolian archipelago. Alongi *et al*. (2004) studied the marine vegetation of Pantelleria Island, in the strait of Sicily, including one sampling site affected by secondary volcanism. Lately, macroalgal community changes and the responses of *P. oceanica* epiphytes at a volcanic vent area off Ischia Island were assessed (Hall-Spencer *et al*. 2008, Martin *et al*. 2008, Porzio *et al*. 2011).

Table 2. Composition of gases (volume %) from submarine hydrothermal vents in the Tyrrhenian and Aegean Seas. Modified from Dando *et al.* 1999.

	°C	**CO_2**	**H_2S**	**H_2**	**N_2**	**CH_4**	**O_2**	**other major components**
Tyrrhenian Sea								
Ischia[a]	13-25	92.7	absent		4.9	0.5	0.7	Ar 0.09
Aeolian Islands								
SE of Porto Levante, Vulcano[b]	101	100						
Porto Levante, Vulcano[b]	86	98.0						
Lisca Banca (Panarea)[c]	27	96.6	2.64	0.003	0.64	<0.001	0.08	
Basiluzzo (Panarea)[c]	26	93.2	n.d	0.021	6.18	<0.001	0.61	
La Calcara, Panarea[c]	27	90.1	n.d.	0.017	5.5	3.01	1.31	
Between Dattilo and Lisca Bianca (Panarea)[d]		93.0	6	<0.001	0.8	0.014	<0.01	
Northern Aegean								
Paradisos, Xanthi, Greece[e]		n.d.	n.d.	96.61	2.28	0.31		O_2+Ar 0.14
Nigrita, Strimon Basin, Greece[e]		94.4	n.d.	n.d.	3.37	0.008		O_2+Ar 2.27
Elephetere, Greece[e]		94.1	n.d.	n.d.	5.69	0.08		O_2+Ar 0.76
Hellenic Arc								
Thermopilae, Sperkios Basin, Greece[e]	40	79.9	0.015	n.d.	19.8			O_2+Ar 0.25
Euobea island, Greece[e]	80	96.9	n.d.	n.d.	2.56			O_2+Ar 0.46
Sousaki, terrestrial fumarole[f]	42	82.0	3					air 13-14, SO_2 1-2
Milos Bay[g]		74.9	0	0				
E. of Spathis Point, Milos[g]		91.9	0.14	0.14				
Paleochori Bay, 4 m depth, Milos[g]	108	76.6	1.34	1.34				

[a] Hall-Spencer *et al.* (2008)
[b] Baubron *et al.* (1990)
[c] Italiano and Nuccio (1991)
[d] Calanchi *et al.* (1995)
[e] Minissale (1989)
[f] Georgalas (1962)
[g] Dando *et al.* (1995a)

1.2 Benthic vegetation as an indicator of environmental quality

The benthic plant organisms, that during their life cycle undergo the impact of the chemico-physical and biotic conditions of the habitat, prove to be excellent indicators of the environmental status (Blandin 1986, Pergent 1991), and still more are the communities they constitute, which represent an integral response of the average environmental conditions. Therefore, the presence or absence of certain phytobenthic communities in a given area is a good indicator for assessing the quality of that environment. Phytobenthic and *P. oceanica* epiphytic assemblages are thus considered useful indicators of changing environmental conditions (May 1982, Cambridge *et al.* 1986) and their sensitivity to anthropogenic disturbances is well documented (Balata *et al.* 2008); Ulvales, for example, can become dominant in nutrient enriched areas (Pergent 1991), ecosystems have been degraded by the invasive behaviour of introduced organisms such as *Caulerpa* spp. (Balata *et al.* 2004) and habitat-forming *Cystoseira* spp. are lost from large stretches of polluted coastlines (Rodriguez-Prieto and Polo 1996, Thibaut *et al.* 2005, Serio *et al.* 2006, Mangialajo *et al.* 2008).

In shallow Mediterranean waters, the species of the genus *Cystoseira* are usually the dominant elements of the benthic vegetation on unpolluted and in some occasions also in moderately degraded hard substratum. The *Cystoseira* algal community is considered the final stage (climax) in a succession of photophilic algal communities (Pérès and Picard 1964) and because of their sensitiveness to anthropogenic impacts the *Cystoseira* species are used as a coastal water biological quality element according to the Water Framework Directive (2000/60/EC) (Orfanidis *et al.* 2003, Ballesteros *et al.* 2007, Pinedo *et al.* 2007, Orlando-Bonaca *et al.* 2008, Asnaghi *et al.* 2009, Ivesa *et al.* 2009). All *Cystoseira* species but *C. compressa* are included in the recent revision of the Annex II of the Barcelona Convention (2010).

Cystoseira species are widespread in the Mediterranean infralittoral and upper circalittoral zones, where they play the same role as kelps do in the sublittoral zone from temperate oceans. Although the genus *Cystoseira* is a taxon with worldwide distribution, about 80% of the species occur along the Mediterranean and the adjoining Atlantic coasts (Roberts 1978), as showed by recent molecular evidences (Draisma *et al*. 2010).

Cystoseira is the main genus of erect macroalgae functioning as ecosystem engineers in the Mediterranean Sea since display a three-dimensional structure (Fig. 10) that provides habitat for a high number of algae and invertebrate species (Molinier 1960, Boudouresque 1972, Ballesteros 1992, Ballesteros *et al*. 2009). Assemblages dominated by Fucales as well as by Laminariales present important parallels with terrestrial forests, with different vegetation layers occupied by morphologically different algae (Ros *et al*. 1985, Dayton 1994). Floristic composition and structure of the assemblages dominated by *Cystoseira* species are fairly well known (Boudouresque 1969, 1971b, 1984, Giaccone 1973, Ballesteros 1992, Giaccone *et al*. 1994). Spatial trends of these assemblages have been studied at local (Feldmann 1937, Ercegovic 1952, Giaccone and Bruni 1973) and regional scales (Báez *et al*. 2005). Temporal trends and productivity have been studied by Ballesteros (1988, 1990a, b) and Pizzuto (1999).

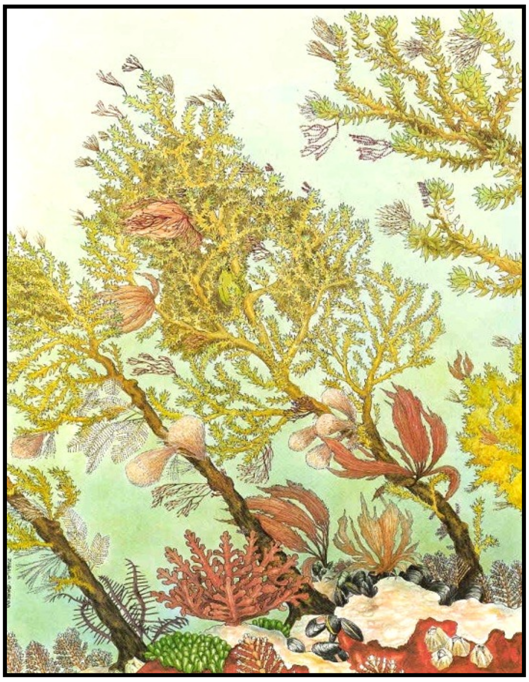


Fig. 10. Scheme of a *Cystoseira* community showing different strata (encrusting, turf, erect and epiphyte). From Llimona *et al*. 1985.

1.3 The community of Cystoseira brachycarpa

Cystoseira brachycarpa J. Agardh *emend.* Giaccone [including *C. brachycarpa* v. *balearica* (Sauvageau) Giaccone according to Pizzuto (1998)] is an endemic Mediterranean species widely distribuied in the western Mediterranean (Ribera *et al*. 1992, Gómez Garreta *et al*. 2001). It is a photophilic species that forms dense populations on hard substrata of both sheltered and moderately exposed sites of the upper infralittoral zone, between sea level and 20 m depth (Boudouresque 1971b, Gómez Garreta *et al*. 1987, Verlaque 1987, Ballesteros 1990b, Cormaci *et al*. 1992, Giaccone *et al*. 1994, Marino *et al*. 1999, Pizzuto 1999, Rindi *et al*. 2002, Alongi *et al*. 2004). Giaccone and Bruni (1973) and Giaccone *et al*. (1994) considered *C. brachycarpa* (as either *C. balearica* Sauvageau or *C. caespitosa* Sauvageau) to be a geographical vicariant of *C. crinita* Duby, the dominant species of a photophilic infralittoral association of sheltered environments described as *Cystoseiretum crinitae* by Molinier (1960). In this way, Cormaci *et al*. (1992) pointed out that almost always *C. crinita* was replaced by *C. brachycarpa* in the *Cystoseiretum crinitae* of Salina Island (Aeolian archipelago). On the other hand, Verlaque (1987) on the basis of several studies carried out on sheltered photophilic communities of Corsica and other Mediterranean Islands in which *C. crinita* was replaced by *C. brachycarpa* (as *C. balearica*), suggested a change of name to *Cystoseiretum crinitae* from *Cystoseiretum balearicae*. However, Gómez Garreta (1981), Ballesteros (1992) and Pizzuto (1999) recognized the community of *C. crinita* as a different one from that of *C. brachycarpa*, and Ballesteros (1990b) described the *Cystoseiretum caespitosae* association on the basis of their studies on the *C. brachycarpa* assemblages (as C. *caespitosa*) of the Costa Brava and the Albères coast. In addition, Pizzuto (1999) studied a community dominated by *C. brachycarpa* and another dominated by *C. crinita* in the eastern coast of Sicily and he concluded that both communities were quite different in both dynamics and floristic composition.

Chapter 2

Materials and methods

2. Materials and methods

2.1 *Study area*

2.1.1 *General features*

The Aeolian archipelago consists of seven major islands and several associated seamounts located in the Southern Tyrrhenian Sea (Fig. 11a). Tens of CO_2 submarine fumaroles and several low-pH hydrothermal emissions occur in the vicinity of many of the Aeolian Islands, such as Salina, Lipari, Vulcano, Stromboli and Panarea (Fig. 11a, b). No in-land hydrothermal manifestations are recognisable on the other islands.

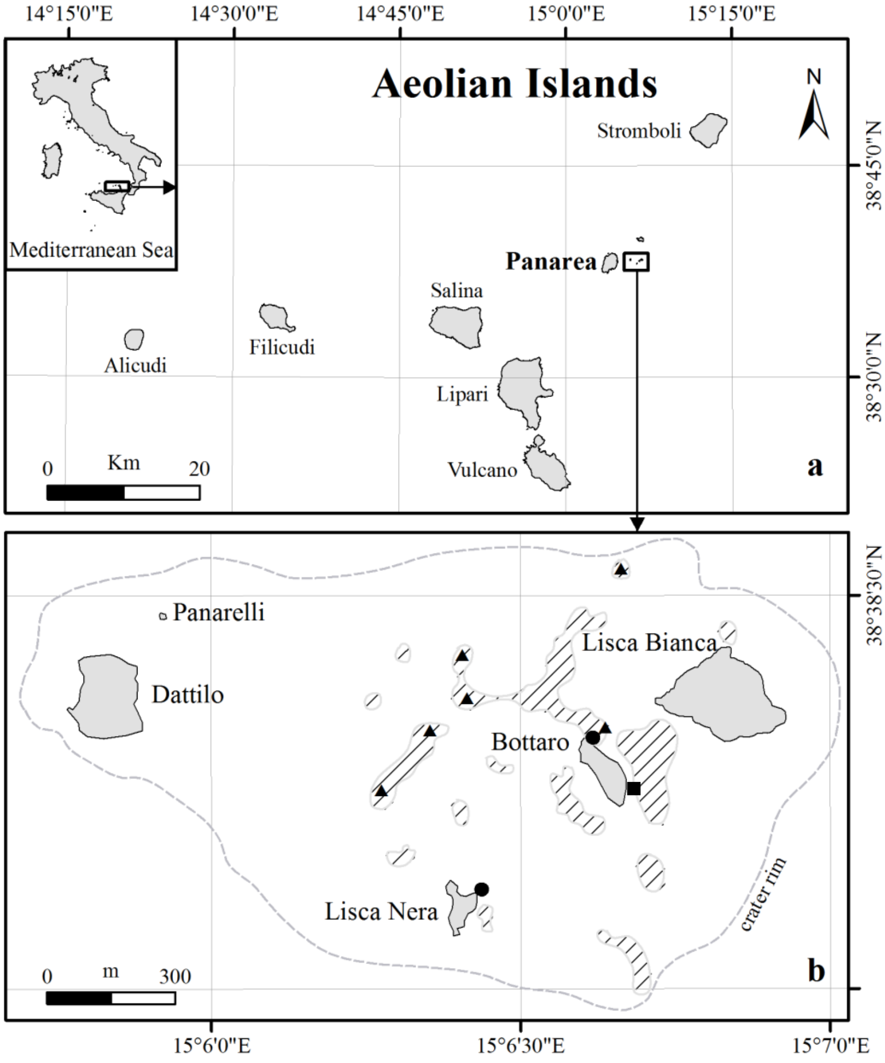


Fig. 11. Location of the study area: a) Aeolian Islands, b) submarine fumarolic fields with thermal springs (black triangles) and location of sampling sites: black dots = community of *C. brachycarpa*; black quadrat = *P. oceanica* meadows. Modified from Tassi *et al*. (2009).

Gas emissions and "boiling" of the seawater, with death of fishes, has been described since historical times in the Aeolian Islands and particularly at Panarea by *Titus Livius*, *Strabo*, *Julis Obsequens*, *Orosius Paulus*, *Posidonius* and *Plinius the Elder* (Storia Geofisica Ambientale 1996). An event that produced "uprise of the sea level, jets of steam, heat, bad smell, death of fishes..., mud emerging from sea, later consolidated into rock..." occurred in 126 B.C. (*Orosius Paulus*, 5.10.11 Storia Geofisica Ambientale 1996). Over the last two decades such manifestations have been limited to weak gas bubbling that could only be seen when the sea was very calm. Panarea, located between Stromboli and Lipari Islands, is the smallest island (3.3 km^2) of the Aeolian archipelago (Fig. 11a). It represents the subaeral portion of a mainly submarine ring-like volcanic arc (*i.e.* the Aeolian Volcanic District - AVD) more than 2000 m high and 20 km wide (Gabbianelli *et al.* 1990, 1993, Gamberi *et al.* 1997). It consists of a volcanic structure that has evolved in recent geological times following different stages of activity: firstly, the central apparatus developed with the Panarea Island, than the volcanic structure enlarged to the east by a fault system NE-SW oriented. The area surrounding the island is characterized by a relatively flat submarine platform (between 15 and 125 m of depth)

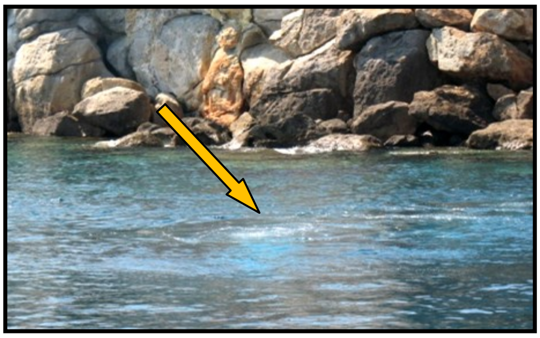


Fig. 12. Surface gas bubbles indicated by the arrow.

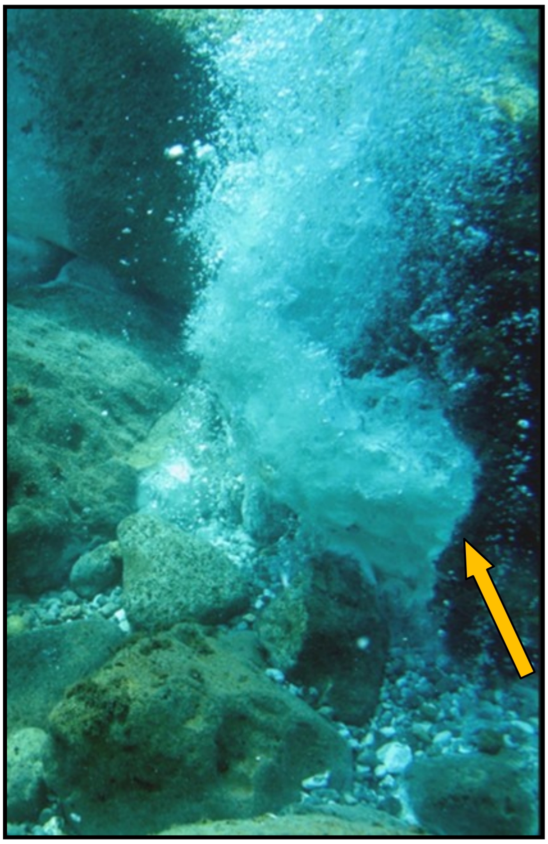


Fig. 13. White mat deposits (indicated by the arrow) surrounding hydrothermal water discharges.

whose substrate is composed of coarse-grained sands and gravels of volcanic origin. The most intense exhalations are located off-shore 3 km east of the island, within a submarine fumarolic field of about 4 km^2 (Gabbianelli *et al*. 1986, 1990), surrounded by five emerging reefs (Dattilo, Bottaro, Lisca Bianca, Panarelli and Lisca Nera) which represent the remnants of an old circular crater rim of about 1 km in diameter (Figs. 11b and 14). The gas exhalations are dominated by CO_2 (up to 99%) and H_2S, with relatively low amounts of atmospheric species, CH_4, H_2, and traces of CO and light unsaturated hydrocarbons (Italiano and Nuccio 1991, Calanchi *et al*. 1995). Generally these fluids release both gases and thermal waters from rocky fractures and/or small holes in the seafloor which reach the surface in the form of gas bubbles (Fig. 12). All the sites where thermal waters discharge are surrounded by a white mat that, sometimes, forms massive, soft and white deposits (Fig. 13) where rocky walls or any hard support is available (Gugliandolo *et al*. 2006).

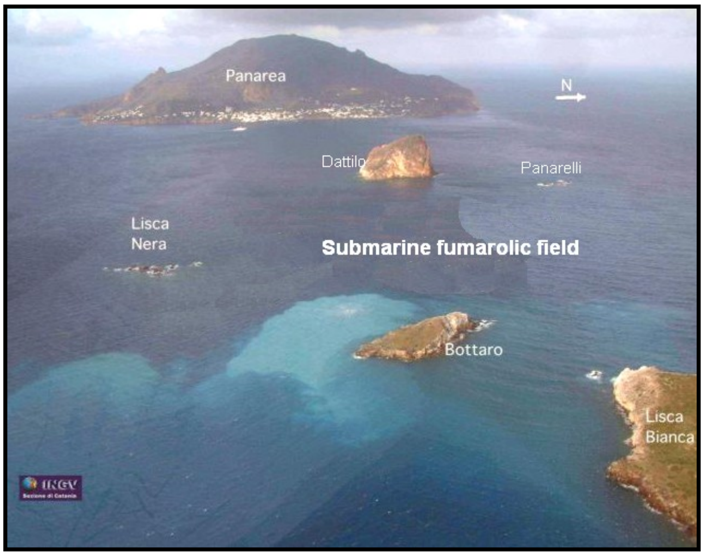


Fig. 14. Aerial photo showing the five emerging reefs which surround a submarine fumarolic field (INGV, modified).

2.1.2 Sampling sites

Two sampling sites were chosen in the above described area: Bottaro and Lisca Nera (Fig. 11b). The first site was located on the northeast side of the Bottaro islet (38º38'18"N, 15º06'42"E) within a hydrothermally active area (Fig. 15) in which continuous high-flux emissions (up to ~0.1 m^3 min^{-1}) discharge the typical composition of thermal fluids (Tassi *et al*. 2009). At this site, for the study of the community of *C. brachycarpa*, four sampling stations were established along a transect 30 m long from the vent outlets towards outside (Fig. 16): (A) within the vent outlets, (B) at a distance of about 1 m from the vent outlets, (C) at a distance of about 6 m from the vent outlets and (D) at a distance of 30 m from the fluids discharges. Concerning the study of the epiphytes of *P. oceanica* leaves, two patched meadows exposed to different levels of gas emission (P1 close to the vents; P2 far from the vents) were selected at a distance of about 150 m from the transect and 50 m from each other. The second site was located at a distance of about 500 m from Bottaro, on the northeast side of the Lisca Nera islet (38º38'07"N, 15º06'27"E); a sampling station (E) was choosed where no visible hydrothermal activity was observed. At this site only the community of *C. brachycarpa* was studied.

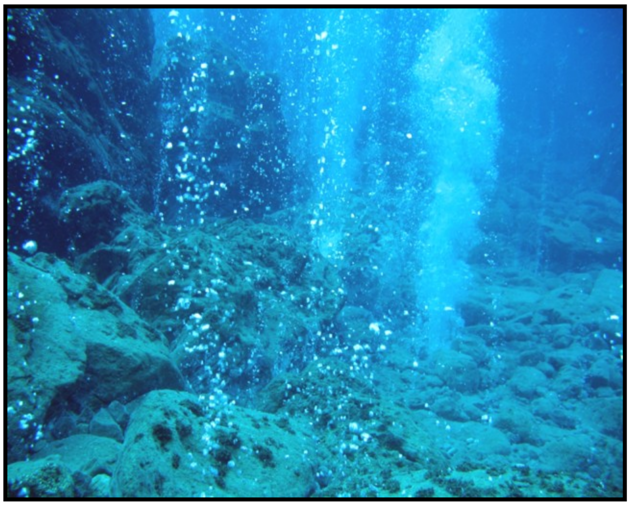


Fig. 15. Hydrothermal venting area at Bottaro islet characterized by active water outflows and gas bubbling randomly distributed on rocky and sandy sediments.

