# UNIVERSITÀ DEGLI STUDI DI TRIESTE

**XXV CICLO DEL DOTTORATO DI RICERCA IN METODOLOGIE DI BIOMONITORAGGIO DELL'ALTERAZIONE AMBIENTALE**

# CARATTERIZZAZIONE DEL CORALLIGENO DEL NORD ADRIATICO: ANALISI DELLA BIODIVERSITÀ E DELLA VARIABILITÀ SPAZIALE DELLE COMUNITÀ MACROALGALI

**(Settore scientifico-disciplinare BIO 03 – Botanica Ambientale e Applicata)**


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**PREMESSA**

La presente tesi, preceduta da un riassunto che riporta le principali linee di ricerca seguite durante il Dottorato di Ricerca in Metodologie di Biomonitoraggio dell'Alterazione Ambientale, è stata redatta sotto forma di articoli, pubblicati o in presentazione, prodotti nel corso dei tre anni di studio.

**[1] Methane-related carbonate cementation of marine sediments and related macroalgal Coralligenous assemblages in the Northern Adriatic Sea 9**

**[2] First contribution to the knowledge of coralline algae distribution in the Slovenian circalittoral zone (Northern Adriatic) 25**

**[3] Species composition and spatial variability of macroalgal assemblages on biogenic reefs in the northern Adriatic Sea 39**

**[4] Morphology-anatomy of *Mesophyllum macroblastum* (Hapalidiaceae, Corallinales, Rhodophyta) in the Northern Adriatic Sea and a key to Mediterranean species of the genus 53**

**[5] *Phymatolithon lamii* (Hapalidiaceae, Corallinales, Rhodophyta): a first report for the Mediterranean Sea 73**

**[6] Sublittoral rocky bottoms and coralligenous outcrops in the Northern Adriatic Sea 82**

Il lavoro svolto è frutto di una stretta cooperazione con la SELC Soc. Coop. L'attività di ricerca ha previsto inoltre la collaborazione con specialisti e istituti nazionali e internazionali di ricerca (OGS-Istituto Nazionale di Oceanografia e Geofisica Sperimentale di Trieste, Dep. Of Botany-La Trobe Univ. Australia, Dip. di Biologia Vegetale-Univ. di Firenze, Centre d'Estudis Avançats de Blanes-Spagna, Istituto Nazionale di Biologia di Pirano Slovenia, Riserva Marina Protetta di Miramare, ARPA-FVG- Osservatorio Alto Adriatico).

**RIASSUNTO**

I fondali che si estendono dal Golfo di Venezia fino alle coste Slovene (Nord Adriatico) prevalentemente fangosi o detritici, sono interrotti da numerosi affioramenti rocciosi distribuiti a profondità tra 7 e 25 m. e distanti dalla costa 0.5-25 miglia nautiche. Tali affioramenti localmente chiamati "*tegnùe", "trezze", "grebeni",* sono maggiormente concentrati tra il Delta del Po e il Golfo di Trieste (Fig. 1).

Stefanon (1967) è stato il primo a descrivere alcuni di questi affioramenti, inizialmente definiti come beachrocks; la loro genesi è invece attualmente connessa alle emissioni di gas metano **[1]**. La migrazione di gas poco profondi attraverso i sedimenti marini induce la deposizione di carbonato di calcio, cementificando il substrato altrimenti non consolidato.