2.2 Sampling

For the study of the community of *C. brachycarpa*, fieldwork was carried out in June 2010, when populations of *Cystoseira* spp. are well developed and are easy to observe and identify (Ballesteros *et al.* 2007) and in October 2010, when the plants loose large parts of their branches. Samples were collected by SCUBA divers at about 7 m of depth, on a (sub-) horizontal rocky bottom, where the community

Fig. 17. Sampling of the *Cystoseira* community.

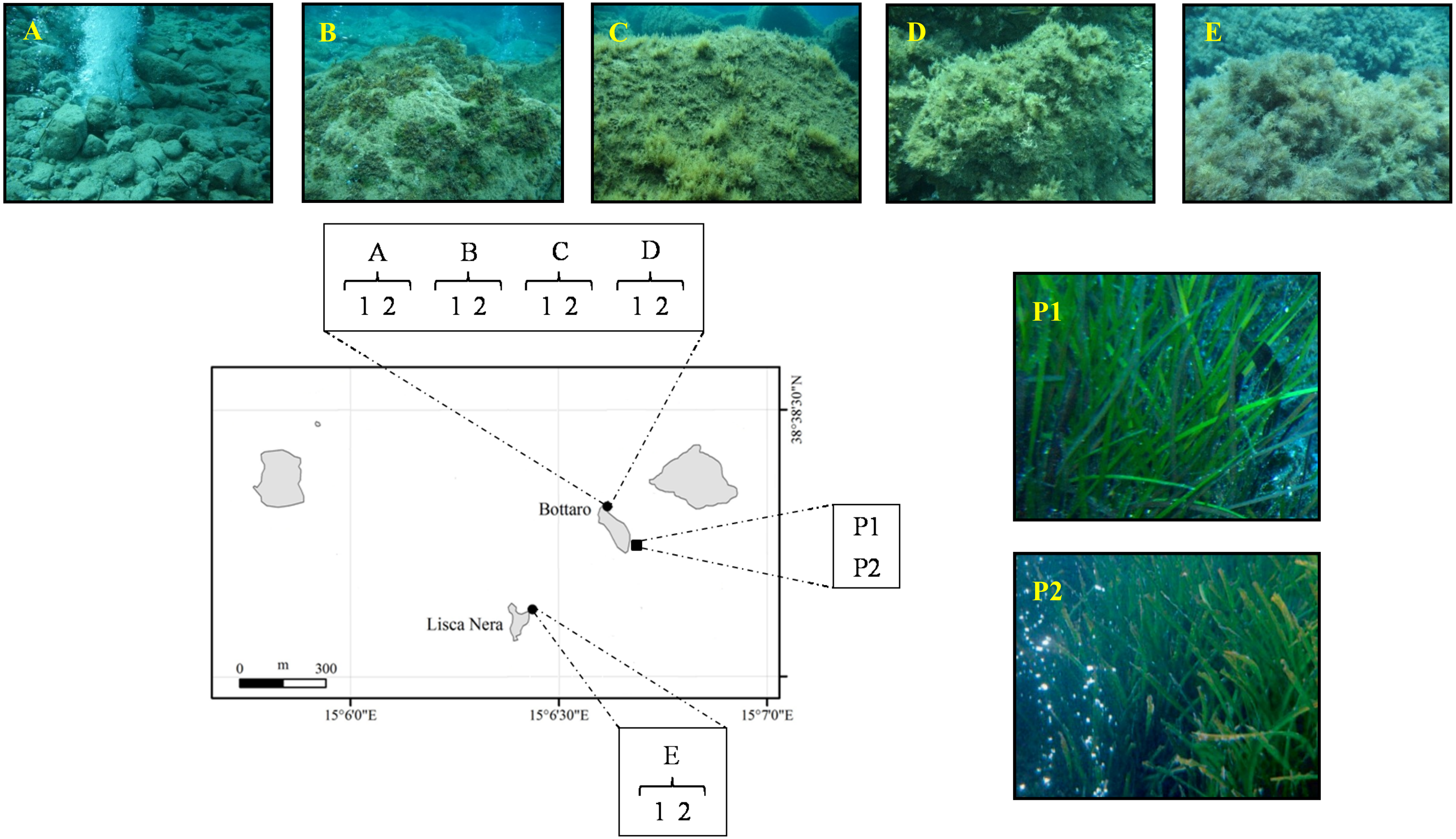


Fig. 16. Map showing the location of the samplig sites and distribution of samples. Five stations (A-D at Bottaro and E at Lisca Nera) were established for the study of the community of *C. brachycarpa* and two stations (P1 and P2) for the study of the epiphytic assemblages of *P. oceanica*. For each station (A-E) two quadrats (1-2) were taken. The appearance of the community (in June) is showed for each station.

appeared physiognomically and structurally homogeneous. In each station all vegetation was collected using a hammer and a chisel (Boudouresque 1971a) from two randomly placed 20x20 cm replicate quadrats (Fig. 17). This area is considered to be the minimal sampling area for the infralittoral communities of the Mediterranean (Dhont and Coppejans 1977, Boudouresque and Belsher 1979).

Fig. 18. Sampling of *P. oceanica* shoots.

On the other hand, for the study of the community of the epiphytes of *P. oceanica* leaves, sampling was carried out in September 2009, which corresponds to the period in which epiphytes reach their maximum development (Panayotidis 1980). Samples were collected by SCUBA divers at about 11-12 m of depth and consisted of ten vertical (orthotropous) shoots of each meadow randomly uprooted (Fig. 18). Shoot density was also measured in a 0.4 m square. The material collected was preserved in buffered 4% formalin in seawater for the floristic study in the laboratory. Also, temperature, salinity, dissolved oxygen, pH and chlorophyll "*a*" values were recorded using a multiparametric probe (Idronaut Ocean Seven 316). The field work was supported by the research boat "Antonino Borzì" owned by the Department of earth and marine science of the University of Palermo (Fig. 19).

Fig. 19. The "Antonino Borzì" boat used during the field work.

2.3 Laboratory analyses

Each sample of the community of *C. brachycarpa* was carefully sorted and all the species, even the smallest ones, were identified with the aid of the stereo- and microscope. Also, the reproductive structures, when present, were recorded. In order to evaluate the morphological phenology of the *C. brachycarpa*, five thalli were selected randomly from each quadrat and their height and the length of five randomly chosen primary branches measured (Pizzuto 1998).

For the study of the epiphytic assemblages of the *P. oceanica* leaves, the oldest part (the first 10 cm from the tip) of the internal face of the two external leaves of the each shoot collected were carefully examined under a stereomicroscope and all the epiphytes were set aside for identification. These leaves and portion represent the oldest ones within the shoot (Buia *et al*. 2004). Only the internal side of leaves was observed because it was considered more colonized than the external side (Casola *et al*. 1987, Casola and Scardi 1989, Alcoverro *et al*. 2004). Moreover, leaf surface area (L.A.I.) per shoot was calculated.

To each of the identified species, the relative abundance was quantified in terms of cover (horizontal surface measured in cm^2 after spreading the algal thalli in a laboratory tray, Ballesteros 1986). In the table 7, the coverage is expressed in percentage and species with negligible abundance were assigned coverage of 0.01%. To identify each macroalgal species, the identification keys proposed by Giaccone (1972-1973), Ballesteros (1980) and Boudouresque *et al*. (1992) as well as the keys contained in other specialized works were used. Scientific names of identified species were updated according to Furnari *et al*. (2010) and *Algaebase* (Guiry and Guiry 2012). To identify cyanobateria, identification keys proposed by Drouet and Daily (1956) and Drouet (1981) were used. The classification of listed taxa (see the appendix) was also based on *Algaebase,* as well as on current check-lists of benthic macroalgae of the Mediterranean coasts: Ribera *et al*. (1992) for the Phaeophyceae, Gallardo *et al*. (1993) for the Chlorophyceae, Gómez Garreta *et al*. (2001) for the Ceramiales (Rhodophyceae). Voucher specimens have been deposited in the BCN-Phyc Herbarium (Centre de Documentació de Biodiversitat Vegetal de la Universitat de Barcelona).

2.4 Analyzed parameters

The following parameters were considered:

Taxonomic and ecological groups. For each quadrat, the species number and coverage of the different taxonomic and ecological groups (Boudouresque 1984) were calculated in order to know their importance in the community (Table 3).

Reproductive phenology. The presence or absence of the reproductive structures was recorded and the % of fertile species was calculated for each quadrat.

R/P (Rhodophyceae/Phaeophyceae) index. This index was proposed by Feldmann (1937) for to characterizing the flora of a determinate region. According to Boudouresque (1971a) it also allows to characterize the communities. Cormaci *et al.* (1985) employed this index as synecological index considering it as a mean between the R/P values calculated for each sample. It represents an indicator of the environmental equilibrium: growing with the increase of pollution or instability (in extreme cases it cannot be calculated due to the absence of brown algae), it decreases in conditions of environmental stability.

Diversity index (DI). This index was calculated with the formula of Shannon and Weaver proposed by Margalef (1957) and modified by Boudouresque (1971a). Therefore, the formula adopted was the following:

$$H' = -\sum_{i=1}^{n} \frac{Ci}{Ct} \log_2 \frac{Ci}{Ct}$$

where H' is the diversity, C_i indicated the coverage of the species i in a quadrat and C_t indicated the total coverage of the quadrat. Normally, the value of this index decreases in polluted environments, but in environments with altered conditions, as for example in ports, it can have high values similar to those of reference communities in non polluted environments (Belsher *et al.* 1975). That is in agreement with the "intermediate disturbance principle" for biodiversity introduced by Connell (1978) according to which the same phenomenon can also be observed in ecotones and communities where either guides species or habitat building species have disappeared (e.g. upper stratum species like the large brown algae and marine angiosperms).

Table 3. Ecological groups according to Boudouresque (1984).

MR	Midlittoral Rocks
UMR	Upper Midlittoral Rocks
LMR	Low Midlittoral Rocks
MO	Midlittoral Overhangs
MF	Midlittoral Fringe
MCv	Midlittoral Cavities
PhI	Photophilous and Infralittoral
PhIW	Photophilous and Infralittoral in Wave-washed environment
PhIQ	Photophilous and Infralittoral in Quiet Waters
PhIT	Photophilous and Infralittoral Thermophilous
SIW	Sciophilous and Infralittoral in Wave-washed environment
SIWCd	Sciophilous and Infralittoral in Cold Wave-washed environment
SIWW	Sciophilous and Infralittoral in Warm Wave-washed environment
SRh	Sciophilous Rheophilous
SQ	Sciophilous Quiet
SI	Sciophilous Infralittoral
SIQ	Sciophilous Infralittoral Quiet
SIQT	Sciophilous Infralittoral Quiet Thermophilous
SIC	Sciophilous Infralittoral and Circalittoral
SStB	Sciophilous from Soft Bottom
AS	Anti Sciophilous
CC	Coralligenous Concretions
ETN	Eutrophic and Thio Nitrophilous
PhIH	Photophilous and Infralittoral Harbour
HSSmH	Hemi-Sciophilous Small Harbour
IHdB	Infralittoral Hard Bottom
PL	*Posidonia* leaves
LER	Large Ecological Repartition

Evenness (J'). This parameter informs about the community homogeneity-heterogeneity degree, since it measures the relative proportions among the species. It was calculated by Pielou’s index (1975) which ranges between 0 and 1. Therefore, the formula adopted was the following:

$$J' = \frac{H'}{\log_2 S}$$

where H' is the diversity of a quadrat and S is the total number of species of the quadrat.

2.5 Community data analyses

K-dominance curves of species coverage data was plotted for comparing diversity between sites; species were ranked on a logarithmic scale and their cumulative percentage dominance was represented with PRIMER v.6. (Clarke and Gorley 2006). Species with <0.1 percentage cover were considered as 0.1% in this analysis. The data from the current study were compared among them and with literature data. In this respect, two *C. brachycarpa* communities from the Spanish coasts (as *C. caespitosa*) and one from Corsica (as *C. balearica*), as well as several *C. brachycarpa* communities from the Sicilian coasts were considered. To compare the current study with those based in Braun-Blanquet methodology, the abundances were converted according to Braun-Blanquet (1964) transformation (Table 4). Among the available literature, only samples from both spring-autumn months and depths of 0.5 to 11m, were taken into account to obtain comparable data. Data were then subjected to a hierarchical cluster analysis using the Jaccard (1932) similarity coefficient for the presence/absence data, and the Bray-Curtis (1957) coefficient for the quantitative data.

Table 4. Classes of coverage and correspondent range of percentage cover. The third column reports the corresponding coverage % values according to Braun-Blanquet transformation (1964).

Class	Degree of coverage %	Corresponding coverage % value
+	≤ 1%	0.1
1	= 1-5%	5.0
2	= 6-25%	17.5
3	= 26-50%	37.5
4	= 51-75%	62.5
5	= 76-100%	87.5

Chapter 3

Results

3. Results

3.1 Chemico-physical parameters

The main chemical and physical parameters were recorded in both sampling sites (Table 5). In June, the seawater temperature along the transect of Bottaro ranged from 26.1°C at the station more distant from the vents (D) to 28.3°C at that more close to the vents (A), whereas it was 26.2°C at station E (Lisca Nera). In October, temperature values along the transect were similar to those of June, whereas at Lisca Nera (station E) the temperature was lower (19.6°C). The higher value was recorded at station A in both periods. On the other hand, at Bottaro, the seawater pH progressively increased along the transect, from the station close to the vents (station A; pH = 6.3) to that more distant from the vents (station D; pH = 7.9). At Lisca Nera (station E) the seawater showed a normal pH condition (pH = 8.1). No important differences were observed in seawater pH between the two sampling periods. A natural pH gradient was thus observed from the station A to the station E.

Table 5. Chemico-physical parameters of both sampling sites. The values reported are means (±sd) of data recorded using a multiparametric probe.

Site	**Bottaro**				**Lisca Nera**	**Bottaro**				**Lisca Nera**
Station	A	B	C	D	E	A	B	C	D	E
Period	June					October				
Temperature (°C)	28.3 ±0.3	27.3 ±0.1	27.2 ±0.1	26.1 ±0.1	26.2 ±0.2	28.1 ±0.2	27.4 ±0.1	26.8 ±0.1	26.4 ±0.1	19.6 ±0.2
Salinity (‰)	37.2 ±0.8	37.7 ±0.1	37.7 ±0.1	37.8 ±0.2	38.1 ±0.3	37.3 ±0.2	37.8 ±0.1	37.7 ±0.2	37.8 ±0.2	38.2 ±0.3
Dissolved Oxygen (%)	--	97.8 ±3.6	99.9 ±0.5	100.4 ±0.8	101.1 ±0.3	--	97.3 ±3.6	98.9 ±0.5	100.7 ±0.8	102.8 ±0.3
pH	6.3 ±0.1	6.9 ±0.1	7.2 ±0.6	7.9 ±0.1	8.1 ±0.1	6.3 ±0.1	6.8 ±0.1	7.3 ±0.1	7.9 ±0.1	8.1 ±0.1
Chlorophyll “*a*” (µg/l)	--	0.1 ±0.1	0.1 ±0.1	0.1 ±0.1	0.1 ±0.1	--	0.1 ±0.1	0.1 ±0.1	0.1 ±0.1	0.1 ±0.1

3.2 The Bottaro community

At this samplig site the community of *C. brachycarpa* was present in all stations along the transect except in that very close to the vent outlets (station A).

3.2.1 The vegetation at vent outlets (station A)

A white mat consisted mainly of sulphur bacteria was observed surrounding the vent outlets and only two Cyanophyceae (*Calothrix scopulorum* and *Pleurocapsa fuliginosa*) at a temperature of 28°C and at mean pH 6.3 were detected (Fig. 20).

Fig. 20. The white mat of sulphur bacteria at station A.

3.2.2 The community of Cystoseira brachycarpa

A community of *C. brachycarpa* was found at the stations B, C and D of Bottaro. Among all samples a total of 92 taxa [12 Cyanophyceae (13%), 49 Rhodophyta (53.3%), 14 Phaeophyceae (15.2%) and 17 Chlorophyta (18.5%)] were identified in the community of *C. brachycarpa* of this site (Tables 6 and 7). A description of the community of each station in June and October is provided as follows.

Table 6. Number of species of the indicated taxonomic groups and in total recorded at each station in June (2 samples) and October (2 samples). Totals for both sampling sites (from 12 samples at Bottaro and 4 samples at Lisca Nera) are also showed.

Site	Bottaro							Lisca Nera		
Station	B	B	C	C	D	D	**Total**	E	E	**Total**
Date 2010	June	Oct.	June	Oct.	June	Oct.		June	Oct.	
pH	6.92		7.23		7.91			8.12		
Cyanophyceae	5	12	5	7	3	11	12	4	2	5
Rhodophyta	17	11	20	18	43	35	49	50	39	50
Phaeophyceae	8	7	10	7	12	10	14	13	9	13
Chlorophyta	12	8	9	8	12	11	17	8	7	11
Total	42	38	44	40	70	67	92	75	57	79

3.2.2.1 The community at Station B

In June, the mean number of species per quadrat was 30.5 and the mean cover was 658.7 cm^2 (164.7%) (Table 8). In this period the community was scarcely developed (Fig. 21), showing a poor erect algal stratum dominated by *C. brachycarpa* (525.9 cm^2; 132.5%); the specimens of this species were very small in size, showing a mean height of 3.5 (±sd0.3 cm) and branches measuring 1.7 (±sd0.2 cm) in average. In the erect substratum *Dictyota mediterranea*, *Padina pavonica* and *Caulerpa racemosa* v. *cylindracea* were the most abundant species (Fig. 22); no encrusting species were observed and therefore the encrusting stratum was lacking. Few species grew as epiphytes on *C. brachycarpa* and although they were mainly Cyanophyceae and Ceramiales, *Anadyomene stellata* (mainly on branches), *Peyssonnelia dubyi* and *Rhodymenia ligulata* (both growing on main axes) were the quantitatively dominant epiphytic species. Qualitatively Rhodophyta was the most important taxonomic group (36.1%) being the Ceramiales the best represented (24.6%) among these; no species of Corallinales were found in the community; in contrast, the Phaeophyceae was the most abundant taxonomic group (558 cm^2; 139.5%) mainly due to *C. brachycarpa* (526 cm^2; 131.5%) (Table 9 and Fig. 23a, b). Photophilic algae dominated both qualitatively (41%) and quantitatively (150.8%) the community (Table 10 and Fig. 24a, b); they were mainly represented by quiet water species such as *C. brachycarpa*, *D. mediterranea* and *P.*

Fig. 21. Appearance of the community in June at the Station B.

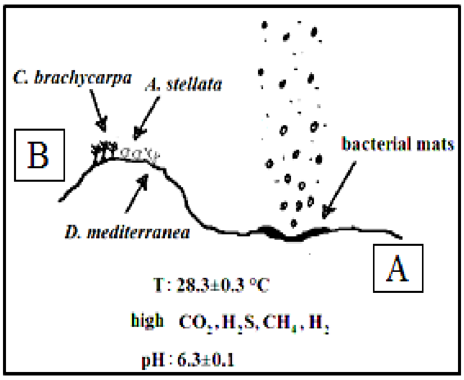
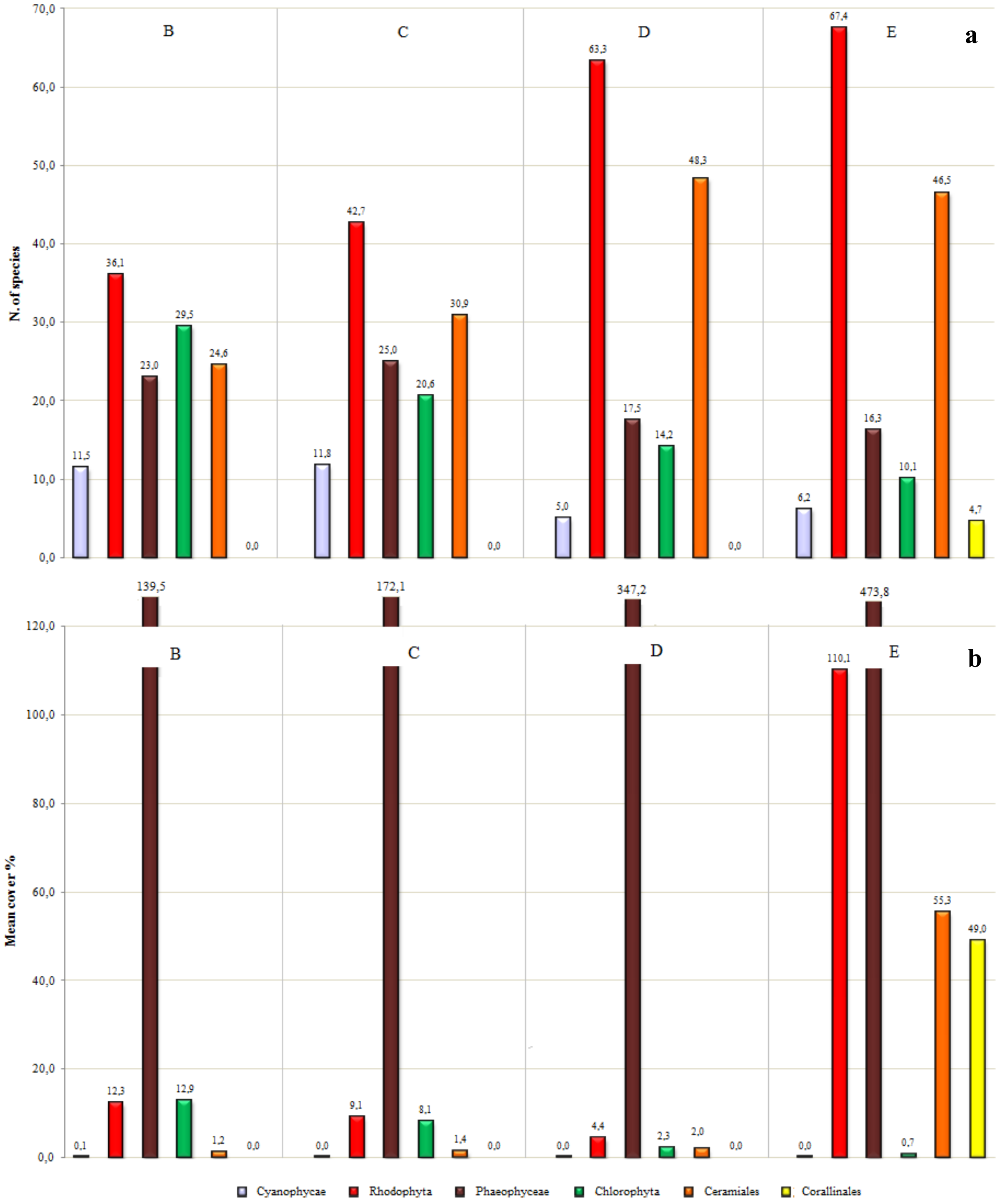


Fig. 22. Scheme of the stations A and B in the shallow water area of Bottaro islet.

pavonica, as well as by the thermophilic algae *A. stellata* and *C. racemosa* v. *cylindracea*; sciaphilic species were also qualitatively well represented (23%) highlighting *Acrochaetium hauckii*, *Pseudochlorodesmis furcellata* and *R. ligulata*. The mean value of R/P Index was 1.5 and the values of diversity and evenness were 1.2 and 0.3 on average, respectively (Table 8). The reproductive capacity of the community was low, since only two fertile species (3.1%) were found (Tables 8 and 11).



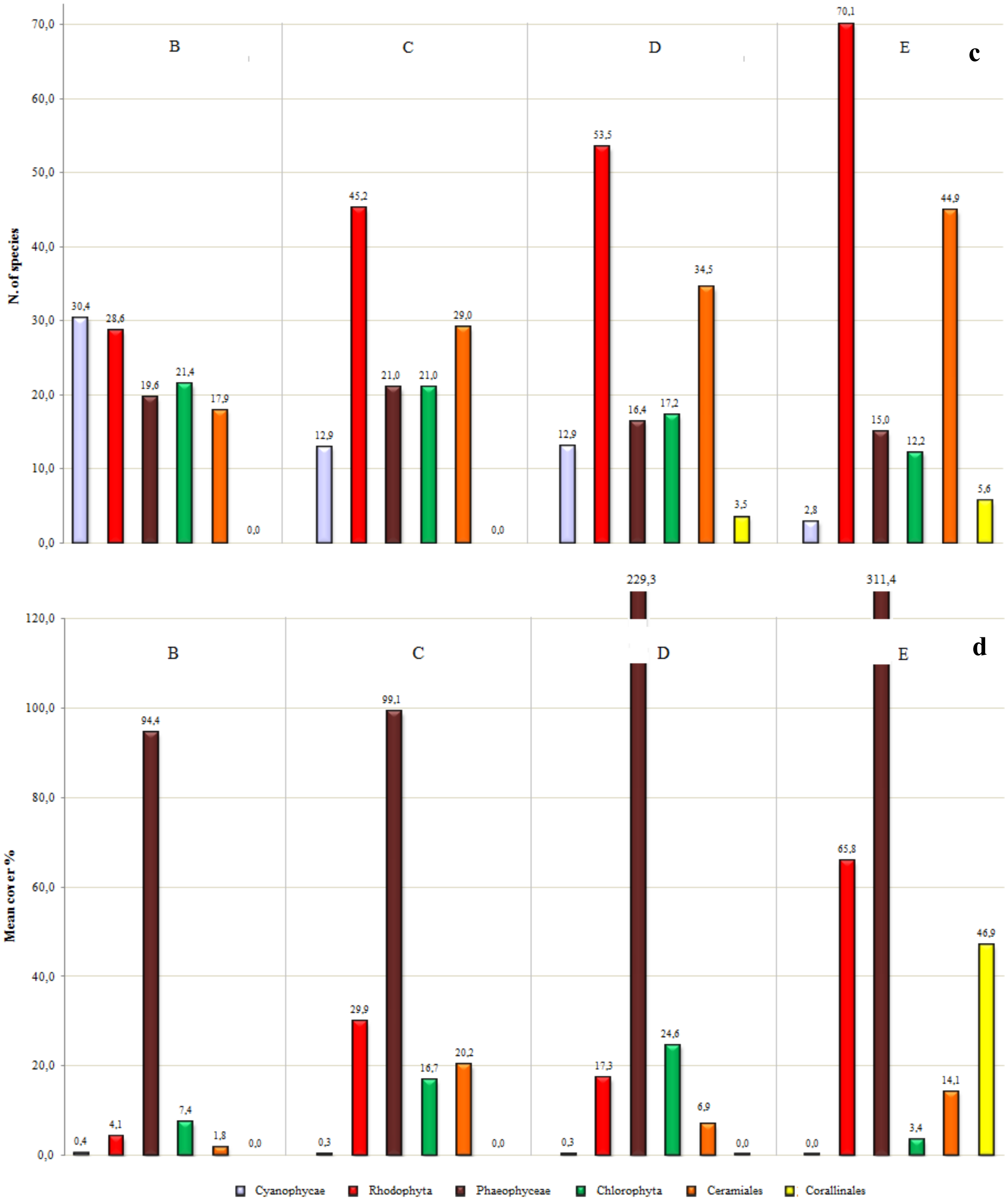
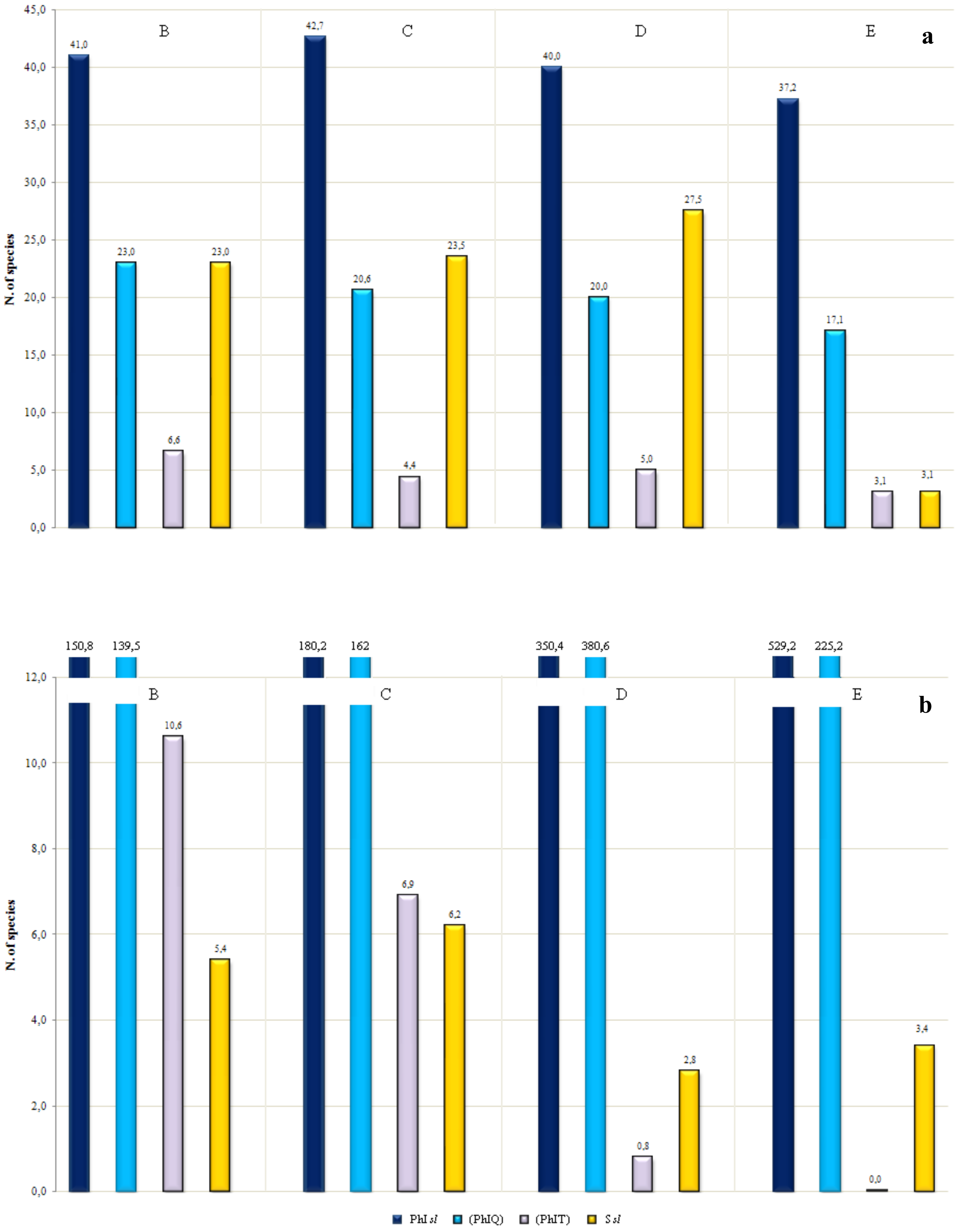


Fig. 23. Qualitative (a-c) and quantitative (b-d) dominance (%) of the main taxonomic groups in the community at each station, (a-b) June and (c-d) October; 0.0 = <0.1%.


a
N. of species
45,0
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
B
C
D
E
41,0
23,0
6,6
23,0
42,7
20,6
4,4
23,5
40,0
20,0
5,0
27,5
37,2
17,1
3,1
3,1
b
N. of species
12,0
10,0
8,0
6,0
4,0
2,0
0,0
150,8
139,5
10,6
5,4
180,2
162
6,9
6,2
350,4
380,6
0,8
2,8
529,2
225,2
0,0
3,4
PhI sl
(PhIQ)
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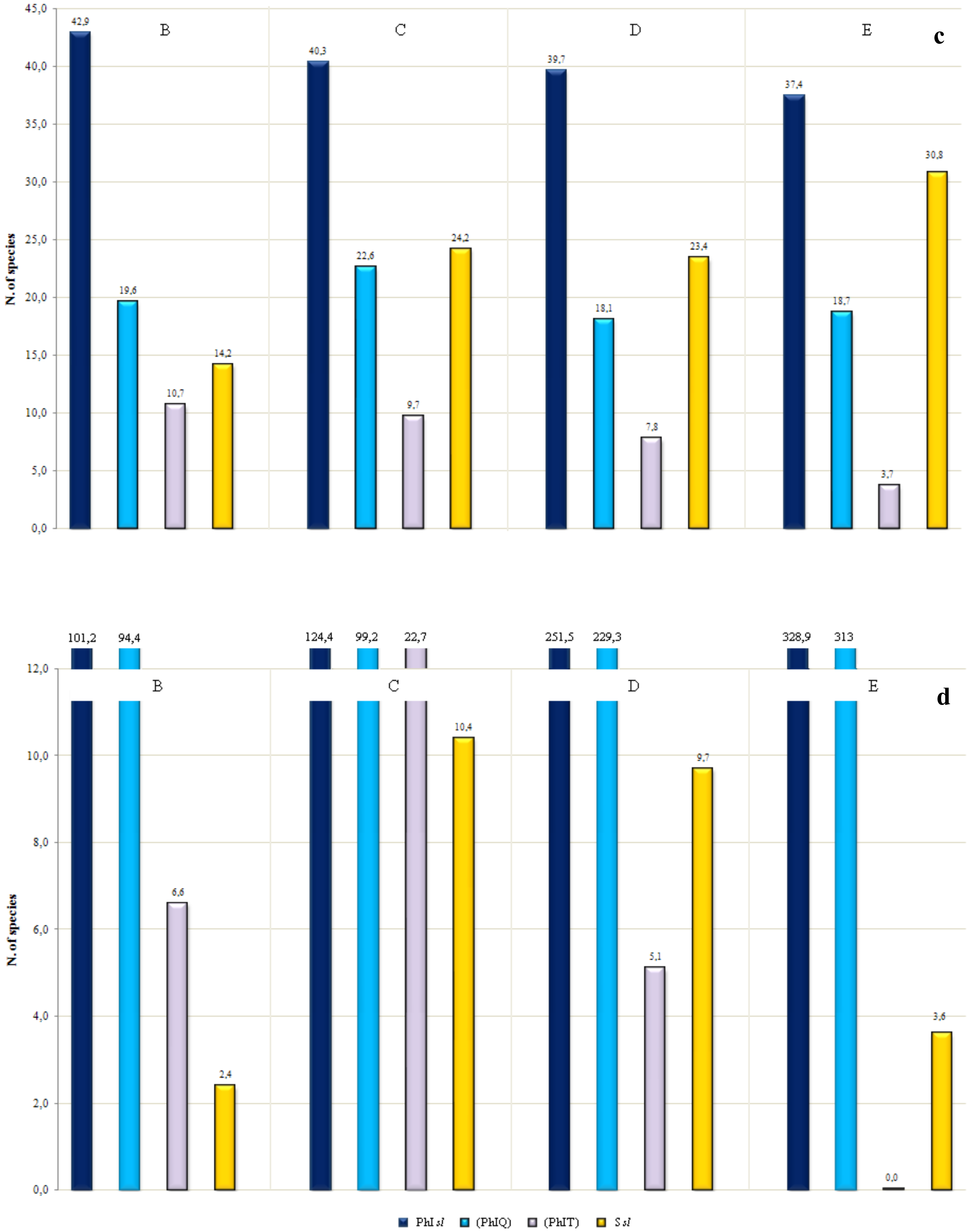


Fig. 24. Qualitative (a-c) and quantitative (b-d) dominance (%) of the main ecological groups in the community at each station, (a-b) June and (c-d) October; 0.0 = <0.1%. See Table 7 for the abbreviations.

In October, the mean number of species per quadrat was similar to that of June (28 species) but the cover was somewhat lower (425 cm^2; 106.3%) (Table 8). The erect algal stratum was dominated by *C. sauvageauana* (214 cm^2; 53.4%) and *C. brachycarpa* (160.1 cm^2; 40%) (Tables 7 and 8); like in June, the specimens of this latter species were little developed, with a mean height of 3.3 (±sd0.2 cm) and branches measuring 1.6 (±sd0.3 cm) in average. In the erect substratum *Flabellia petiolata*, *A. stellata* and *Rytiphlaea tinctoria* were the most abundant species. Very few species grew as epiphytes on both *Cystoseira* species, with a qualitative dominance of Cyanophyceae (*Rivularia polyotis*) and mainly of Ceramiales (*Boergeseniella fruticulosa* and *Chondria capillaris*). Cyanophyceae and Rhodophyta were the taxonomic groups qualitatively best represented in the community (30.4% and 28.6%, respectively), highlighting Ceramiales (17.9%) among the Rhodophyta; Corallinales were not present; quantitatively, the Phaeophyceae was the most important taxonomic group (94.4%), although their abundance was lower than in June (Table 9 and Fig. 23c, d). Photophilic algae also dominated both qualitatively (42.9%) and quantitatively (101.2%) the community (Table 10 and Fig. 24c, d); they were mainly represented by quiet water species such as *C. sauvageauana*, *C. brachycarpa* and *D. mediterranea*, as well as by the thermophilic algae *A. stellata* and *Dasycladus vermicularis*; sciaphilic species were somewhat less important (Table 10). The community showed similar values of the R/P Index and the evenness than in June, but the diversity was somewhat higher (Table 8). No fertile species was found (Tables 8 and 11).

Table 7. List of taxa from quadrats of both sampling sites in both periods. The coverage is expressed in percentage values. Each species is preceded by its ecological group (Boudouresque 1984). MR: Midlittoral Rocks; PhI: Photophilous and Infralittoral (H: Harbour; Q: Quiet waters; T: Thermophilous; W: Wave-washed environment); SQ: Sciaphilous Quiet waters; SI: Sciaphilous Infralittoral (Q, T and W as in PhI; WW: Warm Wave-washed environment); SIC: Sciaphilous Infralittoral and Circalittoral; AS: Anti Sciaphilous; IHdB: Infralittoral Hard Bottom; ETN: Eutrophic and Thio Nitrophilous; LER: Large Ecological Repartition; CC: Coralligenous Concretions; PL: *Posidonia* Leaves.

	Site	**Bottaro**												**Lisca Nera**			
	Station	B	B	B	B	C	C	C	C	D	D	D	D	E	E	E	E
	Quadrat	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
	Sampling area (cm^2)	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
	Exposition	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
	Depth (m)	7.2	7.4	7.2	7.4	7.5	6.8	7.5	6.8	6.6	6.9	6.6	6.9	7	7,1	7	7,1
	Date 2010	June	June	Oct.	Oct.	June	June	Oct.	Oct.	June	June	Oct.	Oct.	June	June	Oct.	Oct.
	Number of species	28	33	30	26	35	33	32	30	63	57	60	56	66	63	52	55
PhIQ	*Cystoseira brachycarpa*	145.37	117.58	32.41	47.65	140.25	175.64	63.82	56.35	272.58	326.41	130.45	183.84	425.24	502.57	311.23	302.85
PhIW	*Boergeseniella fruticulosa*	0.42	0.21	0.18	0.01	0.13	0.51	1.03	0.01	0.01	0.01	3.98	0.03	47.57	42.81	9.12	7.23
PhI	*Sphacelaria cirrosa*	0.14	0.22	0.01	0.03	0.63	19.26	2.14	0.02	38.54	42.14	6.28	13.47	3.84	4.61	2.24	1.85
PhIQ	*Dictyota mediterranea*	1.84	9.81	1.45	0.21	5.28	2.73	1.23	9.42	5.24	3.24	11.94	9.95	0.74	0.92	1.41	2.19
IHdB	*Peyssonnelia dubyi*	2.51	12.21	3.08	0.82	4.63	1.12	1.32	3.13	0.28	0.57	2.32	0.32		0.78	0.26	0.12
LER	*Lophosiphonia obscura*	0.02	0.01		0.01	0.01	0.01	0.01	0.28	0.14	0.01	0.01	0.21	0.01	0.01	0.01	0.01
MR	*Lyngbya confervoides*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		
SQ	*Rhodymenia ligulata*		6.41			0.54	8.63	7.84	5.31	1.32	0.83	4.32	6.87	0.21	0.88	0.14	0.62
PhIQ	*Padina pavonica*	1.45	1.98				0.01	0.42	1.02	3.84	1.87	1.32	4.32	0.92	4.84	0.31	0.25
PhIQ	*Herposiphonia secunda*	0.23	0.11			0.03	0.01	0.28		0.13	2.48	0.32		4.61	4.82	1.27	1.05
PhIQ	*Womersleyella setacea*		0.28		0.01	0.01		0.01	1.95	0.41	0.24	0.32	0.54	0.45	0.36	0.74	0.26
SIQT	*Halopteris filicina*	0.05	0.01			0.05	0.01	0.01	0.01	0.01	0.01		0.01	0.02	0.03	0.01	0.01
MR	*Calothrix crustacea*	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01		0.01	0.01	0.01		0.01
PhIT	*Anadyomene stellata*	0.42	15.34	6.54	1.62	0.57	3.84	4.72	2.62	0.82	0.74	6.14	1.54				
ETN	*Derbesia tenuissima*	0.29	0.21	0.33	0.48	0.01		9.28	7.21	0.01		10.12	6.62			1.15	0.64
PhI	*Laurencia microcladia*	0.27				1.62	0.21	1.72		0.01	0.01	3.84	3.21	0.58	0.84	1.45	4.25
PhI	*Polysiphonia* cf. *dichotoma*		0.14			0.01	0.01	0.01		0.01	0.01	0.01	0.01	0.21	0.23	0.01	0.01
LER	*Phaeophila dendroides*	0.01	0.01			0.01	0.01			0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
AS	*Flabellia petiolata*	0.89	0.96	3.78		2.35		5.82	0.08	2.58		1.96	1.43			0.96	0.43
PhIQ	*Chondria capillaris*		0.08	0.08	0.01			0.12	0.01		0.01		0.23	0.12	0.15	0.26	0.18
PhIQ	*Halopteris scoparia*	0.02	0.01			0.03	0.01			0.01	0.01	0.01		0.02	0.03	0.02	0.01
PhIQ	*Spermothamnion repens*		0.02	0.01		0.01			0.01	0.01	0.01	0.01	0.01	0.03		0.01	0.01
SIC	*Ulvella lens*	0.01				0.01	0.01			0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
IHdB	*Stylonema alsidii*		0.01	0.01				0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
PhIW	*Gelidium pusillum*					0.01	0.03			0.03	1.25	0.52	2.58	3.64	3.82	2.24	3.18