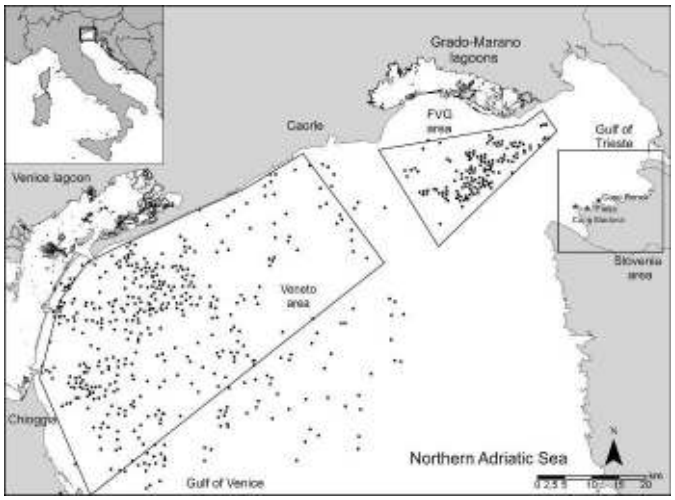


Fig. 1 Area di studio.

La maggior parte degli affioramenti del Nord Adriatico, che mostrano un ampio spettro di morfologie e dimensioni, è formata da una base rocciosa colonizzata da bioconcrezioni calcaree **[1]**. Le tegnùe sono state definite formazioni coralligene, anche se differiscono dal tipico coralligeno mediterraneo *sensu stricto* (Ballesteros, 2006).

Il coralligeno e i fondi a maërl e rodoliti sono considerati tra i principali *hot-spots* di biodiversità in Mediterraneo. Il coralligeno è prodotto dal concrezionamento di alghe calcaree, briozoi, serpulidi, coralli e spugne che si accrescono in condizioni sciafile (Hong, 1980; Ballesteros, 2006), mentre i fondi a rodoliti e maërl sono substrati sedimentari ricoperti da alghe calcaree libere (Corallinales o Peyssonneliaceae) (UNEP-MAP-RAC/SPA, 2008).

La conoscenza dell'estensione e struttura delle formazioni coralligene in Mediterraneo è essenziale per l'individuazione di attività di gestione e protezione di questi habitat, così come indicato dalle più recenti Direttive europee e Convenzioni internazionali. Nell'ambito della Marine Strategy Framework Directive 2008/56/CE (MSFD) il "Coralligeno (C)" e i "Fondi a maërl e rodoliti" sono stati inseriti tra gli S*pecial Habitat* da caratterizzare e di cui valutare lo Stato Ecologico (GES).

Lo scopo ultimo di questo studio, basato sia su attività sperimentali di campo e di laboratorio che sull'analisi di dati di letteratura, è quello di contribuire ad una più approfondita conoscenza delle comunità biotiche degli affioramenti rocciosi del Nord Adriatico. La maggior parte dell'attività di ricerca è stata incentrata sullo studio della struttura e variabilità delle comunità macroalgali, in relazione alle principali variabili ambientali e caratteristiche morfologiche degli affioramenti rocciosi del Veneto e del Friuli Venezia Giulia. È stata inoltre analizzata la componente algale dei fondi a maërl e rodoliti, che si estendono dalle coste venete fino al circalitorale Sloveno.

*HABITAT FONDI A MAËRL E RODOLITI*

Per il Nord Adriatico non sono disponibili dati recenti e rappresentativi sulla distribuzione di maërl e rodoliti. La loro presenza è stata segnalata per la prima volta nel Golfo di Trieste nell'area prospiciente le lagune di Grado e Marano (Giaccone, 1978; Orel *et al*., 1981-82). Successivamente uno studio condotto da Nichetto (1990) ha rilevato la presenza di talli di maërl, prevalentemente morti, sui fondali sabbiosi che si estendono da Grado a Venezia. Infine, Bressan e Giaccone (2005) hanno riportato la presenza di maërl fossile nei sedimenti del Dosso di Santa Croce posto al centro del Golfo di Trieste.

Per meglio definire l'estensione di questo Habitat a scala di sottoregione, a partire dal 2008, sono state campionate 46 stazioni nel versante italiano del Golfo di Trieste **[1]** e al largo della Slovenia **[2]**. Il campionamento in collaborazione con l'ARPA-FVG è tutt'ora in corso. I campioni sono stati raccolti in immersione o mediante bennate e dragaggi.