Table 7 *(continued)*

PhIQ	*Dictyota fasciola*					0.01	0.01			0.34	0.01	0.01	0.08	0.84	0.93	0.01	0.34
SIC	*Pseudochlorodesmis furcellata*	0.35	0.85		0.01	0.01		0.01					0.01	0.01	0.05	0.01	0.01
LER	*Lophosiphonia cristata*				0.01		0.01	0.42	0.01		0.01	0.01	0.15	0.07		0.01	0.01
SIQ	*Discosporangium mesarthrocarpum*			0.01		0.01	0.01	0.01		0.01	0.01	0.13	0.01		0.15		0.01
SIWW	*Botryocladia botryoides*					0.45		1.42		0.01	0.05	0.62	0.23		0.06	0.02	0.28
ETN	*Cladophora echinus*		1.08	0.01	0.01			0.01	0.01	0.01		0.01	0.01	0.75			
SQ	*Acrochaetium hauckii*	0.32	0.58	0.01	0.12			0.01	0.05		0.01	0.01	0.01				
PhI	*Laurencia minuta* ssp. *scammaccae*						0.01			0.01	0.01	0.01	0.01	0.07	0.09	0.05	0.02
CC	*Blastophysa rhyzopus*	0.01			0.01				0.01		0.01	0.01		0.01	0.01	0.01	0.01
SI	*Heterosiphonia crispella*									0.01	0.01	0.01	0.52	1.31	1.17	1.08	0.92
IHdB	*Ceramium siliquosum*	0.58					0.01			0.01	0.01	0.01		1.11	1.25		0.01
PL	*Chondria mairei*					0.01				0.01	0.01		0.01	0.63	0.84	0.01	0.01
PhIH	*Nitophyllum micropunctatum*									0.01	0.01	0.01	0.15	0.14	0.29	0.01	0.01
SI	*Botryocladia microphysa*			0.68			0.01	0.25				0.01	0.01	0.04		0.01	0.01
MR	*Chaetomorpha linum*	0.02				0.01	0.01		0.23	0.01	0.01	0.01	0.08				
SQ	*Ceramium codii*		0.03			0.01	0.01		0.01	0.01	0.01	0.01	0.01				
SIQ	*Polysiphonia scopulorum*							0.01		0.01	0.01	0.01	0.01	0.02		0.01	0.01
LER	*Acrochaete viridis*	0.01		0.01		0.01	0.01			0.01				0.01	0.01		
PhIT	*Anotrichium barbatum*									0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
IHdB	*Antithamnion cruciatum*									0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PhIT	*Dipterosiphonia rigens*									0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PhIT	*Caulerpa racemosa* v. *cylindracea*	0.68	4.72				9.41	1.35	2.14			1.97	0.52				
SQ	*Peyssonnelia bornetii*									0.32	0.18	1.72	1.23		0.68	0.31	0.11
PhIQ	*Dictyota linearis*			0.05						0.01		0.03	0.05	0.74	0.62		0.05
IHdB	*Gayliella flaccida*		0.01							0.01		0.01	0.01	0.02	0.03		0.01
LER	*Ceramium tenerrimum*									0.01	0.01	0.01	0.01		0.02	0.01	0.01
PhI	*Chroococcus minutus*			0.01	0.01					0.01	0.01	0.01		0.01	0.01		
PhIQ	*Cystoseira sauvageauana*			63.68	43.21			41.32	22.47			67.58	28.92				
IHdB	*Haliptilon virgatum*											0.01	0.01	0.96	0.83	0.54	0.41
PL	*Hydrolithon farinosum*											0.01	0.01	0.15	0.11	0.12	0.12
MR	*Rivularia atra*				0.01	0.01	0.01		0.53			0.23	0.01				
LER	*Ceramium comptum*									0.01	0.01			0.04	0.03	0.01	0.01
SIQ	*Lejolisia mediterranea*									0.01	0.01			0.02	0.03	0.01	0.01
SIW	*Rhodophyllis divaricata*									0.01	0.01			0.04	0.01	0.01	0.01
SIQ	*Callithamnion corymbosum*									0.01	0.01			0.01	0.01	0.01	0.01
PhI	*Chroococcus submarinus*	0.01		0.01		0.01						0.01		0.01	0.01		
LER	*Dasya baillouviana*					0.01				0.01	0.01	0.01		0.01	0.01		
ETN	*Erythrotrichia carnea*									0.01	0.01	0.01			0.01	0.01	0.01
MR	*Lyngbya sordida*			0.01					0.01			0.01	0.01			0.01	0.01

Table 7 *(continued)*

PhIT	*Rytiphlaea tinctoria*			1.13	2.05			16.08	18.42			0.01					
SQ	*Peyssonnelia* cf. *inamoena*									0.01				0.32	0.48	0.87	1.26
SQ	*Cutleria chilosa*		0.27	0.08			0.32					0.24		0.36			
MR	*Rivularia polyotis*	0.01		0.01	0.62				0.01			0.31					
SQ	*Lomentaria clavaeformis*		0.03											0.07	0.08	0.01	0.01
SIC	*Dasya rigidula*					0.08				0.01	0.01			0.02	0.01		
MR	*Neogoniolithon brassica-florida*													48.37	47.61	46.12	46.47
PhI	*Wrangelia penicillata*													0.08	0.13	0.02	0.02
SIC	*Apoglossum ruscifolium*													0.02	0.03	0.01	0.01
PhI	*Crouania attenuata*									0.01	0.01			0.02	0.03		
SIC	*Antithamnion heterocladum*									0.01	0.01			0.01	0.01		
MR	*Leptolyngbya fragilis*			0.01				0.01				0.01	0.01				
MR	*Michrochaete grisea*	0.01		0.01	0.01								0.01				
PhIQ	*Codium bursa*											10.54	8.14			3.54	
PhIQ	*Acetabularia acetabulum*									0.13	0.13				0.22		
PhIQ	*Cladostephus spongiosus* f. *verticillatus*		0.18							0.01	0.01						
PhIQ	*Stilophora tenella*						0.01				0.01			0.1			
IHdB	*Dasya corymbifera*		0.02			0.01				0.01							
SIQ	*Spermothamnion flabellatum*									0.01				0.02	0.01		
MR	*Calothrix aeruginea*				0.01				0.01				0.01				
PhIT	*Dasycladus vermicularis*			0.92	1.01												
SIW	*Valonia utricularis*									0.01				0.25			
SIWW	*Feldmannophycus rayssiae*											0.01		0.14			
SQ	*Erythroglossum sandrianum*													0.05	0.04		
SIC	*Radicilingua reptans*									0.01				0.03			
MR	*Brachytrichia quoyi*			0.01			0.01										
IHdB	*Falkenbergia rufolanosa* stadium													0.01	0.01		
PL	*Giraudia sphacelarioides*										0.01				0.01		
MR	*Lyngbya aestuarii*				0.01								0.01				
SQ	*Ptilothamnion pluma*										0.01			0.01			
PL	*Ascocyclus orbicularis*													0.01			
PhIQ	*Chylocladia pelagosae*														0.08		
PhIH	*Bryopsis plumosa*									0.01							
SIQ	*Cladophora lehmanniana*		0.01														
SIWW	*Griffithsia phyllamphora*									0.01							

Table 8. Values of the indicated parameters for each quadrat and on average. (Av ±sd) at each station in both sampling periods.

Site									**Bottaro**									
Station	B	B		B	B		C	C		C	C		D	D		D	D	
Quadrat	1	2	Av.	1	2	Av.	1	2	Av.	1	2	Av.	1	2	Av.	1	2	Av.
Period	June	June		Oct.	Oct.		June	June		Oct.	Oct.		June	June		Oct.	Oct.	
N. of species	28	33	30.5 ±3.5	30	26	28 ±4.2	35	33	34 ±1.4	32	30	31 ±1.4	63	57	60 ±4.2	60	56	58 ±2.8
Cover (cm^2)	623.84	693.64	658.74 ±49.35	458.20	391.88	425.04 ±46.89	627.40	887.68	757.54 ±184.04	642.84	525.44	584.14 ±83.01	1308.72	1522.28	1415.50 ±151.01	1074.24	1102.12	1086.18 ±22.54
***C. brachycarpa* cover (cm^2)**	581.48	470.32	525.90 ±78.60	129.64	190.60	160.12 ±43.10	561	702.56	631.78 ±100.09	255.28	225.40	240.34 ±21.12	1090.32	1305.64	1197.98 ±152.25	521.80	735.36	628.58 ±151.01
N. of fertile species (%)	-	6.1	3.1 ±4.3	-	-	-	2.9	6.1	4.5 ±2.3	-	-	-	15.9	21.1	18.5 ±3.7	9.8	8.8	9.3 ±0.7
R/P	1.2	1.8	1.5 ±0.4	1.1	2	1.6 ±0.6	2.3	1.3	1.8 ±0.7	2.3	2	2.2 ±0.2	3.9	3.4	3.7 ±0.3	3.3	3.6	3.5 ±0.2
DI	0.60	1.86	1.23 ±0.89	1.87	1.53	1.7 ±0.24	0.79	1.24	1.01 ±0.32	2.67	2.63	2.65 ±0.03	0.97	0.82	0.90 ±0.11	2.48	2.02	2.25 ±0.32
Evenness	0.12	0.37	0.25	0.38	0.32	0.35	0.16	0.24	0.20	0.53	0.53	0.53	0.16	0.14	0.15	0.42	0.34	0.38

Site			**Lisca Nera**			
Station	E	E		E	E	
Quadrat	1	2	Av.	1	2	Av.
Period	June	June		Oct.	Oct.	
N. of species	66	63	64.5 ±2.1	52	55	53.5 ±2.1
Cover (cm^2)	2180.80	2495.16	2337.98 ±222.28	1542.96	1501.60	1522.28 ±29.24
***C. brachycarpa* cover (cm^2)**	1700.96	2010.28	1855.62 ±218.72	1244.92	1211.40	1228.16 ±23.70
N. of fertile species (%)	31.8	33.3	32.6 ±1.1	17.3	16.7	17 ±0.42
R/P	4.9	4.3	4.6 ±0.42	5.4	3.8	4.6 ±1.1
DI	1.28	1.21	1.25 ±0.05	1.17	1.15	1.16 ±0.01
Evenness	0.21	0.20	0.21	0.20	0.19	0.20

3.2.2.2 The community at Station C

In June, the mean number of species per quadrat was 34 (Table 8) and the mean cover was 757.5 cm^2 (189.4%). The erect algal stratum was dominated by *C. brachycarpa* (631.8 cm^2; 158%) whose specimens were slightly developed (Fig. 25), with a mean height of 6.3 (±sd0.2 cm) and branches with a mean length of 4.5 (±sd0.3 cm). In the erect substratum *D. mediterranea* and *Caulerpa racemosa* v. *cylindracea* were the most abundant species; no encrusting species were observed. *C. brachycarpa* supported an epiphyte stratum mainly constituted by Cyanophyceae and Ceramiales, but quantitatively dominated by *Sphacelaria cirrosa* on branches and *R. ligulata*, *P. dubyi* and *A. stellata* on main axes.

Fig. 25. Appearance of the community in June at the Station C.

Qualitatively, Rhodophyta was the most important taxonomic group (42.7%), being the Ceramiales the best represented among these (30.9%); no Corallinales were detected; quantitatively, Phaeophyceae was the most abundant taxonomic group (172.1%) (Table 9 and Fig. 23a, b). Photophilic algae dominated both qualitatively (42.7%) and quantitatively (180.1%) the community (Table 10 and Fig. 24a, b); they were mainly represented by quiet water species such as *C. brachycarpa* and *D. mediterranea*, as well as by the thermophilic algae *A. stellata* and *C. racemosa* v. *cylindracea*; sciaphilic species were also qualitatively well represented (23.5%), particularly by *R. ligulata* and *F. petiolata*. The mean value of R/P Index was 1.8 and the values of diversity and evenness were 1 and 0.2 on average, respectively (Table 8). Very few fertile species (4.5%) were recorded (Tables 8 and 11).

In October, the mean number of species per quadrat was not much different than in June (31 species; Table 8) and de mean cover was somewhat fewer (584.1 cm^2; 146%). The erect algal stratum was dominated by *C. brachycarpa* (240.4 cm^2; 60.1%) and *C. sauvageauana* (127.6 cm^2; 31.9%) (Tables 7 and 8); thalli of *C. brachycarpa* were slightly smaller, with a mean height of 5.5 (±sd0.4 cm) and branches measuring 3.9 (±sd0.2 cm) in average. In the erect substratum *R. tinctoria*, *D. mediterranea* and *Derbesia tenuissima* were the most abundant species. Very few species grew as epiphytes on both *Cystoseira* species, with a qualitative dominance of Cyanophyceae and Ceramiales. Rhodophyta, and especially Ceramiales (29%), were continuing dominating qualitatively the community, wereas the Phaeophyceae was quantitatively the most abundant (99.1%) taxonomic group (Table 9 and Fig. 23c, d); Corallinales were not present. Photophilic algae dominated both qualitatively (40.3%) and quantitatively (124.3%) the community (Table 10); they were mainly represented by quiet water species, such as *C. sauvageauana*, *C. brachycarpa* and *D. mediterranea*, as well as by the thermophilic algae *R. tinctoria* and *A. stellata*; sciaphilic species were also well represented both qualitatively and quantitatively (Table 10 and Fig. 24c, d). The mean value of R/P Index was 2.2; the diversity increased significantly (2.6 on average) and the mean value of evenness was 0.5 (Table 8). No fertile species was found (Tables 8 and 11).

Table 9. Qualitative (Q) and quantitative (K) dominances (%) of the main taxonomic groups in the community at each station. Mean (±sd).

Site	Bottaro												Lisca Nera			
Station	B		B		C		C		D		D		E		E	
Dominance	Q	K	Q	K	Q	K	Q	K	Q	K	Q	K	Q	K	Q	K
Period	June		Oct.		June		Oct.		June		Oct.		June		Oct.	
Cyanophyceae	11.48	0.07	30.35	0.39±0.14	11.76	0.04±0.18	12.92	0.30±0.18	5	0.03	12.93	0.33±0.09	6.20	0.04	2.80	0.01
Rhodophyta	36.06	12.25±2.84	28.58	4.11±0.89	42.65	9.08±1.75	45.16	29.87±4.64	63.33	4.43±0.36	53.45	17.31±1.31	67.44	110.05±9.67	70.10	65.77±7.56
Phaeophyceae	22.96	139.46±47.64	19.64	94.39±24.50	25	172.13±52.41	20.96	99.12±23.33	17.5	347.16±89.77	16.38	229.32±50.34	16.28	473.77±139.77	14.95	311.39±104.67
Chlorophyta	29.50	12.93±3.63	21.43	7.36±1.99	20.59	8.13±2.63	20.96	16.74±3.18	14.17	2.26±0.66	17.24	24.58±0.64	10.08	0.68±0.21	12.15	3.40±0.99
Bryopsidales	13.12	4.48±1.48	7.14	2.30±1.76	5.88	5.89±4.45	11.29	12.95±3.71	2.50	1.30±1.48	7.76	20.66±4.24	1.55	0.03±0.03	6.54	3.37±1.21
Cladophorales	8.20	8.43±6.70	7.14	4.09±3.40	5.88	2.21±1.84	8.06	3.79±2.10	4.17	0.79±0.42	5.17	3.89±2.44	0.77	0.38	--	--
Dictyotales	6.55	7.54±4.03	5.36	0.86±0.76	7.36	4.02±2.36	6.46	6.04±4.28	5.83	7.28±2.08	6.90	13.85±4.87	6.20	5.27±0.08	6.54	2.28±0.82
Ceramiales	24.59	1.21±0.17	17.86	1.75±0.69	30.88	1.38±0.36	29.03	20.19±5.50	48.33	1.97±0.32	34.48	6.89±0.97	46.51	55.30±8.17	44.87	14.12±1.75
Corallinales	--	--	--	--	--	--	--	--	--	--	3.45	0.02	4.65	49.01±24.52	5.61	46.89±23.75
Peyssoneliales	3.28	7.36±6.85	3.57	1.95±1.59	2.94	2.87±2.48	3.22	2.22±1.28	4.17	0.68±0.20	3.45	2.79±0.84	3.10	1.13±0.31	5.60	1.47±0.47
Rhodymeniales	3.28	3.22±4.51	1.79	0.34	5.88	4.81±4.15	6.46	7.42±3.50	3.33	1.10±0.63	5.17	6.03±2.90	5.42	0.71±0.30	7.48	0.55±0.21
Other orders	40.98	132.44±36.60	57.14	94.97±16.67	41.18	168.20±41.65	35.48	93.42±19.37	31.67	340.75±69.03	33.62	217.41±36.85	31.8	472.66±101.45	23.36	311.89±84.91

3.2.2.3 The community at Station D

In June, the mean number of species per quadrat was 60 and the mean cover 1415.5 cm^2 (354%) (Table 8). The community appeared to be well structured (Fig. 26) showing a well developed erect stratum dominated by *C. brachycarpa* (1198 cm^2; 299.5%) which had high mean values of both thallus height (10.2 ±sd0.2 cm) and primary branch length (7.5 ±sd0.2 cm). The erect substratum was mainly represented by *D. mediterranea* and *P. pavonica*. Several epiphytic species, mainly Ceramiales, were found on *C. brachycarpa* and *S. cirrosa* was the most abundant. Qualitatively, Rhodophyta was the most important taxonomic group (63.3%), mainly represented by Ceramiales (48.3%); no Corallinales were detected; quantitatively, Phaeophyceae (347.2%) was the most abundant taxonomic group (Table 9 and Fig. 23a, b). Photophilic species were quantitatively dominant in the community (350.4%), mainly due to those inhabiting quiet waters (308.6%) and in particular to *C. brachycarpa* (299.5%); on the contary, the thermophilic algae showed very low values from a quantitative point of view (Table 10 and Fig. 24a, b). The mean value of R/P Index was 3.7 and the values of diversity and evenness were 0.9 and 0.2 on average, respectively (Table 8). Several fertile species (18.5%) were recorded (Tables 8 and 11).

Fig. 26. Appearance of the community in June at the Station D.

In October, the community shows a similar mean number of species per quadrat (58 species) and a mean cover somewhat lower (1086.2 cm^2; 271.6%) (Table 8). *C. brachycarpa* (628.4 cm^2; 157.1%) and *C. sauvageauana* (193.2 cm^2; 48.3%) dominated the erect algal stratum (Tables 7 and 8); thalli of *C. brachycarpa* were slighly smaller, with a mean height of 8.5 (±sd0.2 cm) and branches measuring 5.6 (±sd0.2 cm) in average. In the erect substratum *D. mediterranea*, *D. tenuissima*, *R. ligulata* and *Laurencia microcladia* were the most abundant species. *C. brachycarpa* supported an epiphyte stratum also dominated qualitatively by Ceramiales and quantitatively by *S. cirrosa*. Rhodophyta (53.5%), and Ceramiales among these (34.5%), were the taxonomic groups best represented qualitatively and Phaeophyceae (229.3%) was the most abundant (Table 9 and Fig. 23c, d); the calcitic red algae *Hydrolithon farinosum* and *Haliptilon virgatum* (Corallinales) were also detected, even though with a very low mean cover (0.02%). Photophilic algae dominated both qualitatively (39.7%) and quantitatively (251.5%) the community (Table 10 and Fig. 24c, d); they were mainly represented by quiet water species, such as *C. brachycarpa*, *C. sauvageauana* and *D. mediterranea*; sciaphilic species were scarcely represented both qualitatively and quantitatively (Table 10). The mean value of R/P Index was 3.5; the diversity increased (2.3 on average) and the mean value of evenness was 0.4 (Table 8). Very few fertile species was recorded (12.1%) (Tables 8 and 11).

Table 10. Qualitative (Q) and quantitative (K) dominances (%) of the main ecological groups in the community at each station. Mean (±sd).

Site	**Bottaro**												**Lisca Nera**			
Station	B		B		C		C		D		D		E		E	
Dominance	Q	K	Q	K	Q	K	Q	K	Q	K	Q	K	Q	K	Q	K
Period	June		Oct.		June		Oct.		June		Oct.		June		Oct.	
PhI *s.l.*	40.98	150.77 ±36.33	42.86	101.15 ±14.75	42.65	180.15 ±40.78	40.32	124.35 ±17.68	40	350.42 ±60.83	39.65	251.48 ±34.17	37.21	529.18 ±94.85	37.38	328.87 ±66.75
(PhIQ)	22.95	139.48 ±47.64	19.64	94.38 ±24.50	20.58	162.02 ±57.55	22.58	99.21 ±22.77	20	308.57 ±86.43	18.10	229.30 ±48.29	17.05	474.68 ±48.29	18.69	312.99 ±94.31
(PhIT)	6.56	10.58 ±6.98	10.71	6.63 ±2.16	4.41	6.91 ±4.47	9.67	22.66 ±7.62	5	0.80 ±0.39	7.76	5.11 ±2.02	3.10	0.02	3.74	0.02
S *s.l.*	22.95	5.39 ±1.61	14.28	2.35 ±1.31	23.53	6.26 ±2.17	24.19	10.42 ±2.62	27.5	2.79 ±0.48	23.41	9.71 ±1.58	31	3.38 ±0.30	30.84	3.60 ±0.37
IHdB	6.55	7.67 ±4.82	3.57	1.95 ±1.59	5.88	2.88 ±2.18	6.45	2.23 ±1.47	8.33	0.46 ±0.18	9.48	1.36 ±0.69	10.07	2.53 ±0.50	8.41	0.69 ±0.20
LER	8.19	0.03	5.35	0.01	11.76	0.04	6.45	0.36 ±0.20	9.16	0.12 ±0.03	8.62	0.22 ±0.07	9.30	0.13 ±0.01	9.34	0.05
Others	21.33	0.83 ±0.33	33.94	0.79±0.18	16.18	0.05 ±1.81	22.59	8.67 ±3.09	15.01	0.07 ±2.45	18.84	8.77 ±17.35	12.42	49.26 ±13.15	14.03	47.34 ±17.31

3.3 The Lisca Nera community (Station E)

As a whole, a total of 79 taxa [5 Cyanophyceae (6.3%), 50 Rhodophyta (63.3%), 13 Phaeophyceae (16.5%) and 11 Chlorophyta (13.9%)] were found in the community of *C. brachycarpa* of this site (Table 6).

Fig. 27. Appearance of the community in June at the Station E.