Considerando anche i dati di letteratura sui fondi mobili dal Veneto alle coste Slovene sono state rinvenute 23 Corallinales, la cui distribuzione batimetrica è compresa tra 9 e 24 m (Orel *et al*., 1981-82; Nichetto, 1990; Bressan e Giaccone, 2005; **[1]**; **[2]**). 15 Corallinales sono state rinvenute sotto forma di rodoliti: *Lithophyllum incrustans* Philippi*, Lithophyllum racemus* (Lamarck) Foslie*, Lithophyllum corallinae* (P.L.Crouan & H.M.Crouan) Heydrich, *Lithophyllum pustulatum* (J.V. Lamouroux) Foslie*, Lithothamnion corallioides* (P.L.Crouan & H.M.Crouan) (P.L.Crouan & H.M.Crouan)*, Lithothamnion minervae* Basso*, Lithothamnion philippii* Foslie*, Lithothamnion sonderi* Hauck*, Lithothamnion valens* Foslie*, Neogoniolithon brassica-florida* (Harvey) Setchell & Mason*, Neogoniolithon mamillosum* (Hauck) Setchell & L.R. Mason*, Phymatolithon calcareum* (Pallas) W.H. Adey & D.L. McKibbin*, Phymatoltihon lenormandii* (Areschoug) W.H. Adey*, Spongites fruticulosa* Kützing), *Sporolithon ptycoides* Heydrich.

Delle 11 Corallinales raccolte mediante dragaggi nel circalitorale sloveno 5 taxa rappresentano nuove segnalazioni per l'area di studio: *Hydrolithon boreale* (Foslie) Y.M.

Chamberlain, *L. philippii, L. minervae*, *L. sonderi*, *N. brassica-florida* **[2]**. Nella biocenosi del Detritico Costiero e presso i banchi di *Cladocora caespitosa* Linnaeus, *L. philippii*, *L. sonderi*, *L. minervae, L. pustulatum, L. racemus*, *N. brassica-florida*, *N. mamillosum*, *P. lenormandii* sono stati campionati come rodoliti vivi, morti o fossili. Alcuni siti sono risultati caratterizzati prevalentemente da rodoliti sub-fossili **[2]**.

Sui fondi mobili da Venezia a Trieste sono state censite 15 Corallinales in forma di rodoliti, in prevalenza caratteristiche del Detritico Costiero. I dati degli anni '90 avevano evidenziato la dominanza di talli morti in particolare nell'area di Grado, che risultava anche impoverita in termini di abbondanza. Il presente studio ha invece individuato proprio al largo di Grado la presenza di *facies* vive di maërl e rodoliti. In particolare i fondali sabbiosi sono risultati caratterizzati da *L. racemus*, mentre sul substrato pelitico-sabbioso sono stati rinvenuti per la prima volta nel Golfo di Trieste talli vivi di *P. calcareum*, assieme alle altre due specie caratteristiche del maërl mediterraneo (*L. corallioides* e *L. minervae*) (Curiel *et al.*, 2009; AA.VV., 2010; **[1]**).

Poiché l'analisi della morfologia dei rodoliti sembra essere indicativa delle caratteristiche idrodinamiche e del tasso di sedimentazione, i talli raccolti in due siti al largo di Grado caratterizzati da una più cospicua presenza di forme libere sono stati classificati in base all'indice di sfericità e alla densità delle ramificazioni **[1]**.

*HABITAT CORALLIGENO*

La posizione, la profondità, la topografia e la struttura geologica degli affioramenti rocciosi del Nord Adriatico sono ben documentati già da tempo, come lo sono la biodiversità e la variabilità spaziale delle comunità zoobentoniche. Al contrario solo pochi studi sono stati condotti sulle macroalghe **[3]**.

Nel presente studio sono state analizzate la biodiversità e la variabilità spaziale delle comunità macroalgali di 37 affioramenti rocciosi situati sui fondali antistanti le lagune di Venezia e Grado-Marano, a distanze dalla costa comprese tra 0.5-10 miglia nautiche e profondità tra 7 e 25 m **[3]**. In base alla loro morfologia ed elevazione dal substrato tali affioramenti sono stati suddivisi in 3 tipologie: i) piccole rocce sparse con elevazione di 0.5-1m; ii) rocce raggruppate con elevazione di 0.5-1m; iii) strutture ampie con rilievo fino a 3-4m. Sulle superfici orizzontali superiori di ciascun affioramento le macroalghe sono state campionate mediante grattaggi di tre aree (2500 $cm^2$). In laboratorio sono stati analizzati il numero di taxa, la copertura di Rhodophyta, Chlorophyta, Ochrophyta e dei gruppi morfo-funzionali (forme incrostanti, filamentose ed erette).

Le relazioni di questi parametri con la tipologia del substrato, la profondità e la distanza dalla costa sono state valutate mediante analisi statistica **[3]**.

In totale sono stati identificati 173 taxa, di cui 124 Rhodophyta, 25 Ochrophyta e 24 Chlorophyta. Con l'aggiunta di dati di letteratura il numero di macroalghe censite sugli affioramenti del Nord Adriatico è di 190 taxa., comprendendo gran parte della flora della regione. Considerando il contesto biogeografico e i fondali mobili circostanti le tegnùe presentano una elevata biodiversità algale, se comparata con le formazioni coralligene del Mediterraneo.

L'analisi floristica ha portato al ritrovamento di *Mesophyllum macroblastum* (Foslie) Adey (Hapalidiaceae, Corallinales, Rhodophyta) componente importante del coralligeno nel Mediterraneo occidentale e prima segnalazione per il Nord Adriatico. I talli gametangiali sono stati invece rinvenuti per la prima volta in Mediterraneo **[4]**. La morfologia e l'anatomia dei talli raccolti nel Golfo di Trieste sono state analizzate al SEM e successivamente comparate con campioni d'erbario provenienti dal Tirreno e con dati di letteratura. In base alla struttura e anatomia dei concettacoli tetrasporangiali è stata proposta una nuova chiave dicotomica per l'identificazione dei taxa Mediterranei del genere *Mesophyllum*.

È stato inoltre segnalato per la prima volta in Mediterraneo *Phymatolithon lamii* (Lemoine) Y. Chamberlain (Hapalidiaceae, Corallinales, Rhodophyta), specie aliena incrostante nord atlantica **[5]**. Lo studio morfo-anatomico al SEM dei campioni raccolti ha evidenziato alcune differenze rispetto ai tipi e ai campioni delle Isole Britanniche. Sono stati inoltre individuati e descritti i caratteri che distinguono *P. lamii* dalle altre due specie del genere ed è stata proposta una nuova chiave dicotomica basata sulla morfologia esterna del tallo e la struttura dei concettacoli.
Il ritrovamento di *P. lamii* al di fuori del suo range ottimale di temperatura e la presenza di entrambe le fasi riproduttive sembrano indicare una maggiore capacità adattativa di questa specie. È quindi possibile che *P. lamii* sia presente anche in altre aree del Mediterraneo, ma confuso con il congenerico *P. lenormandii*.

Oltre a *P. lamii* sugli affioramenti rocciosi campionati sono state rinvenute altre 7 specie aliene, già segnalate nella laguna di Venezia: *Antithamnion hubbsii* E.Y.Dawson, *Desmarestia viridis* (O.F.Müller) J.V.Lamouroux, *Heterosiphonia japonica* Yendo, *Neosiphonia harveyi* (J.W.Bailey) M.S.Kim, H.G.Choi, Guiry & G.W.Saunders, *Polysiphonia morrowii* Harvey, *Polysiphonia stricta* (Dillwyn) Greville, *Solieria filiformis* (Kützing) P.W.Gabrielson **[3]**.