In June, the mean number of species per quadrat was 64.5 and the mean cover 2338 cm^2 (584.5%) (Table 8). The community appeared well structured (Fig. 27), showing a well developed erect stratum dominated by *C. brachycarpa* (1855.6 cm^2; 463.9%) displaying high mean values of both the height of thallus (11.4 ±sd0.3 cm) and length of the primary branches (8.4 ±sd0.2 cm). The erect substratum was scarcely represented, being mainly composed of the turf species *Gelidium pusillum*. In contrast, numerous epiphytic species, mainly Ceramiales, were found on *C. brachycarpa* and, among these, *B. fruticulosa* and *H. secunda* were the most abundant; the calcitic red algae *H. farinosum* and *H. virgatum* were also detected, even though with a very low mean cover. The encrusting stratum consisted mainly of the coralline alga *Neogoniolithon brassica-florida*. Qualitatively, Rhodophyta was the most important taxonomic group (67.4%), emphasizing particularly the Ceramiales (46.5%); some species of Corallinales (*Neogoniolithon brassica-florida*, *H. farinosum* and *H. virgatum*) were detected in the community, representing 4.7% in species number and 49% in coverage; quantitatively, Phaeophyceae (473.8%) was the most abundant taxonomic group (Table 9 and Fig. 23a, b). Photophilic species were quantitatively dominant in the community (529.2%), mainly due to those inhabiting quiet waters (474.7%) and in particular to *C. brachycarpa* (463.9%) (Table 10 and Fig. 24a, b); on the contrary, the photophilic groups were much less important in species number, being similar in this respect to the whole of sciaphilic species (31%). The mean value of R/P Index was 4.6 and the values of diversity and evenness were 1.3 and 0.2 on average, respectively (Table 8). The community showed a moderate reproductive capacity, since several fertile species (32.6%) were recorded (Tables 8 and 11).

In October, the mean number of species per quadrat was similar than in June (58 species) and the mean cover was lower (1086.2 cm^2; 271.6%) (Table 8). In this period the community displayed a significative reduction of the *C. brachycarpa* canopy, which showed lower mean values of both the height of thallus (10.3±sd0.2 cm) and length of the primary branches (7.3±sd0.2 cm). The erect substratum was scarcely developed and was mainly composed of the turf species *G. pusillum* and the green algae *D. tenuissima* and *F. petiolata* which were not present in June. A strong reduction of epiphytic species, mainly Ceramiales, was recorded on *C. brachycarpa* (*B. fruticulosa* and *H. secunda* showed a decrease of their coverage of 82% and 75%, respectively). Qualitatively, Rhodophyta (70.1%), and Ceramiales among these (44.9%), were the most important taxonomic groups, although the Ceramiales displayed a significant drop (74.5%) from a quantitative point of view (Table 9 and Fig. 23c, d); conversely, an increase of Bryopsidales both qualitatively and quantitatively was recorded; Corallinales showed similar abundances than in June; quantitatively, Phaeophyceae (311.4%) was the most abundant taxonomic group (Table 9 and Fig. 24c, d). Like in June, photophilic species were quantitatively dominant in the community (328.9%), mainly due to those inhabiting quiet waters (313%) and in particular to *C. brachycarpa* (307%) (Table 10). Mean values of R/P Index (4.6), diversity (1.2) and evenness (0.2) were similar to those of June (Table 8). It was also noteworthy the lower reproductive capacity of the community, with a reduction of 47,8% of fertile species (Tables 8 and 11).

Table 11. Reproductive phenology of species: c: carposporangia; e: spermatangia; o: conceptacle; p: plurilocular sporangia; t: tetrasporangia; u: unilocular sporangia.

Site	**Bottaro**												**Lisca Nera**			
Station	B	B	B	B	C	C	C	C	D	D	D	D	E	E	E	E
Quadrat	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Date 2010	June	June	Oct.	Oct.	June	June	Oct.	Oct.	June	June	Oct.	Oct.	June	June	Oct.	Oct.
Acetabularia acetabulum																
Acrochaete viridis																
Acrochaetium hauckii																
Anadyomene stellata																
Anotrichium barbatum									t	t			ct	t		
Antithamnion cruciatum																
Antithamnion heterocladum													t			
Apoglossum ruscifolium																
Ascocyclus orbicularis																
Blastophysa rhyzopus																
Boergeseniella fruticulosa										e			ce	t		
Botryocladia botryoides											c	c				
Botryocladia microphysa																
Brachytrichia quoyi																
Bryopsis plumosa																
Callithamnion corymbosum									t	et			ct	e	e	e
Calothrix aeruginea																
Calothrix crustacea																
Caulerpa racemosa v. *cylindracea*																
Ceramium codii																
Ceramium comptum													t	t	c	c
Ceramium siliquosum									t	t	t			et		
Ceramium tenerrimum									c	c				t		
Chaetomorpha linum																
Chondria capillaris											ct	t	c			
Chondria mairei					c				ct	cet			e	ct	c	c
Chroococcus minutus																
Chroococcus submarinus																

Table 11 *(continued)*

Chylocladia pelagosae													c		
Cladophora echinus															
Cladophora lehmanniana															
Cladostephus spongiosus f. *verticillatus*															
Codium bursa															
Crouania attenuata													t		
Cutleria chilosa	t											t			
Cystoseira brachycarpa								o	o			o	o		
Cystoseira sauvageauana															
Dasya baillouviana									t						
Dasya corymbifera															
Dasya rigidula												t	t		
Dasycladus vermicularis															
Derbesia tenuissima															
Dictyota fasciola															
Dictyota linearis												t			
Dictyota mediterranea															
Dipterosiphonia rigens															
Discosporangium mesarthrocarpum					p			p	p	p	p		p		
Erythroglossum sandrianum															
Erythrotrichia carnea															
Falkenbergia rufolanosa stadium												t	t		
Feldmannophycus rayssiae															
Flabellia petiolata															
Gayliella flaccida												t	t		
Gelidium pusillum															
Giraudia sphacelarioides															
Griffithsia phyllamphora															
Haliptilon virgatum															
Halopteris filicina												p			
Halopteris scoparia					u										
Herposiphonia secunda										t		t	t		
Heterosiphonia crispella															
Hydrolithon farinosum															
Laurencia microcladia								ct	ct	t	t			t	t
Laurencia minuta ssp. *scammaccae*												ct	c		
Lejolisia mediterranea														t	t

Table 11 *(continued)*

Leptolyngbya fragilis															
Lomentaria clavaeformis															
Lophosiphonia cristata															
Lophosiphonia obscura															
Lyngbya aestuarii															
Lyngbya confervoides															
Lyngbya sordida															
Michrochaete grisea															
Neogoniolithon brassica-florida												c	c	c	c
Nitophyllum micropunctatum								t	t			c,t	t	t	t
Padina pavonica															
Peyssonnelia bornetii															
Peyssonnelia cf. *inamoena*															
Peyssonnelia dubyi															
Phaeophila dendroides															
Polysiphonia cf. *dichotoma*								et	cet		t	c	t	ct	t
Polysiphonia scopulorum															
Pseudochlorodesmis furcellata															
Ptilothamnion pluma															
Radicilingua reptans															
Rhodophyllis divaricata															
Rhodymenia ligulata															
Rivularia atra															
Rivularia polyotis															
Rytiphlaea tinctoria															
Spermothamnion flabellatum												c	c		
Spermothamnion repens	e														
Sphacelaria cirrosa															
Stilophora tenella												u			
Stylonema alsidii															
Ulvella lens															
Valonia utricularis															
Womersleyella setacea															
Wrangelia penicillata													t	c	c

3.4 *Epiphytic assemblages of* Posidonia oceanica *leaves*

A total of 27 epiphytic macroalgal taxa were found on *P. oceanica* leaves of the two meadows investigated: 13 Rhodophyta (48.2%), 6 Phaeophyceae (22.2%) and 8 Chlorophyta (29.6%) (Tables 12 and 13).

Table 12. Number of species and qualitative dominance (%) of the main taxonomic groups in each meadow.

Site	**Bottaro**					
Meadow	P1		P2		**Total**	
Rhodophyta	11	50.0	9	39.1	13	48.2
Phaeophyceae	6	27.3	6	26.1	6	22.2
Chlorophyta	5	22.7	8	34.8	8	29.6
Total	22	100	23	100	27	100

3.4.1 *The community in the meadow within the vents (meadow P1)*

The meadow P1 occurred within the vents, at about 11 m depth (Fig. 28). The seawater temperature at this site was 28°C (Table 14). Mean density value of *P. oceanica* was 218 shoot/m^2 and leaf surface area was 148 cm^2 (Table 15). A total of 22 taxa [11 Rhodophyta (50%), 6 Phaeophyceae (27.3%) and 5 Chlorophyta (22.7%)] were identified on *Posidonia* leaves of the meadow within the vents (Tables 12 and 13). The leaf epiphyte assemblages were dominated by the brown algae *Ascocyclus orbicularis* and *S. cirrosa* and by the green algae *Phaeophila dendroides*, *Blastophysa rhyzopus* and *Ulvella lens*. The mean number of species per shoot was 8 and the mean cover was very low (less than 0.5 cm^2). Qualitatively Rhodophyta and Phaeophyceae were the most important taxonomic group being the Ceramiales and Ectocarpales the best represented (31.8 and 22.7%, respectively) among

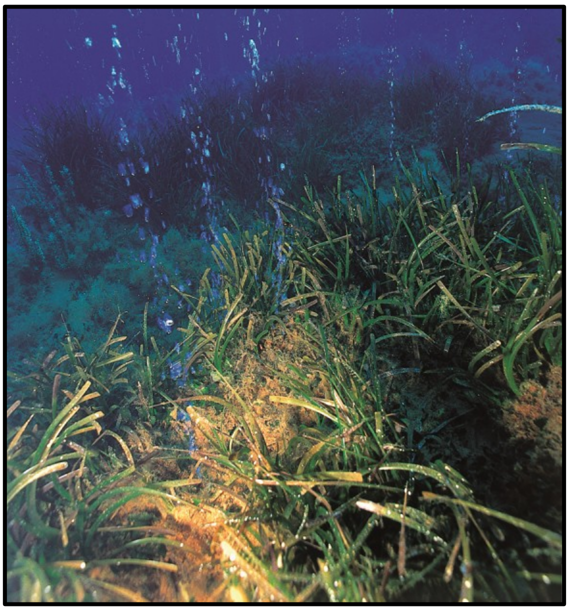


Fig. 28. Detail of the *Posidonia* meadow growing within the vents (P1).

these (Fig. 29). The leaves were mainly colonized by species of large ecological repartition (22.7%) and typical epiphytic species of *Posidonia* leaves (22.7%) (Table 16 and Fig. 30). No both articulated and crustose calcareous algae were detected.

Table 13. List of taxa identified in the epiphytic assemblages on leaves of two *P. oceanica* meadows (meadow P1 located within the vents); + = cover ≤ 0.1 cm^2.

	Site	**Bottaro**																			
	Meadow	P1										P2									
	Shoot number	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
	Depth (m)	11										12									
	Date 2009	September																			
	Number of species	7	5	5	7	7	8	8	10	9	14	10	9	8	10	7	6	8	7	8	9
PL	*Ascocyclus orbicularis*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
LER	*Phaeophila dendroides*	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
PhI	*Sphacelaria cirrosa*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+
CC	*Blastophysa rhyzopus*	+	+		+	+	+	+	+	+	+		+	+	+	+	+	+	+		+
LER	*Ulvella lens*	+	+	+	+	+		+	+		+	+	+	+	+	+		+			+
IHdB	*Ceramium diaphanum*	+				+	+	+	+	+	+	+	+	+	+			+		+	+
PL	*Giraudia sphacelarioides*				+	+					+		+			+			+	+	+
PL	*Cladosiphon cylindricus*						+			+	+		+							+	
PL	*Cladosiphon irregularis*						+	+					+			+			+		
PL	*Chondria mairei*	+								+		+						+		+	
SQ	*Ceramium codii*						+	+	+		+										
LER	*Acrochaete viridis*				+							+			+						
IHdB	*Colaconema daviesii*			+					+												+
ETN	*Erythrotrichia carnea*								+								+	+			
LER	*Polysiphonia dichotoma*									+		+			+						
IHdB	*Stylonema alsidii*			+					+											+	
PhI	*Asperococcus bullosus*										+	+									
PhIQ	*Cladophora echinus*											+		+							
LER	*Lophosiphonia obscura*										+						+				
PhI	*Pringsheimiella scutata*														+				+		
SIC	*Pseudochlorodesmis furcellata*									+											+
PhIQ	*Herposiphonia secunda*										+										
SIQ	*Lejolisia mediterranea*										+										
SIQ	*Polysiphonia scopulorum*																+				
IHdB	*Gayella flaccida*										+										
SIQ	*Spermothamnion flabellatum*													+							
LER	*Pseudendoclonium submarinum*														+						

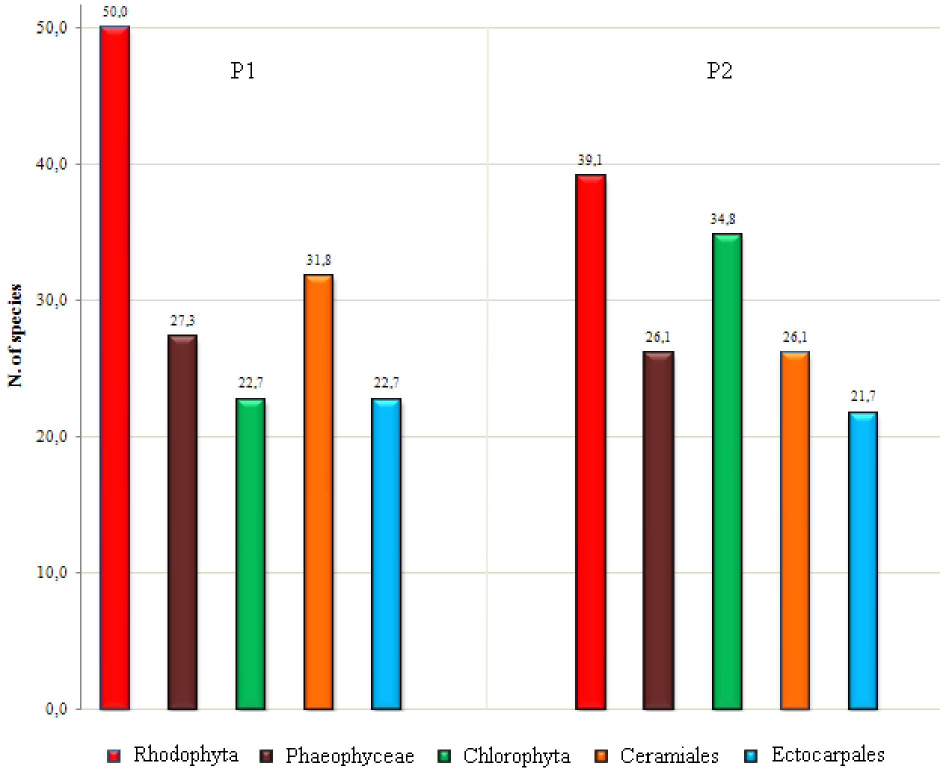


Fig. 29. Qualitative dominance (%) of the main taxonomic groups in each meadow.

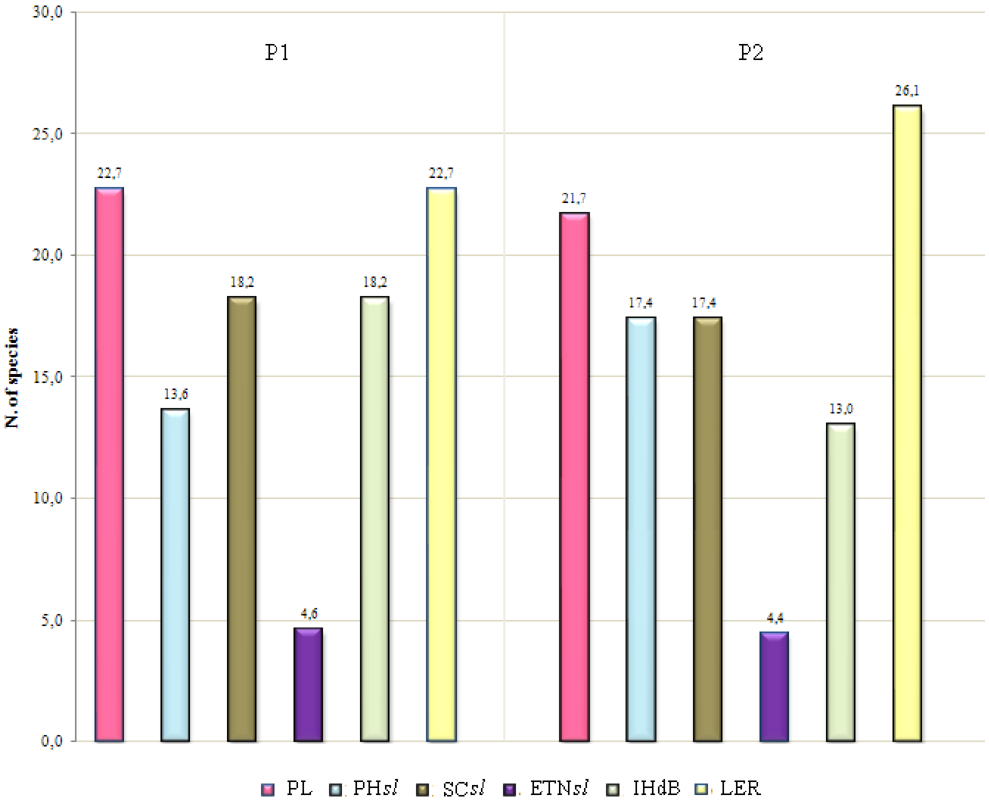


Fig. 30. Qualitative dominance (%) of the main ecological groups in each meadow; see Table 7 for the abbreviations.

Table 14. Chemico-physical parameters of both *P. oceanica* meadows. The values reported are means (±sd) of data recorded using a multiparametric probe.

***P. oceanica* meadows**					
Meadow	**Depth (m)**	**Temperature (°C)**	**Salinity (‰)**	**Oxigen (%)**	**pH**
P1	10.68±0.04	28.341±0.001	37.88±0.01	86.50±0.64	8.031±0.002
P2	11.74±0.01	28.282±0.007	37.91±0.01	84.98±0.25	8.073±0.002

3.4.2 The community in the meadow far from the vents (meadow P2)

The meadow P2 occurred in an area without visible hydrothermal activity, at about 12 m depth (Fig. 31). The seawater temperature in this area was 28°C (Table 14). Mean density value of *P. oceanica* was 178 shoot/m^2 and leaf surface area was 241 cm^2 (Table 15). A total of 23 taxa [9 Rhodophyta (39.1%), 6 Phaeophyceae (26.1%) and 8 Chlorophyta (34.8%)] were identified on *Posidonia* leaves of this meadow (Table 12 and Fig. 29). As in the meadow within the vents, the leaf epiphyte assemblages were dominated by the brown algae *A. orbicularis* and *S. cirrosa* and by the green algae *P. dendroides*, *B. rhyzopus* and *U. lens*. The mean number of species per shoot was 8.2 and the mean cover was very low (less than 0.5 cm^2). Qualitatively Rhodophyta and Chlorophyta were the most important taxonomic group highlighting Ceramiales (26.1%) among the Rhodophyta and Ectocarpales among the Phaeophyceae (21.7%) (Fig. 29). The leaves were also mainly colonized by species of large ecological repartition (26.1%) and typical epiphytic species of *Posidonia* leaves (21.7%) (Table 16 and Fig. 30). No calcareous species were detected.

Fig. 31. Detail of *Posidonia* leaves of the meadow far from vents (P2).

Table 15. Phenological parameters of the *P. oceanica* meadows; (L.A.I. = Leaf Area Index).

***P. oceanica* meadows**		
Meadow	**Density (shoot/m^2)**	**L.A.I. (cm^2)**
P1	218	148
P2	178	241

Table 16. Number of species and qualitative dominance (%) of the main ecological groups in each meadow.