In totale sono state rinvenute 5 Peyssonneliaceae e 22 Corallinales, tra cui le più comuni sono *L. pustulatum* e *L. philippii*. È peculiare l'assenza di alcune alghe comuni nelle formazioni coralligene tipiche del Mediterraneo, che sono invece presenti sui substrati rocciosi sottocosta e

poco profondi del Golfo di Trieste, quali *Halimeda tuna* (Ellis & Solander) J.V. Lamouroux e *Flabellia petiolata* (Turra) Nizamuddin.

La copertura media (14.8 % ± 29.2 %) è bassa rispetto ai valori riportati per il Mediterraneo occidentale (>120 %) Le specie più abbondanti sono *Peyssonnelia* sp.pl., *L. philippii*, *L. pustulatum* e *Zanardinia typus* (Nardo) P.C.Silva. Per quanto riguarda i gruppi morfo-funzionali il numero delle alghe filamentose (13.4 ± 9.0 taxa) è maggiore rispetto alle forme incrostanti (6.4 ± 5.6 taxa) ed erette (5.4 ± 3.8 taxa). Risultati opposti sono stati ottenuti considerando invece le coperture medie (incrostanti: 8.2 % ± 19.3 %; erette: 4.2 % ± 8.6 % ; filamentose: 2.3 % ± 5.0 % ).

Sia il numero di macroalghe che la copertura mostrano un'elevata variabilità correlata alla distanza dalla costa, alla topografia degli affioranti e alla profondità. Tale variabilità è più marcata sottocosta in vicinanza di sbocchi fluviali e alla laguna di Venezia. Questi affioramenti, sottoposti ad elevata sedimentazione, sono caratterizzati da bassi valori di copertura e dalla presenza di taxa a tallo eretto o comuni nelle acque di transizione e sulle strutture artificiali, quali ad esempio *Ulva laetevirens* Areschoug, *Cryptonemia lomation* (Bertoloni) J.Agardh, *Rhodophyllis divaricata* (Stackhouse) Papenfuss, *Rhodymenia ardissonei* (Kuntze) Feldmann, *Ceramium diaphanum* (Lightfoot) Roth, *Chondria capillaris* (Hudson) M.J.Wynne, *Dictyota dichotoma v. intricata* (C.Agardh) Greville. Gli affioramenti posti a maggior profondità al largo delle lagune di Grado e Venezia mostrano invece elevati valori di copertura di specie biocostruttrici, quali *L. stictaeforme*, *L. philippi, N. mamillosum*. In particolare gli affioramenti del Golfo di Trieste, caratterizzati da una minor torbidità e sedimentazione, presentano il numero di macroalghe e i valori di copertura di specie incrostanti maggiori. In generale le forme filamentose mostrano un elevato numero di taxa in entrambe le aree ma con bassi valori di copertura, ad eccezione di *Pseudochlorodesmis furcellata* (Zanardini) Børgesen .

Dato che la MSFD richiede che il GES sia definito a livello ecosistemico, lo studio è stato integrato con dati relativi alle comunità zoobentoniche e alla fauna ittica [**6**]. È stata quindi ottenuta una check-list di 1001 taxa, che evidenzia la grande biodiversità degli affioramenti del Nord Adriatico. I gruppi principali presenti sugli affioramenti biogenici sono molluschi (256 taxa), alghe (190 taxa), policheti (144 taxa), crostacei (124 taxa), spugne (68 taxa), tunicati (40 taxa) e pesci (80 taxa). In generale gli affioramenti Adriatici sono contraddistinti da un maggior numero di sospensivori e da una ridotta complessità strutturale delle comunità biotiche rispetto al coralligeno mediterraneo. Gli affioramenti del Veneto, probabilmente anche in relazione al numero di studi condotti, presentano un maggior numero di taxa zoobentonici rispetto a quelli del Friuli Venezia Giulia e ai fondali Sloveni.

I principali biocostruttori delle tegnùe sono rappresentati da alghe calcaree e policheti. *C. caespitosa* risulta rara sugli affioramenti italiani mentre mostra un'importante attività di biocostruzione in Slovenia. Complessivamente sono stati censiti 17 taxa considerati caratteristici del coralligeno (*sensu* Ballesteros, 2006), al contrario i grandi antozoi e briozoi sono assenti, ad eccezione di *Myriapora truncata* Pallas rinvenuta in Slovenia. L'assenza di queste specie è probabilmente legata alla scarsa elevazione degli affioramenti, alla risospensione dei sedimenti e alle ridotte dimensioni delle superfici colonizzabili. Il ruolo dei bioerosori sui processi di biocostruzione è stato poco indagato. In totale sono stati censiti 14 taxa bioerosori, di cui 4 poriferi, 2 sipunculidi, 4 bivalvi, 3 policheti e 1 echinoderma.

In conclusione questo studio rappresenta un importante contributo alla caratterizzazione della componente macroalgale del coralligeno di fondo duro e mobile in Nord Adriatico. Sono state individuate *facies* vive di maërl in diversi siti al largo della laguna di Grado e definite le tipicità del coralligeno degli affioramenti rocciosi adriatici, adattato a elevati tassi di sedimentazione e ampie escursioni termiche e di salinità. Le tegnùe, per la ridotta profondità e particolare topografia, presentano caratteristiche in parte simili al coralligeno descritto per le coste Pugliesi (Sarà, 1969).

Le conoscenze acquisite durante questa ricerca hanno permesso di:

- designare due affioramenti come nuova area SIC per il Friuli Venezia Giulia (IT3330009 "Trezze San Pietro e Bardelli") che con la Deliberazione della Giunta regionale n. 1623 del 20 settembre 2012 è entrata a far parte della rete Natura 2000.
- includere ai fini dell'attuazione della MSFD il nord Adriatico tra le 11 *assessment area* per gli Habitat "Coralligeno" e "Fondi a maërl e rodoliti". Lo Stato Ecologico è stato indicato in base al "giudizio esperto", dato che per i due Habitat mancano a livello nazionale ed europeo indici validati per la definizione dei valori soglia del GES.

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# 9 Methane-Related Carbonate Cementation of Marine Sediments and Related Macroalgal Coralligenous Assemblages in the Northern Adriatic Sea

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## Abstract

This multidisciplinary study presents the major characteristics of a set of submarine rock outcrops in the Northern Adriatic Sea: the rock occurrence, embedded down to about 1 m from the seafloor in the bottom sediments; numerous gas accumulations in the proximity of the outcrops (e.g., bubbling gas from the sediment–water interface); small-scale mud volcanoes; and microbial mats around the seepage site. Geochemical analysis revealed that these features are related to the seepage of $CH_4$-rich fluids, which causes the precipitation of methane-derived calcium carbonate as a cement ($\delta^{13}C = -49.80‰$ V-PDB). $^{14}C$ data gave radiocarbon ages of about 21,700 ± 2,265 years BP for two cement samples. From the biological point of view, a total of 112 macroalgal taxa were recorded. The different number of taxa recorded at the San Pietro and Bardelli sampling sites has been related to the different distance from the coast and to water depth. Some species that characterize these outcrops are acknowledged as important bioconstructors distinctive of the Mediterranean area.