Site			**Bottaro**			
Meadow	P1		P2		**Total**	
PhI *s.l.*	3	13.6	4	17.4	5	18.5
LER	5	22.7	6	26.1	6	22.2
SC *s.l.*	4	18.2	4	17.4	6	22.2
PL	5	22.7	5	21.7	5	18.5
ETN *s.l.*	1	4.6	1	4.4	1	3.7
IHdB	4	18.2	3	13.0	4	14.9
Total	22	100	23	100	27	100

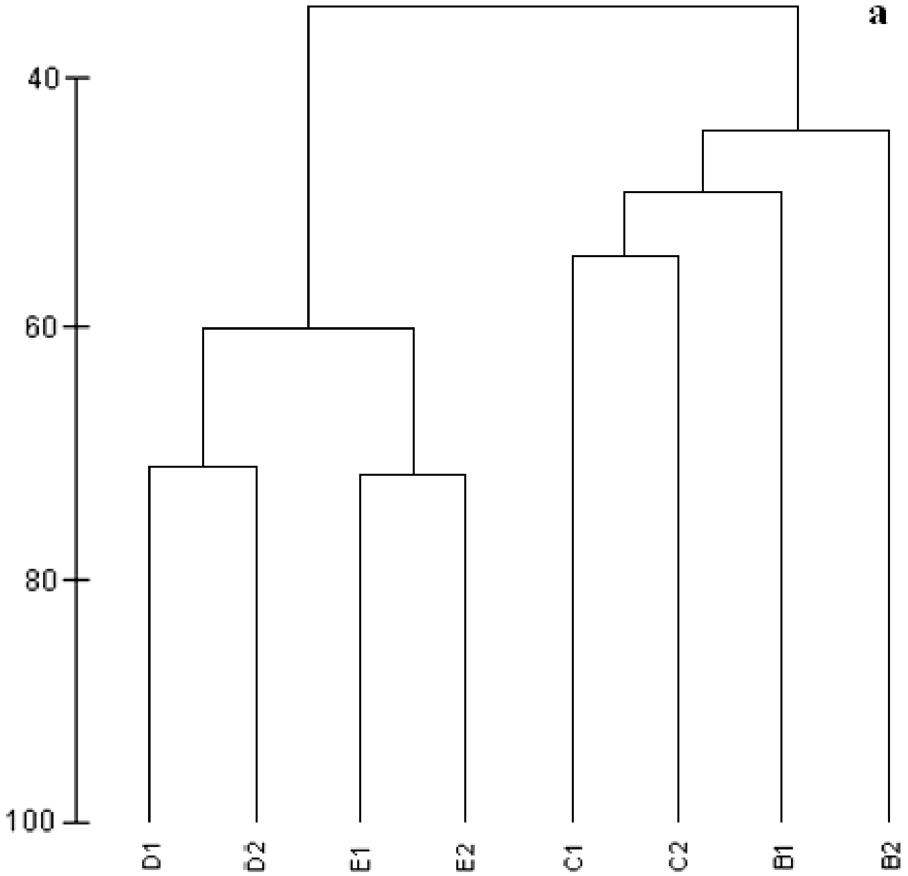
Chapter 4

Discussion

4. Discussion

Qualitative and quantitative differences were detected in the community of *Cystoseira brachycarpa* along the pH gradient of Bottaro (vent area), as well as between the community of this site (especially Stations B and C) and that of Lisca Nera (non vent area). These differences are showed in the similarity dendrograms based on Jaccard and Bray-Curtis formulas in which quadrats from Stations D and E and those of Stations B and C belongs to two different groups linking to each other at low level of similarity (Figs. 32 and 33).

At Bottaro, important differences in species composition and the structural complexity were detected in the community along the pH gradient. The number of species per quadrat and cover (mainly of *C. brachycarpa*), as well as the R/P index and the reproductive capacity of the community considerably decreased towards the vents coinciding with a drop in the seawater pH (Figs. 34 and 35). Also low values of the diversity index and evenness were detected in the community growing near to the vents. This result was due to the fact that, apart from the species guide of the community, only very few other species evidenced an important coverage, as shown in Figure 36. Samples collected close to the vents displayed a great heterogeneity because of the patchy distribution of *C. brachycarpa* community which also showed a thinned physiognomy and a non homogeneous cover. The progressive decrease of the R/P index values towards the vent outlets indicate that the community develops under every time more instability environmental conditions (Cormaci *et al.* 1985). Such environmental conditions seemed to have favoured the settlement of a large number of ephemeral and resilient species (mainly green algae) which are known to proliferate in altered ecosystems, as well as the spread of some alien macroalgae which commonly display a high adaptability to a wide ecological range (Ribera and Boudouresque 1995, Boudouresque and Verlaque 2002). It was worth noting that coralline algae (Corallinales), both erect and crustose, were absent in the stations closer to the vents (stations C and B) and


a
40
60
80
100
D1
D2
E1
E2
C1
C2
B1
B2

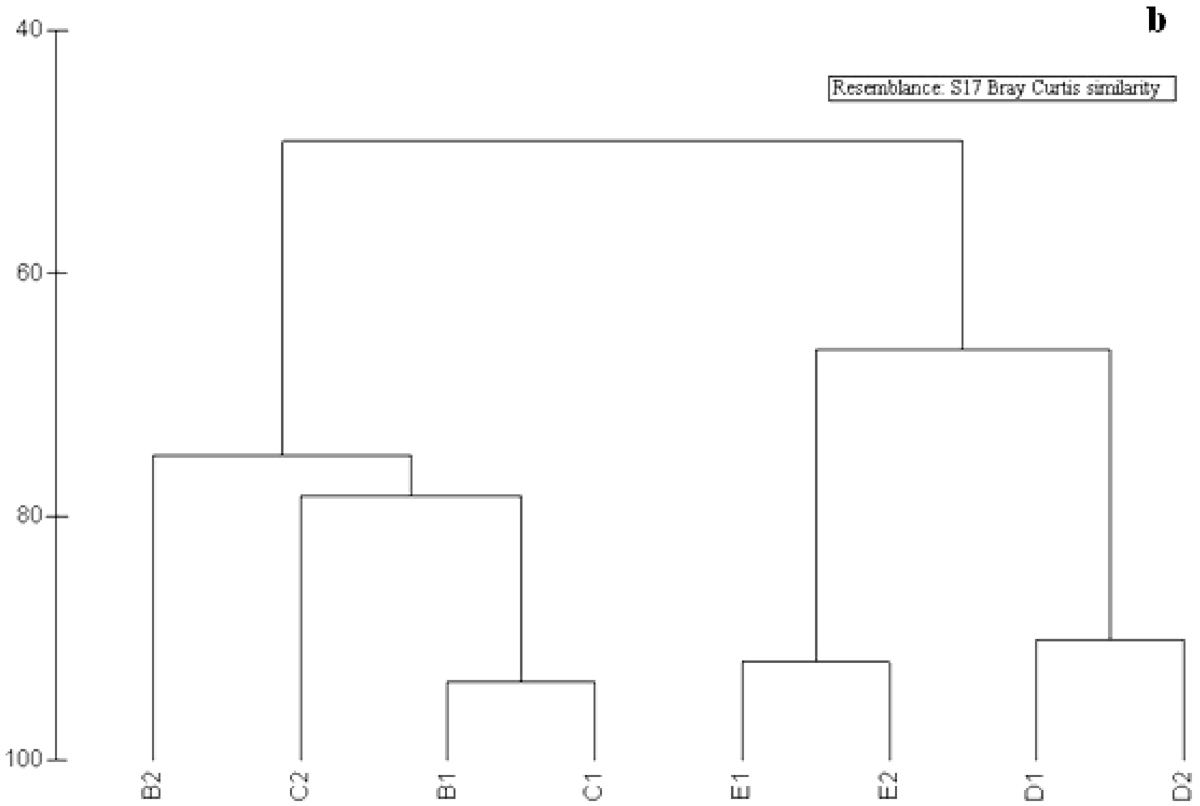
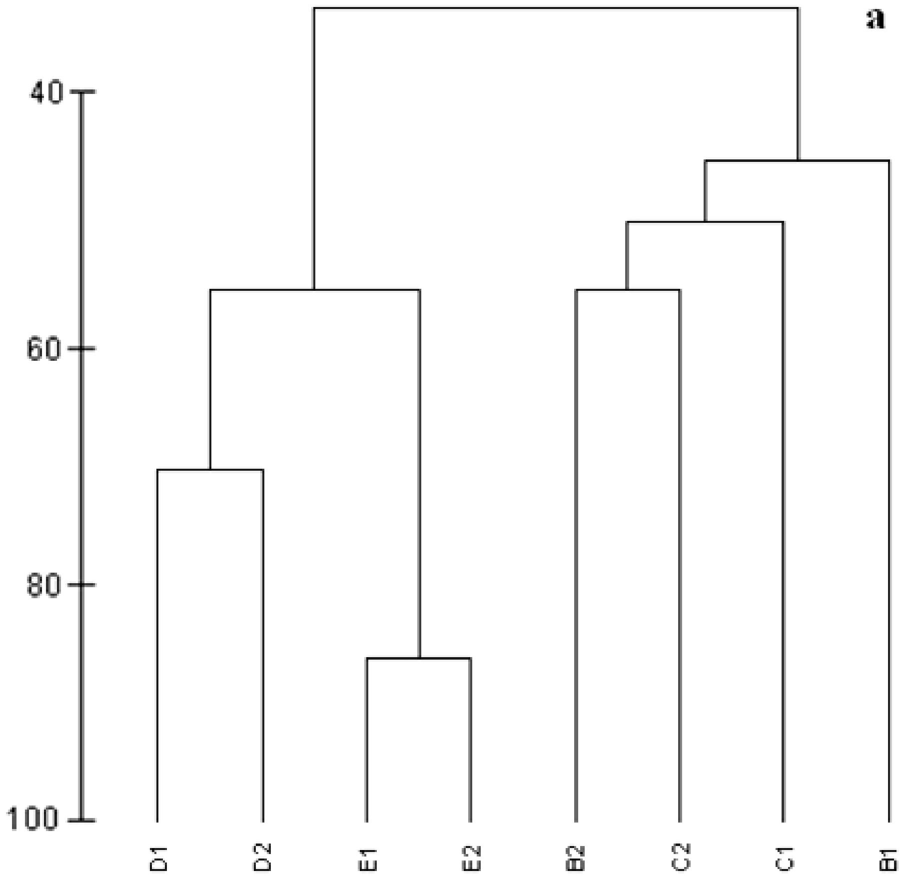


Fig. 32. Similarity dendrograms among the quadrats of the *C. brachycarpa* community in June (this study); a) qualitative similarity Jaccard; b) quantitative similarity (Bray-Curtis). Sites are indicate as follows: B, C, D = Bottaro; E = Lisca Nera.


a
40
60
80
100
D1
D2
E1
E2
B2
C2
C1
B1

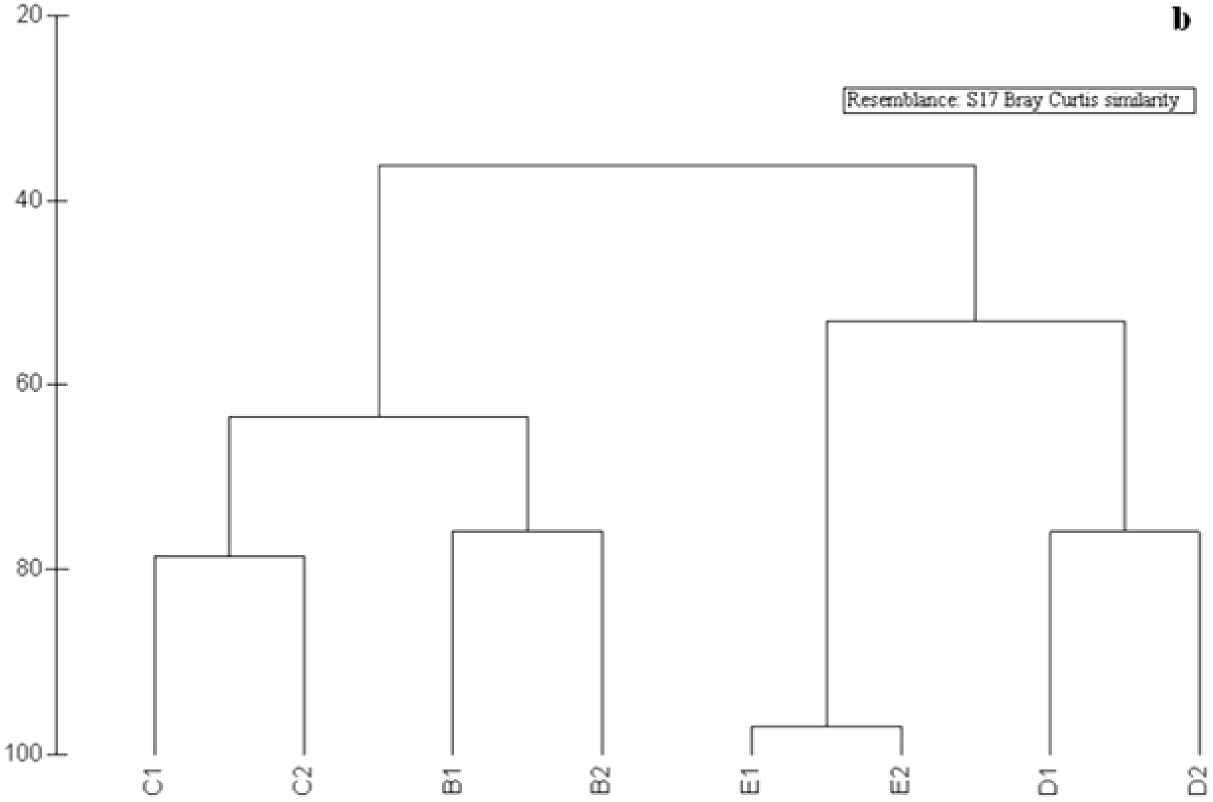


Fig. 33. Similarity dendrograms among the quadrats of the *C. brachycarpa* community in October (this study); a) qualitative similarity (Jaccard); b) quantitative similarity (Bray-Curtis). Sites are indicate as follows: B, C, D = Bottaro; E = Lisca Nera.

were largely replaced by turf-forming algae, in agreement with that pointed out by Russell *et al*. (2009). This lack of Corallinales is probably due to the low seawater pH values and reduced calcite saturation levels, which are the most likely features affecting coralline algal cover by reducing or inhibiting the calcification of their high magnesian calcite skeletons (Gao *et al*. 1993, Martin and Gattuso 2009). In this way, our results confirm predictions based on short-term experiments on isolated organisms and mesocosms where skeleton dissolution and drop in recruitment rate were reported at a pH of 7.9 (Jokiel *et al*. 2008, Kuffner *et al*. 2008). The decrease of coralline algae may cause a dramatic shift in the biogeochemical cycles of carbon and carbonate chemistry in shallow water coastal systems. On the other hand, calcified aragonitic species (such as *P. pavonica* and *F. petiolata*) were found near the vents, fact which can be explained by their low Mg content which according to Martin *et al*. (2008) makes likely them more resistant to chemical dissolution allowing to survive pH lower than 7.

Important differences on species growth and reproduction were also detected along the transect. The size of the specimens of *C. brachycarpa* clearly decreases towards the vent outlets (Fig. 35). In the same way, Acunto *et al*. (1997) pointed out that *C. tamariscifolia* showed a reduced length of axes and a tendency to form a caespitose base within hydrothermal areas. This negative effect on growth is likely related with the low seawater pH caused by the CO_2 and H_2S emissions in the vent area. Although high CO_2 levels may enhance the growth in some marine macroalgae by increasing photosynthesis (Xu *et al*. 2010, Zou and Gao 2010, Suárez-Álvarez *et al*. 2011), it is also possible that they do not affect or inhibit the species growth by decreasing of the photosynthetic activity at high CO_2 levels or as a result of the medium acidification (García Sánchez *et al*. 1994, Israel *et al*. 1999). Thus, the high CO_2 levels might explain the small size of the specimens of *C. brachycarpa* at the stations close to the vents at Bottaro, although some other factors such as temperature or sulphur compounds would also take part. Concerning the former, at Bottaro (stations A-D) the seawater temperature do not shows important differences between both sampling periods (June and October), and at stations B and C, where the specimens of *C. brachycarpa* showed the smallest size, the temperature was 1ºC higher than at station D, which showed a temperature similar to that of Lisca Nera (station E) in June, but more than 6ºC higher

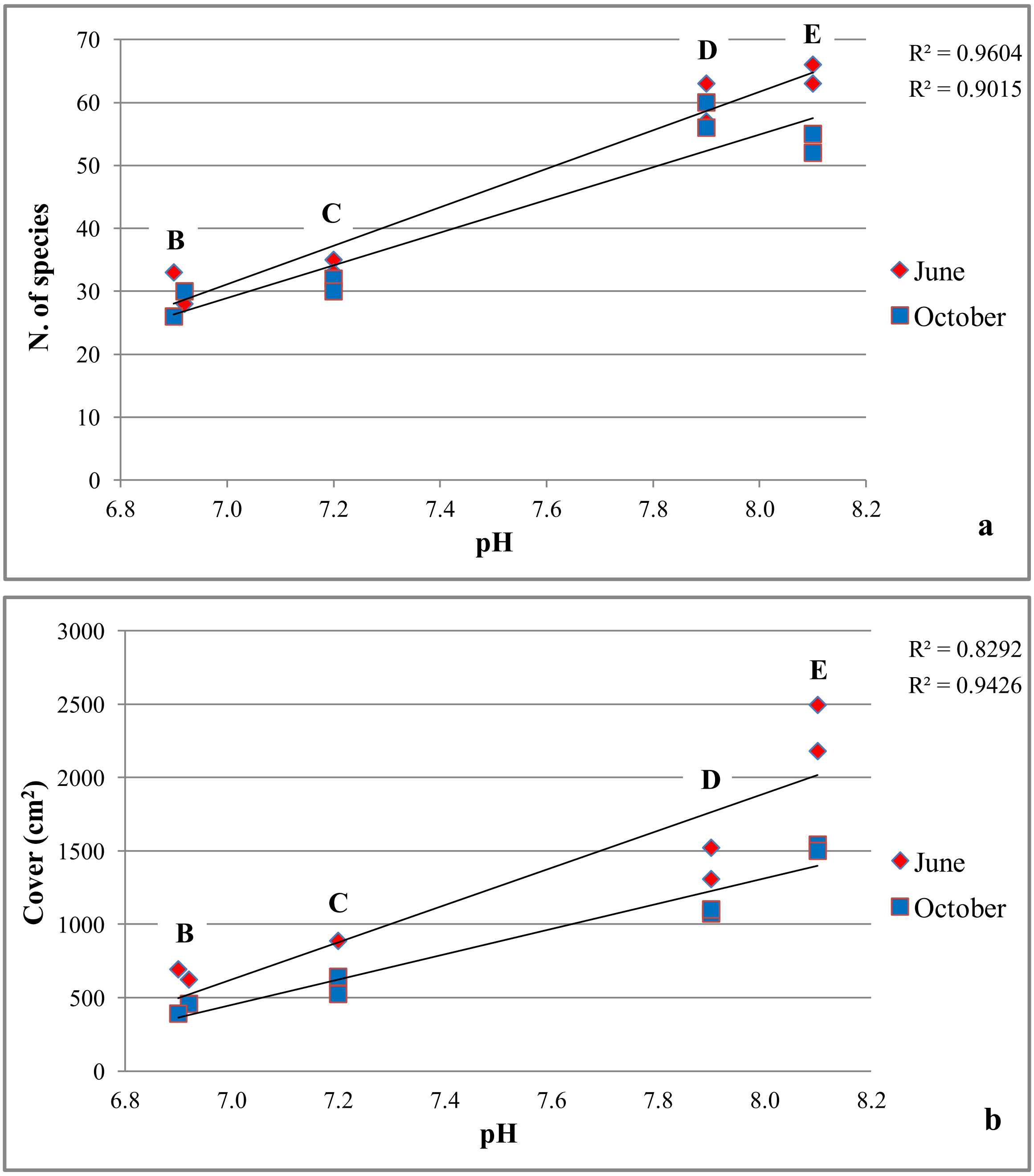


Fig. 34. N. of species (a) and cover (b) for each quadrat of each station along a pH gradient in both periods.

than in October (Table 16). However the specimens of both Lisca Nera and station D showed similar sizes than those of the eastern coast of Sicily (not influenced by hydrothermal activity) in the same periods (Pizzuto 1998). With respect to the sulphur compounds, it must be considered that sulphide concentrations are inversely related to pH values and thus the highest values occur in the immediate vicinity of vents characterized by acidic (pH 5-6) hydrothermal fluids (Thiermann *et al*. 1997). Here, the interaction of hydrogen sulphide with marine sulphates and with the dissolved oxygen in the seawater, give rise to colloidal sulphur, mainly covered by bacterial mats. Usually the effect of H_2S on benthic organisms is detectable only on a small spatial scale and restricted to a very narrow zone in a close proximity to discharge or a plume, and bottom currents can cause rapid dilution of these fluids (Bianchi and Morri 1983, Kamenev *et al*. 1993, Cocito *et al*. 2000). The exclusion of the *C. brachycarpa* community at the station A, and in general at a radius of about 1 m from the thermal fluid discharges observed in our study, agrees with this fact. However, Cardigos *et al*. (2005) pointed out that some Dictyotales (*Dictyota* spp., *P. pavonica* and *Zonaria tournefortii*) were found close to the vent outlets at high sulphide concentrations. Anyway, although *C. brachycarpa* seems to be negatively affected by the hydrothermal vent fluids, it was able to tolerate mean low pH environmental conditions probably due to its morphological complexity, which may limit the effects of acidification on cellular homeostasis.