***Key Words:*** Northern Adriatic Sea, rock outcrop, methane-related carbonate cementation, Quaternary, subbottom profiler Chirp, sidescan sonar, multibeam, $CH_4$ seepage, geochemistry, macroalgal taxa

## Introduction

The investigated area is located in the Gulf of Trieste (Northern Adriatic Sea) (Figure 9.1), in a maximum water depth of 22 m, close to the Slovenian–Croatian coast. Due to the orientation of this portion of the Adriatic Sea (NE–SW), the study

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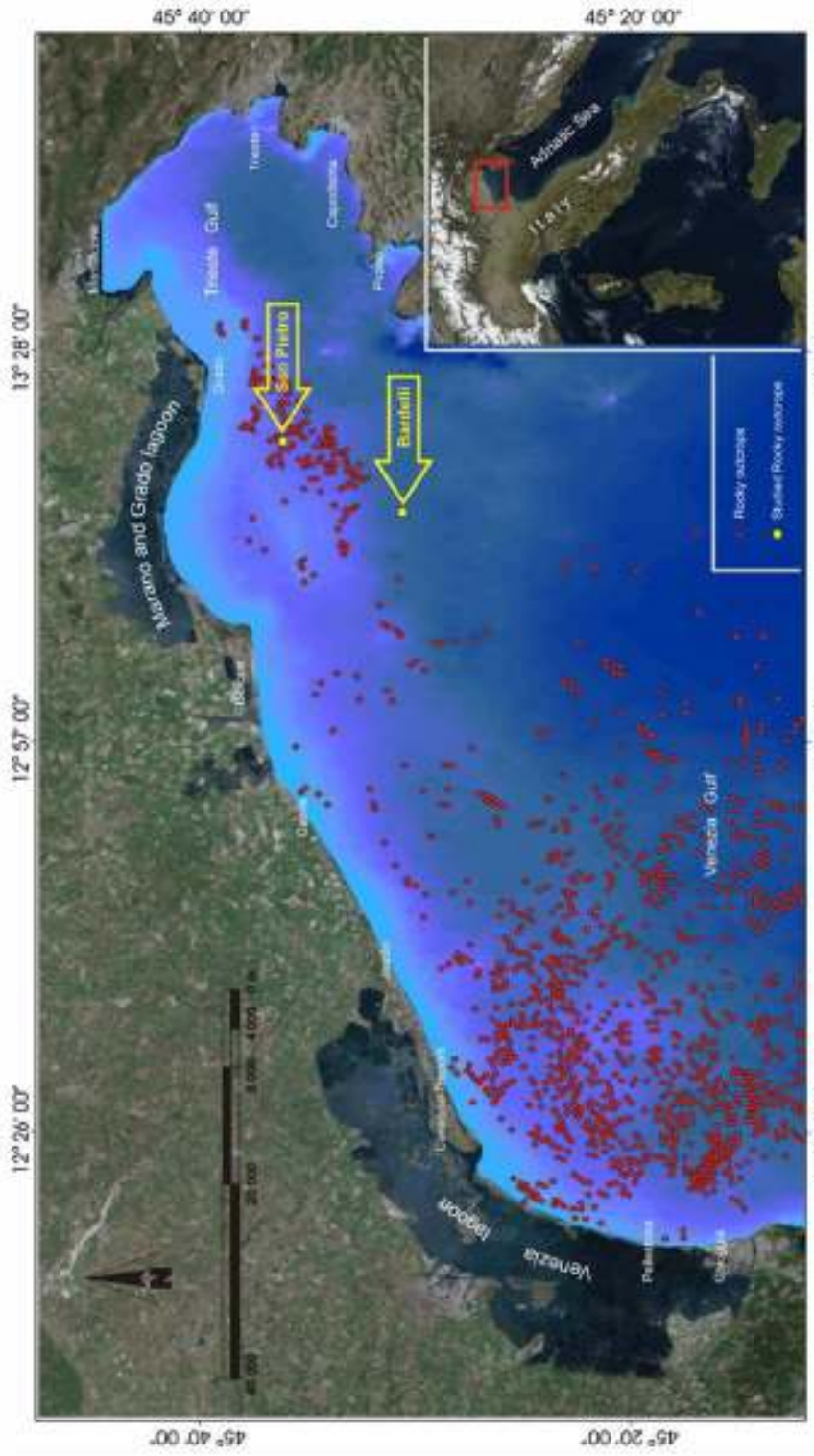