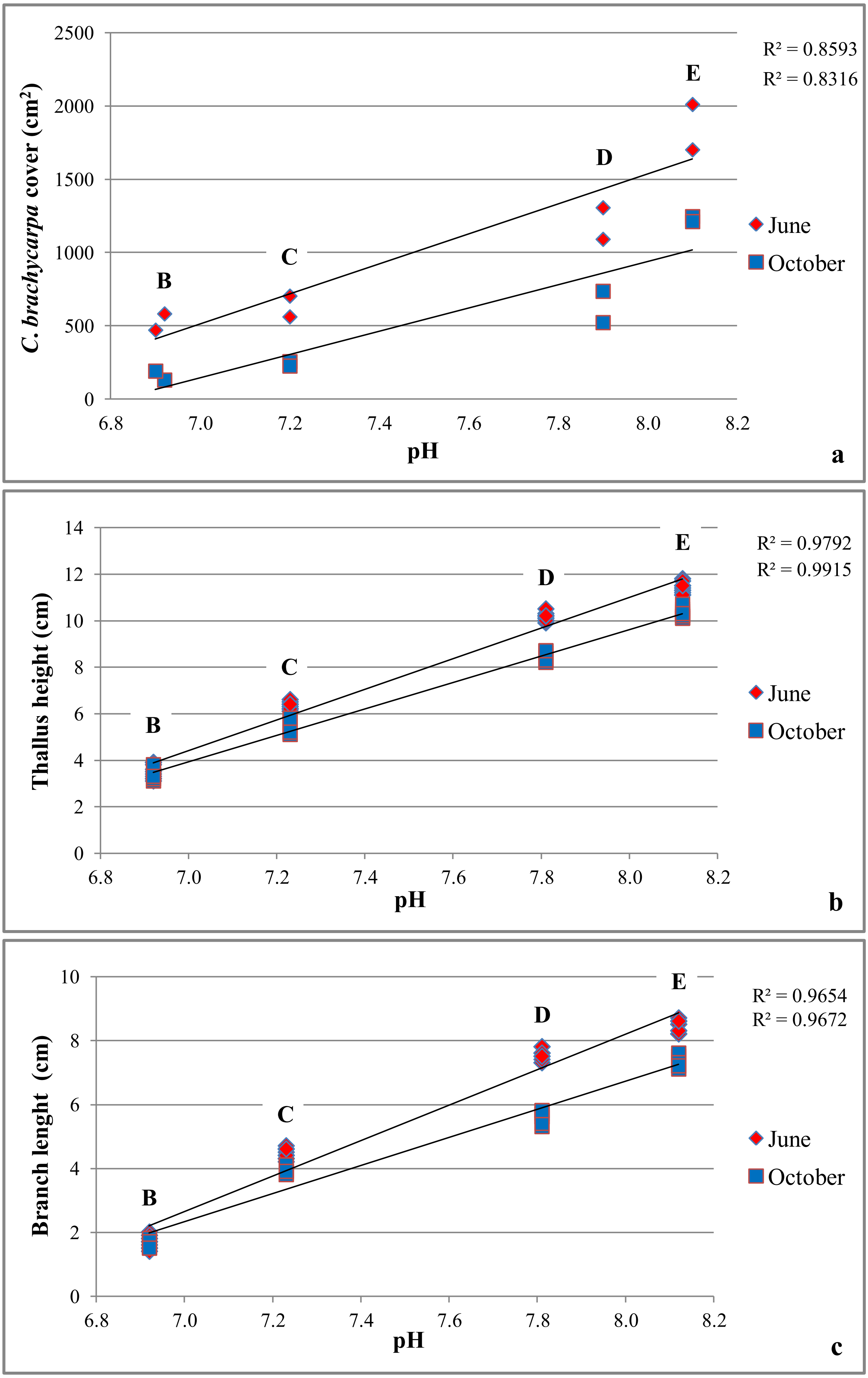


Fig. 35. *C. brachycarpa* cover (a), height of five thalli (b) and length of five branches (c) for each quadrat of each station along a pH gradient in both periods.

On the other hand, as it was above commented, high CO_2 levels may enhance the growth in some marine macroalgae by increasing photosynthesis (Zou and Gao 2010). In the same way, Palacios and Zimmerman (2007) and Hall-Spencer *et al*. (2008) reported a positive effect of the high CO_2 concentration on the seagrass productivity and Ballesteros (pers. com.) pointed out that high CO_2 levels might be the responsible for exuberant vegetation in some marine places. In this case, the positive effect of CO_2 may be associated to the lack of grazers, mainly sea urchins, which are highly sensitive to a rise in CO_2 (Miles *et al*. 2007).

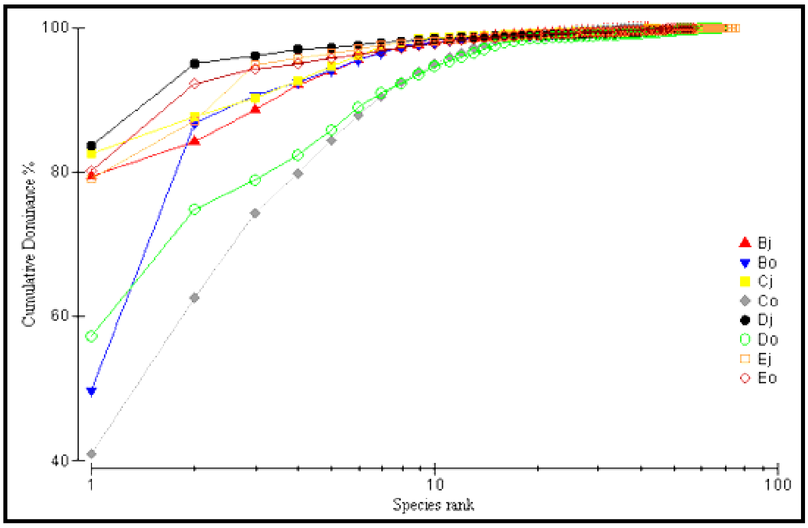


Fig. 36. K-dominance curves for mean coverage of each quadrate in both periods (j: june, o: october).

Concerning the species fertility, a significant reduction in the reproductive capacity of several algal species was detected towards the vents coinciding with a drop of the seawater pH. So, for example, *B. fruticulosa, H. secunda* and *C. brachycarpa* were present in all stations (except at Station A) along the transect but they were fertile only at the Station D which was the most distant from the vent outlets and showed a pH condition almost normal (pH = 7.9). These same species were also present and fertile at Lisca Nera (normal pH condition).The decreased reproductive capacity of *C. brachycarpa* species was

Table 17. Temperature values and *C. brachycarpa* thallus height for each station in both sites and periods.

Site	**Bottaro**				**Lisca Nera**	**Bottaro**				**Lisca Nera**
Station	A	B	C	D	E	A	B	C	D	E
Period	June					October				
Temperature (°C)	28.3 ±0.3	27.3 ±0.1	27.2 ±0.1	26.1 ±0.1	26.2 ±0.2	28.1 ±0.2	27.4 ±0.1	26.8 ±0.1	26.4 ±0.1	19.6 ±0.2
***C. brachycarpa* thallus height**	-	3.5 ±0.3	6.3 ±0.2	10.2 ±0.2	11.4 ±0.3	-	3.3 ±0.2	5.5 ±0.4	8.5 ±0.2	10.3 ±0.2

assumed to be related to reduction of their thalli and, in turn, their terminal branchlets in which the reproductive structures occur. In this way, biometric values of *C. brachycarpa* of Bottaro (stations B and C) were similar to those recorded by Pizzuto (1998) at Isola Lachea (Sicily) in autumn months when the plants loose large parts of their branches. Hence, we suggest that monthly samplings should be required throughout a year to better know the reproductive and morphological phenology of this perennial species within hydrothermal areas. Such a decrease of reproductive capacity may also be attributed to an abnormal ratio of Zn and Cu that is known to affect physiological processes, first of all, reproduction (Khristoforova and Malinovskaya 1991). According to these authors, the fucoids (Phaeophyceae) growing in areas affected by venting showed a decrease of the concentration of these microelements which is associated with the accumulation of high amounts of iron. Conversely, the specimens of *C. brachycarpa* of both station D and Lisca Nera were more developed, in agreement with previous seasonal records (Table 6) and as it is typical in late spring when maximum community coverage is attained (Ballesteros 1990b).

On the other hand, the above mentioned negative effect of the hydrothermal vents on the size of the specimens of *C. brachycarpa*, and therefore on their reproductive capacity, may affect the recruitment in the hydrothermal areas. At Bottaro, since thermal springs are variable both temporally and spatially because of the frequent migration of degassing events (Italiano and Nuccio 1991, Calanchi *et al*. 1995), *Cystoseira* specimens could likely exhibit high-pulsed recruitment when emissions disappear and, on the contrary, persist through many years with low absolute recruitment and long periods of steady growth when emissions occur. In the latter case, the low recruitment could be mitigating by recruiting from the surrounding non-vent communities (Porzio *et al*. 2011).

As it has been already commented, the station D of Bottaro differs significantly from the other stations of this site but it is quite similar to the station E (Lisca Nera). However, in both sampling periods, the community of *C. brachycarpa* of the station D showed lower values of both total coverage and *C. brachycarpa* coverage, as well as a lower rate of fertile species. Also the specimens of *C. brachycarpa* were rather smaller and the Corallinales, although present, were much less abundant than in Lisca Nera. Moreover, the R/P index was lower, showing that in the station D the community develops under a certain degree of instability. At Lisca Nera the community seemed to be well structured as expected in the typical *Cystoseira* assemblages in the same periods (Ballesteros 1990b, Rull Lluch and Gómez Garreta 1990) and apparently it develops in environment stability conditions (at least at normal pH).

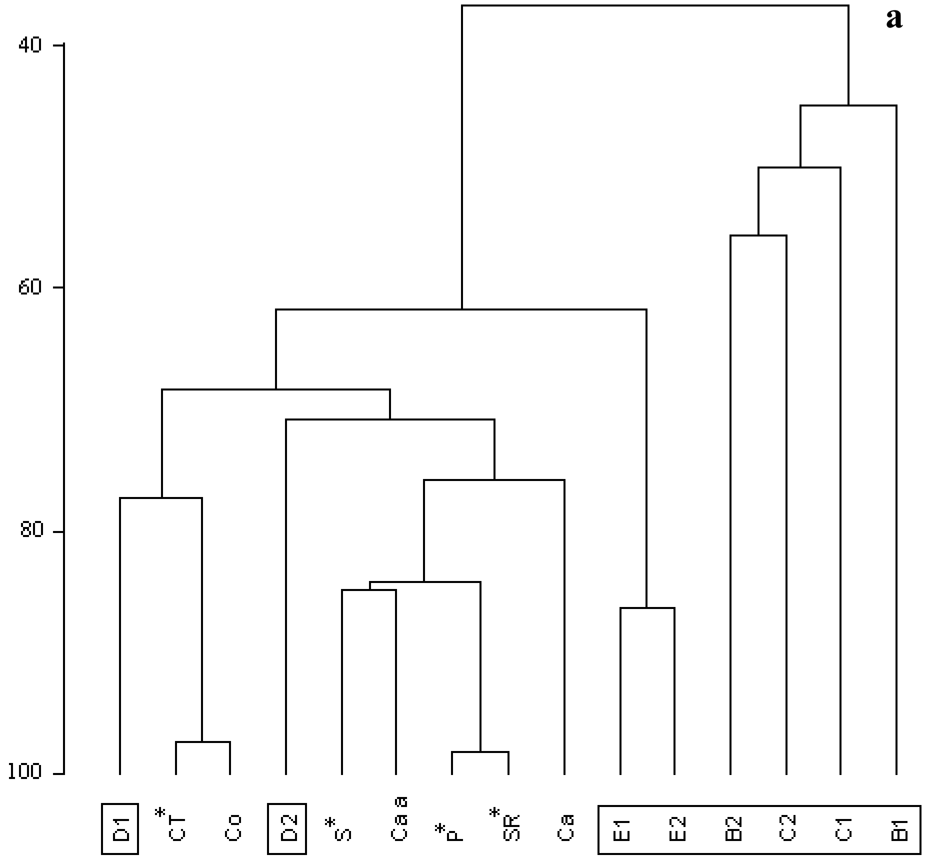
Nevertheless, it showed a sparse proportion of Corallinales suggesting that it could have been affected by the influence of hydrothermal activity which would be still present at a significant distance from the vent outlets. Despite the differences mentioned, the communities of *C. brachycarpa* of the stations D and E are qualitatively more similar between them and with those described by other authors than with those of the other stations of Bottaro (Figs. 37a and 38a). However, quantitatively, the communities of stations D and E are more similar to those of the stations B and C of Bottaro than those described from other localities of the Mediterranean by other authors, except for those of the Sicilian Coast in June (Figs. 37b and 38b). On the basis of Table 18 the community of Lisca Nera is especially similar in the number of species per quadrat to that from Catania described by Pizzuto (1999), although in our study the sampling area was much smaller. In addition, the values of coverage of the community of Lisca Nera are clearly higher than those recorded by Pizzuto (1999) and the other authors. This fact was probable due to our different form of considering coverage, since with the Braun Blanquet method (used by the other authors), the maximum coverage a species can reach is 100% (87.5% after converting data), when it can in fact exceed this value, as occurs in *C. brachycarpa*.

Concerning the epiphytic assemblages of *Posidonia oceanica* leaves, no significant differences were detected between the two meadows studied. In both cases, epiphytic assemblages showed very few species per shoot and a very low coverage, as well as the complete lack of Corallinales. Calcareous crustose algae offer substrata suitable for settlement and growth of a large number of algae (Mazzella *et al*. 1989) and their absence probably affected the structure of epiphytic assemblages. In fact, the number of species recorded in both meadows was very low if compared with the studies reported in the literature (Van der Ben 1971, Panayotidis 1980, Ballesteros *et al*. 1984, Balata *et al*. 2007, Nesti *et al*. 2009). On the other hand, it must be reminded that both meadows occur at Bottaro and, although no bubbling activity was observed in the meadow P2, at this site the thermal springs are variable both temporally and spatially. Thus, this variability could explain the absence of significant differences between the epiphytic assemblages of both meadows.

In summary, our results show that the hydrothermal vents, and its associate decrease in seawater pH, have a clear negative effect not only on the species composition and structure of the community of *C. brachycarpa* and the epiphytic assemblages of *Posidonia oceanica* leaves, but also on the growth and reproduction of the species. However, it would be necessary monitor and, in particular, estimate mean annual growth, recruitment and mortality rates of the *Cystoseira* assemblages in order to obtain more information regarding their possible decline in naturally acidified sites. Further studies extending through longer time periods are required to understand if populations of *C. brachycarpa* are in equilibrium at vent areas and whether recruitment settlement can be irreversibly inhibited by acidification which case these old-growth stands are faced with extinction. Our investigation displayed the response of a *Cystoseira* community to a natural disturbance showing the high vulnerability and fragility of these species and the assemblages they form. The benthic communities of shallow water venting areas have many characteristics in common with communities subject to anthropogenic impact (thermal, residential or industrial) or to changes resulting from a sharp deterioration of the marine environment (Tarasov 2006). *Cystoseira* spp. are known highly sensitive to anthropogenic impacts and several destabilizing factors, such as increased pollution levels and water turbidity, eutrophication, effects of invasive species or erosive effects of anchoring are held responsible of their disappearance from some regions across the Mediterranean (Thibaut *et al*. 2005, Serio *et al*. 2006).

Table 18. Structural parameters of the *C. brachycarpa* community from different sites of Mediterannean coasts; p: period; S: sampling area (cm^2); N: mean number of species per quadrat; DI: Diversity Index; C: mean coverage (%); R/P: Rhodophyceae/Phaeophyceae Index.

Community	**p**	**S**	**N**	**DI**	**C**	**R/P**	**reference**	**Site**
C. brachycarpa	June	400	42	1	236	2.3	this study	Bottaro
C. brachycarpa	June	400	65	1.3	585	4.6	this study	Lisca Nera
C. brachycarpa (as *C. caespitosa*)	June	625	49	2.5	320	2.3	Gómez *et al.* (1987)	Catalonia (Spain)
C. brachycarpa (as *C. balearica*)	May	250	107	4.4	351	6.6	Verlaque (1987)	Corsica (France)
C. brachycarpa (as *C. caespitosa*)	May	784	59	2.0	999	3.4	Ballesteros (1990)	Catalonia (Spain)
C. brachycarpa – *C. brachycarpa* v. *balearica*	May	1600	50	1.8	147	2.3	Cormaci *et al.* (1992)	Salina Island (Italy)
C. brachycarpa v. *balearica*	May	1600	39	3.8	249	3.6	Marino *et al.* (1999)	Syracuse (Italy)
C. brachycarpa	May/June	1600	63	1.3	107	5.1	Pizzuto (1999)	Catania (Italy)
C. brachycarpa	May/June	1600	34	1.2	102	2.7	Alongi *et al.* (2004)	Pantelleria Island (Italy)
C. brachycarpa	October	400	39	2.2	175	2.4	this study	Bottaro
C. brachycarpa	October	400	54	1.2	380	4.6	this study	Lisca Nera
C. brachycarpa (as *C. balearica*)	October	250	77	2.8	220	5.0	Verlaque (1987)	Corsica (France)
C. brachycarpa (as *C. caespitosa*)	November	784	83	4.5	263	2.6	Ballesteros (1990)	Catalonia (Spain)
C. brachycarpa v. *balearica*	October	1600	37	3.6	188	2.7	Marino *et al.* (1999)	Syracuse (Italy)
C. brachycarpa	Oct./Nov.	1600	53	2.0	139	8.9	Pizzuto (1999)	Catania (Italy)


a
40
60
80
100
D1
*CT
Co
D2
*S
Caa
*P
*SR
Ca
E1
E2
B2
C2
C1
B1

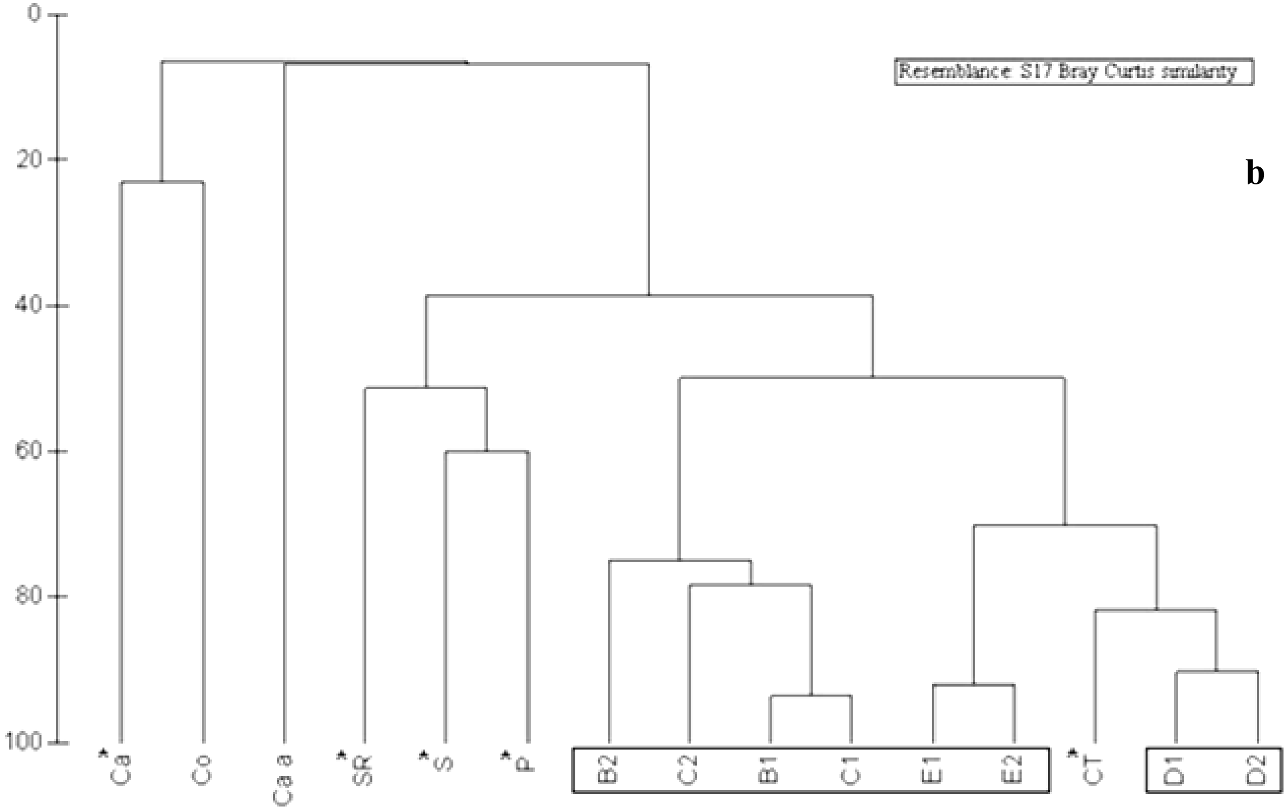
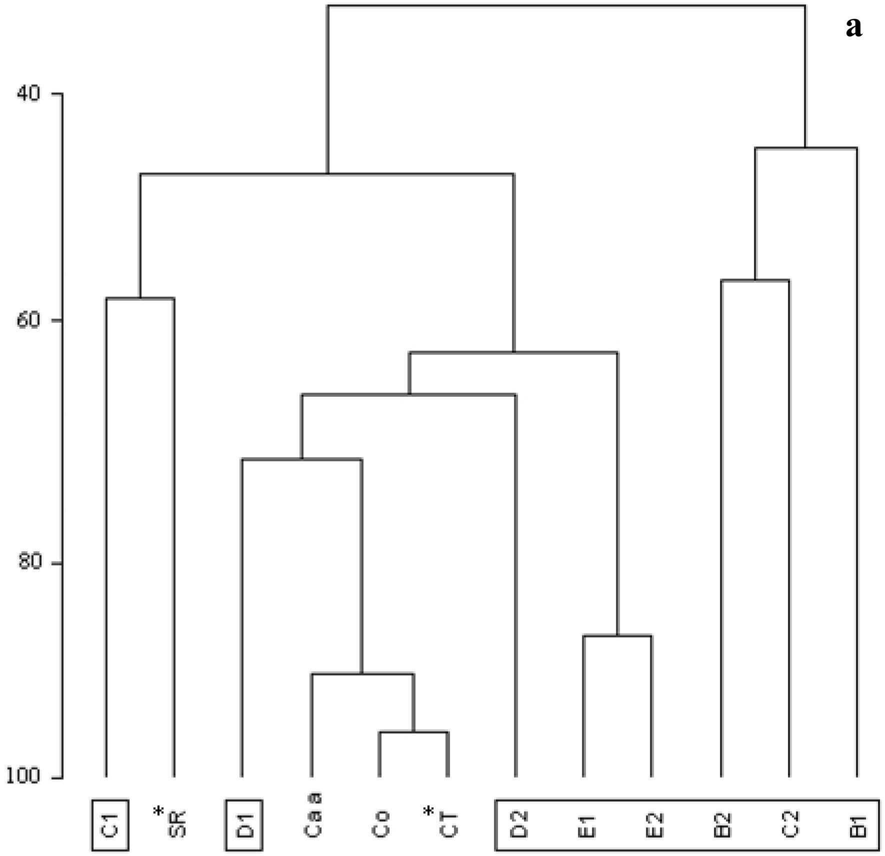


Fig. 37. Similarity dendrogram among the quadrats of the *C. brachycarpa* community in June (this study and literature); a) qualitative similarity Jaccard; b) quantitative similarity (Bray-Curtis). Sites are indicate as follows: B, C, D = Bottaro; E = Lisca Nera; Ca* = Catalonia (Gómez Garreta *et al*. 1987); Co = Corsica (Verlaque 1987); Ca a (Ballesteros 1990); S* = Salina Island (Cormaci *et al*. 1992), SR* = Syracuse (Marino *et al*. 1999); CT* = Catania (Pizzuto 1999); P* = Pantelleria Island (Alongi *et al*. 2004). The stations of this study are inside rectangles; * = mean number of stations.


a
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*SR
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*CT
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E1
E2
B2
C2
B1

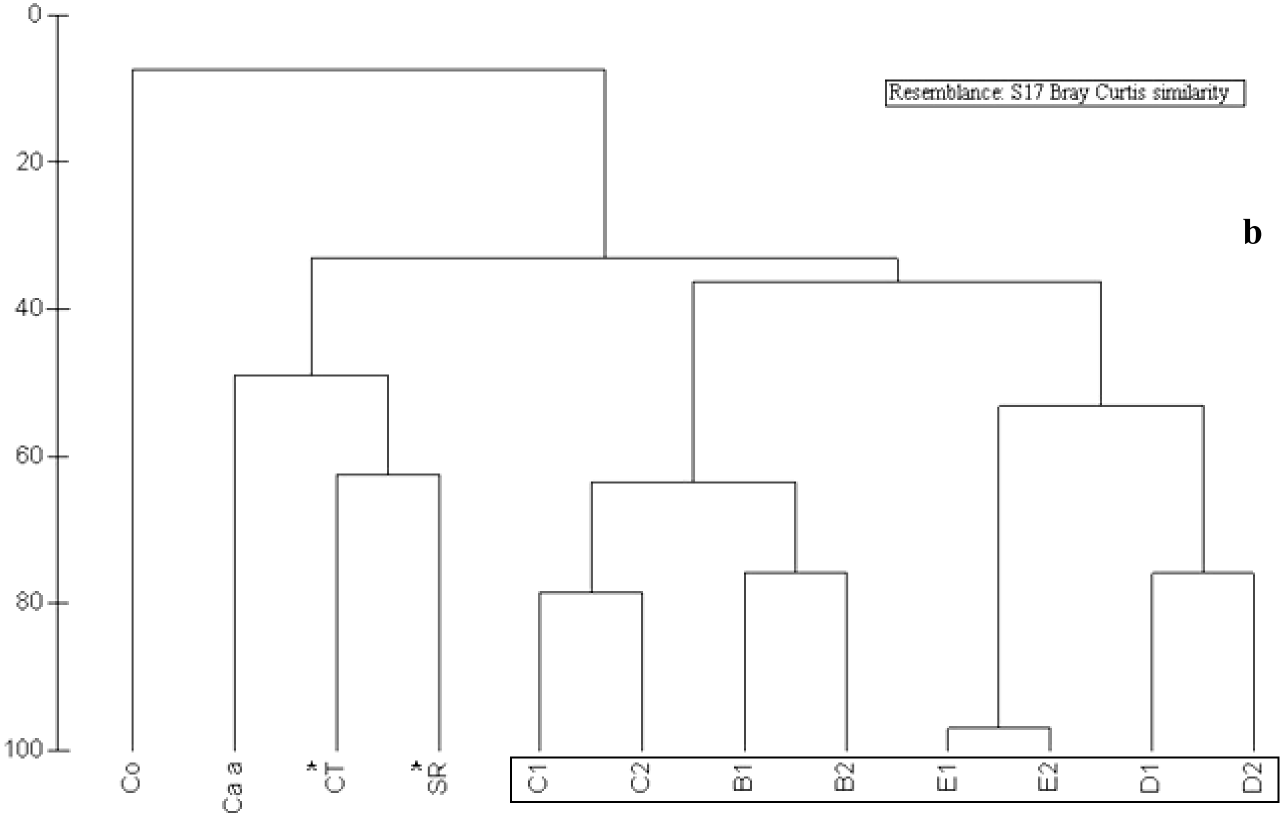

Fig. 38. Similarity dendrogram among the quadrats of the *C. brachycarpa* community in October (this study and literature); a) qualitative similarity Jaccard; b) quantitative similarity (Bray-Curtis). Sites are indicate as follows: B, C, D = Bottaro; E = Lisca Nera; Co = Corsica (Verlaque 1987); Ca a = Catalonia (Ballesteros 1990); SR* = Syracuse (Marino *et al*. 1999); CT* = Catania (Pizzuto 1999). The stations of this study are inside rectangles; * = mean number of stations.

Chapter 5

Conclusion

5. Conclusion

Shallow hydrothermalism is important in geochemical cycling on a global scale and the Mediterranean provides a number of ideal sites for both studying the processes and their impact. Although many organisms are unable to survive close to the most toxic of the vents other species have adapted to these conditions.

Our field observations show that a diverse range of macroalgal species are resilient to even greater changes in seawater carbonate chemistry than those predicted to occur due to anthropogenic CO_2 emissions over the coming century. However, our observations show that we need to plan for shifts in community structure and the loss of biodiversity because some algal species are intolerant of increased CO_2 levels whilst others thrive under these conditions. Many macroalgal species have reduced abundance at mean pH 7.2, and further work is required to determine the mechanisms that cause this. Our results show the high vulnerability and fragility of the *Cystoseira* species and the assemblages they form, sharing many characteristics with communities subject to anthropogenic impact or to changes resulting from a sharp deterioration of the marine environment.

Changes in inorganic carbon chemistry may disrupt a range of processes (e.g., calcification, reproduction, membrane transport and cellular physiology), putting some species at a competitive disadvantage. Research effort has been preoccupied with the detrimental effects of ocean acidification on marine organisms but we also need to better understand which marine organisms will proliferate as CO_2 levels increase. Volcanic vents show that some invasive macroalgae can tolerate persistent high CO_2 levels and also demonstrate what ecological shifts can be expected in vegetated marine ecosystems. Ecophysiological studies are required to better understand why some species can live in a wide range of CO_2 conditions and what processes restrict others to the lowest or highest CO_2 concentration zones. As volcanic vents can persist for millennia it would also be interesting to investigate whether tolerant species have undergone genotype selection within high CO_2 environments.

Further studies are needed to investigate whether the observed response of macroalgal communities can be replicated throughout several years and from a range of geographical regions for incorporation into global modelling studies to predict effects of CO_2 emissions on Earth's ecosystems.

Appendix

Appendix

Floristic List

- Phylum CYANOBACTERIA
  - **Class** Cyanophyceae
    - **Subclass** Nostocophycideae
      - **Order** Nostocales
        - **Family** Microchaetaceae
          - **Genus** *Microchaete* Thuret *ex* Bornet *et* Flahault
            - *Microchaete grisea* Thuret*
        - **Family** Rivulariaceae
          - **Genus** *Calothrix* C. Agardh *ex* Bornet *et* Flahault
            - *Calothrix aeruginea* (Kützing) Thuret
            - *Calothrix crustacea* Schousboe *ex* Thuret
            - *Calothrix scopulorum* (Weber *et* Mohr) C. Agardh
          - **Genus** *Rivularia* C. Agardh *ex* Bornet *et* Flahault
            - *Rivularia atra* Roth *ex* Bornet *et* Flahault
            - *Rivularia polyotis* (J. Agardh) Hauck*
        - **Family** Symphyonemataceae
          - **Genus** *Brachytrichia* Zanardini *ex* Bornet *et* Thuret
            - *Brachytrichia quoyi* (C. Agardh) Bornet *et* Flahault
    - **Subclass** Oscillatoriophycideae
      - **Order** Chroococcales
        - **Family** Chroococcaceae
          - **Genus** *Chroococcus* Nägeli
            - *Chroococcus minutus* (Kützing) Nägeli*
            - *Chroococcus submarinus* (Hansgirg) Kovácik
        - **Family** Hydrococcaceae
          - **Genus** *Pleurocapsa* Thuret in Hauck
            - *Pleurocapsa fuliginosa* Hauck
      - **Order** Oscillatoriales
        - **Family** Oscillatoriaceae
          - **Genus** *Lyngbya* C.Agardh *ex* Gomont
            - *Lyngbya aestuarii* (Mertens) Liebman *ex* Gomont*
            - *Lyngbya confervoides* C. Agardh*
            - *Lyngbya sordida* Gomont
    - **Subclass** Synechococcophycideae
      - **Order** Pseudanabaenales
        - **Family** Pseudanabaenaceae
          - **Genus** *Leptolyngbya* Anagnostidis *et* Komárek
            - *Leptolyngbya fragilis* (Gomont) Anagnostidis *et* Komárek

- Phylum RHODOPHYTA
  - **Class** Compsopogonophyceae
      - **Order** Erythropeltidales
        - **Family** Erythrotrichiaceae
          - **Genus** *Erythrotrichia* Areschoug
            - *Erythrotrichia carnea* (Dillwyn) J. Agardh
  - **Class** Florideophyceae
    - **Subclass** Corallinophycidae
      - **Order** Corallinales
        - **Family** Corallinaceae
          - **Genus** *Haliptilon* (Decaisne) Lindley
            - *Haliptilon virgatum* (Zanardini) Garbary *et* H.W. Johansen
          - **Genus** *Hydrolithon* (Foslie) Foslie
            - *Hydrolithon farinosum* (J.V. Lamouroux) D. Penrose *et* Y.M. Chamberlain
          - **Genus** *Neogoniolithon* Setchell *et* L.R.Mason
            - *Neogoniolithon brassica-florida* (Harvey) Setchell *et* L.R. Mason

Subclass Nemaliophycidae
  Order Acrochaetiales
    Family Acrochaetiaceae
      Genus *Acrochaetium*
          Acrochaetium hauckii (Schiffner)*
  Order Colaconematales
    Family Colaconemataceae
      Genus *Colaconema*
          Colaconema daviesii (Dillwyn) Stegenga
Subclass Rhodymeniophycidae
  Order Bonnemaisoniales
    Family Bonnemaisoniaceae
      Genus *Falkenbergia* F. Schmitz in Engler *et* Prantl
          Falkenbergia rufolanosa (Harvey) F. Schmitz
  Order Ceramiales
    Family Ceramiaceae
      Genus *Antithamnion* Nägeli
          Antithamnion cruciatum (C. Agardh) Nägeli
          Antithamnion heterocladum Funk
      Genus *Ceramium* Roth
          Ceramium codii (H. Richards) Feldmann-Mazoyer
          Ceramium comptum Børgesen
          Ceramium diaphanum (Lightfoot) Roth
          Ceramium siliquosum (Kützing) Maggs *et* Hommersand
          Ceramium tenerrimum (G. Martens) Okamura
      Genus *Gayliella*
          Gayliella flaccida (Harvey *ex* Kützing) T.O. Cho *et* L.J. McIvor
    Family Callithamniaceae
      Genus *Callithamnion* Lyngbye
          Callithamnion corymbosum (J.E. Smith) Lyngbye
          Crouania attenuata (C. Agardh) J. Agardh
    Family Dasyaceae
      Genus *Dasya* C. Agardh
          Dasya baillouviana (S.G. Gmelin) Montagne
          Dasya corymbifera J. Agardh
          Dasya rigidula (Kützing) Ardissone
      Genus *Heterosiphonia* Montagne
          Heterosiphonia crispella (C. Agardh) M.J. Wynne
    Family Delesseriaceae
      Genus *Apoglossum* J. Agardh
          Apoglossum ruscifolium (Turner) J. Agardh
      Genus *Erythroglossum* J. Agardh
          Erythroglossum sandrianum (Zanardini) Kylin
      Genus *Nitophyllum* Greville
          Nitophyllum micropunctatum Funk
      Genus *Radicilingua* Papenfuss
          Radicilingua reptans (Kylin) Papenfuss
    Family Rhodomelaceae
      Genus *Boergeseniella* Kylin
          Boergeseniella fruticulosa (Wulfen) Kylin
      Genus *Chondria* C. Agardh
          Chondria capillaris (Hudson) M.J. Wynne
          Chondria mairei Feldmann-Mazoyer
      Genus *Laurencia* J.V. Lamouroux
          Laurencia microcladia Kützing
          L. minuta Vandermeulen, Garbary *et* Guiry ssp. *scammaccae* G. Furnari *et* Cormaci
      Genus *Dipterosiphonia* F. Schmitz *et* Falkenberg in Engler *et* Prantl
          Dipterosiphonia rigens (C. Agardh) Falkenberg
      Genus *Herposiphonia* Nägeli
          Herposiphonia secunda (C. Agardh) Ambronn

- **Genus** *Lophosiphonia* Falkenberg in F. Schmitz *et* Falkenberg
  - *Lophosiphonia cristata* Falkenberg
  - *Lophosiphonia obscura* (C. Agardh) Falkenberg
- **Genus** *Polysiphonia* Greville
  - *Polysiphonia* cf. *dichotoma* Kützing
  - *Polysiphonia scopulorum* Harvey
- **Genus** *Rytiphlaea* C. Agardh
  - *Rytiphlaea tinctoria* (Clemente) C. Agardh
- **Genus** *Womersleyella* Hollenberg
  - *Womersleyella setacea* (Hollenberg) R.E. Norris

Family Wrangeliaceae
- **Genus** *Griffithsia* C. Agardh
  - *Griffithsia phyllamphora* J. Agardh
- **Genus** *Lejolisia* Bornet
  - *Lejolisia mediterranea* Bornet
- **Genus** *Ptilothamnion* Thuret in Le Jolis
  - *Ptilothamnion pluma* (Dillwyn) Thuret
- **Genus** *Spermothamnion* Areschoug
  - *Spermothamnion flabellatum* Bornet
  - *Spermothamnion repens* (Dillwyn) Rosenvinge
- **Genus** *Wrangelia* C. Agardh
  - *Wrangelia penicillata* (C. Agardh) C. Agardh

Order Gelidiales
- **Family** Gelidiaceae
  - **Genus** *Gelidium* J.V. Lamouroux
    - *Gelidium pusillum* (Stackhouse) Le Jolis

Order Gigartinales
- **Family** Caulacanthaceae
  - **Genus** *Feldmannophycus* Augier *et* Boudouresque
    - *Feldmannophycus rayssiae* (Feldmann *et* G. Feldmann) Augier *et* Boudouresque
- **Family** Cystocloniaceae
  - **Genus** *Rhodophyllis* Kützing
    - *Rhodophyllis divaricata* (Stackhouse) Papenfuss

Order Peyssonneliales
- **Family** Peyssonneliaceae
  - **Genus** *Peyssonnelia* Decaisne
    - *Peyssonnelia bornetii* Boudouresque *et* Denizot
    - *Peyssonnelia dubyi* P.L. Crouan *et* H.M. Crouan
    - *Peyssonnelia* cf. *inamoena* Pilger

Order Rhodymeniales
- **Family** Champiaceae
  - **Genus** *Chylocladia* Greville in W.J. Hooker
    - *Chylocladia pelagosae* Ercegović
- **Family** Lomentariaceae
  - **Genus** *Lomentaria* Lyngbye
    - *Lomentaria clavaeformis* Ercegović
- **Family** Rhodymeniaceae
  - **Genus** *Botryocladia* (J. Agardh) Kylin
    - *Botryocladia botryoides* (Wulfen) Feldmann
    - *Botryocladia microphysa* (Hauck) Kylin
  - **Genus** *Rhodymenia* Greville
    - *Rhodymenia ligulata* Zanardini

Class *Stylonematophyceae*
- **Order** Stylonematales
  - **Family** Stylonemataceae
    - **Genus** *Stylonema* Reinsch
      - *Stylonema alsidii* (Zanardini) K.M. Drew

- Phylum OCHROPHYTA
  - **Class** Phaeophyceae
    - **Order** Cutleriales
      - **Family** Cutleriaceae
        - **Genus** *Cutleria* Greville
          - *Cutleria chilosa* (Falkenberg) P.C. Silva
    - **Order** Discosporangiales
      - **Family** Choristocarpaceae
        - **Genus** *Discosporangium* Falkenberg
          - *Discosporangium mesarthrocarpum* (Meneghini) Hauck
    - **Order** Ectocarpales
      - **Family** Chordariaceae
        - **Genus** *Ascocyclus* Magnus
          - *Ascocyclus orbicularis* (J. Agardh) Kjellman
        - **Genus** *Asperococcus* J.V.Lamouroux
          - *Asperococcus bullosus* J.V.Lamouroux
        - **Genus** *Cladosiphon Kützing*
          - *Cladosiphon cylindricus* (Sauvageau) Kylin
          - *Cladosiphon irregularis* (Sauvageau) Kylin
        - **Genus** *Stilophora* J. Agardh
          - *Stilophora tenella* (Esper) P.C. Silva
        - **Genus** *Giraudia* Derbès *et* Solier
          - *Giraudia sphacelarioides* Derbès *et* Solier
    - **Order** Dictyotales
      - **Family** Dictyotaceae
        - **Genus** *Dictyota* J.V. Lamouroux
          - *Dictyota fasciola* (Roth) J.V. Lamouroux
          - *Dictyota linearis* (C. Agardh) Greville
          - *Dictyota mediterranea* (Schiffner) G. Furnari
        - **Genus** *Padina* Adanson
          - *Padina pavonica* (Linnaeus) J.V. Lamouroux
    - **Order** Fucales
      - **Family** Sargassaceae
        - **Genus** *Cystoseira* C. Agardh
          - *Cystoseira brachycarpa* J. Agardh *emend.* Giaccone
          - *Cystoseira sauvageauana* G. Hamel
    - **Order** Sphacelariales
      - **Family** Cladostephaceae
        - **Genus** *Cladostephus* C. Agardh
          - *C. spongiosus* (Hudson) C. Agardh f. *verticillatus* (Lightfoot) Prud'Homme van Reine
      - **Family** Sphacelariaceae
        - **Genus** *Sphacelaria* Lyngbye in Hornemann
          - *Sphacelaria cirrosa* (Roth) C. Agardh
      - **Family** Stypocaulaceae
        - **Genus** *Halopteris* Kützing
          - *Halopteris filicina* (Grateloup) Kützing
          - *Halopteris scoparia* (Linnaeus) Sauvageau

- Phylum CHLOROPHYTA
  - **Class** Bryopsidophyceae
    - **Order** Bryopsidales
      - **Family** Bryopsidaceae
        - **Genus** *Bryopsis* J.V. Lamouroux
          - *Bryopsis plumosa* (Hudson) C. Agardh
      - **Family** Caulerpaceae
        - **Genus** *Caulerpa* J.V. Lamouroux
          - *Caulerpa racemosa* (Forsskål) J. Agardh v. *cylindracea* (Sonder) Verlaque *et al.**
      - **Family** Chaetosiphonaceae

- **Genus** *Blastophysa* Reinke
  - *Blastophysa rhyzopus* Reinke*
- **Family** Codiaceae
  - **Genus** *Codium* Stackhouse
    - *Codium bursa* (Olivi) C. Agardh
- **Family** Derbesiaceae
  - **Genus** *Derbesia* Solier
    - *Derbesia tenuissima* (Moris *et* De Notaris) P.L. Crouan *et* H.M. Crouan
- **Family** Udoteaceae
  - **Genus** Flabellia Reichenbach
    - *Flabellia petiolata* (Turra) Nizamuddin
  - **Genus** *Pseudochlorodesmis* Børgesen
    - *Pseudochlorodesmis furcellata* (Zanardini) Børgesen
- **Class** Dasycladophyceae
  - **Order** Dasycladales
    - **Family** Dasycladaceae
      - **Genus** *Dasycladus* C. Agardh
        - *Dasycladus vermicularis* (Scopoli) Krasser
    - **Family** Polyphysaceae
      - **Genus** *Acetabularia* J.V. Lamouroux
        - *Acetabularia acetabulum* (Linnaeus) P.C. Silva
- **Class** Siphonocladophyceae
  - **Order** Cladophorales
    - **Family** *Anadyomenaceae*
      - **Genus** *Anadyomene* J.V. Lamouroux
        - *Anadyomene stellata* (Wulfen) C. Agardh
    - **Family** Cladophoraceae
      - **Genus** *Cladophora* Kützing
        - *Cladophora echinus* (Biasoletto) Kützing
        - *Cladophora lehmanniana* (Lindenberg) Kützing
      - **Genus** *Chaetomorpha* Kützing
        - *Chaetomorpha linum* (O.F. Müller) Kützing
  - **Order** Siphonocladales
    - **Family** Valoniaceae
      - **Genus** *Valonia* C. Agardh
        - *Valonia utricularis* (Roth) C. Agardh
- **Class** Ulvophyceae
  - **Order** Ulvales
    - **Family** Kornmanniaceae
      - **Genus** *Pseudendoclonium*
        - *Pseudendoclonium submarinum* Wille
    - **Family** Phaeophilaceae
      - **Genus** *Phaeophila* Hauck
        - *Phaeophila dendroides* (P.L. Crouan *et* H.M. Crouan) Batters
    - **Family** Ulvellaceae
      - **Genus** *Acrochaete* N. Pringsheim
        - *Acrochaete viridis* (Reinke) R. Nielsen
      - **Genus** *Pringsheimiella* Höhnel
        - *Pringsheimiella scutata* (Reinke) Marchewianka
      - **Genus** *Ulvella* P.L.Crouan *et* H.M.Crouan
        - *Ulvella lens* P.L. Crouan *et* H.M. Crouan

* first record in the Aeolian Islands.

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