**Figure 9.1** Location map of the northern Adriatic Sea rock outcrops (red dots) where the position of San Pietro and Bardelli is highlighted. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this book.)

area is exposed to different winds and wave regimes. The prevailing winds, especially during the fall and winter, are mainly represented by an ENE wind called Bora [1]. The entire area is also affected by the northern winds (diurnal) caused by thermal variations; the Sirocco and Libeccio winds blow less frequently from the southwest [2,3].

The tidal variations observed along the coast are microtidal (<1 m). The greatest amplitude occurs during spring tide, with an average semidiurnal difference of 86 cm in the northeasternmost part of the Adriatic Sea, in the proximity of Trieste, and 100 cm in Venice (with peaks of 130 up to 200 cm). The minimum amplitude is noted during the mean neap tides, with diurnal differences of about 22 and 20 cm in Trieste and Venice, respectively [4,5]. Annual mean significant wave heights are lower than 0.5 m [6], while the highest offshore wave height, generated by the Bora- and Sirocco-related storms, is about 5 m [7]. The mean basin circulation is counterclockwise.

From the stratigraphical and depositional point of view, the study area is characterized by sedimentary deposits interpreted as late Quaternary transgressive systems [8–10]. They are represented by lowstand system tract (LST) alluvial clays and sands of continental origin, buried by sediments displaying different thicknesses that constitute the transgressive system tract (TST) deposits, mainly characterized by "barrier–lagoon–estuary" systems. The highstand system tract (HST) deposits are located in correspondence to the actual shoreline or sometimes even more inland [11]. The seismic stratigraphy and tectonic evolution of the Gulf of Trieste is described in detail [12,13].

The seafloor sedimentary deposits show a gradual increase of the fine fraction from the coast toward the offshore; then a progressive increase in the coarse fraction in the central part of the study area (residual sands of the TST) is recognized.

Geophysical (multibeam, singlebeam, sidescan sonar (SSS), and Chirp subbottom profiler) and underwater surveys carried out in the Gulf of Trieste allowed a more detailed understanding of the depositional and erosional features of this sea floor sector. It is characterized by a series of reliefs (called Trezze and Banco della Mula di Muggia), elongated and round depressions, and widespread subaqueous sand-dunes fields.

However, the most peculiar features of the Northern Adriatic Sea are submarine rock exposures, irregularly distributed on the seabed [14], whose origin is still largely debated. These rock formations have been initially interpreted as beachrocks [15–17], while the current hypothesis on their genesis suggests they are most likely related to seeping methane and cementation and lithification processes [18–23]. The migration of shallow gas through marine sediments usually causes the precipitation of methane-derived calcium carbonate as a cement within otherwise unconsolidated sediment [22,24–26]. The peculiarity of this cement is the remarkable carbon isotopic depletion in $^{13}C$ compared to normal marine carbonates. It has been interpreted as the result of coupled processes, that is, anaerobic methane oxidation and sulfate reduction, operated by *Archaea* and sulfate-reducing bacteria.

These rock outcrops are characterized by a rich community of associated flora and fauna and thus represent a unique hotspot of biodiversity on the rather monotonous seabed of the Northern Adriatic Sea. The coralligenous biogenic concretions that characterize these reefs play a fundamental role as habitat for reproduction

and nurseries of demersal and pelagic species. These structures are very sensitive to human impacts. Scuba diving confirmed the widespread fragmentation of these features, probably as a result of fishing and overexploitation of *Callista chione* (Linnaeus), 1758, and *Venus verrucosa* (Linnaeus), 1758.

This chapter discusses the most relevant results concerning the study of two rock outcrops, San Pietro (45°36′191″N″−13°20′276″E″) and Bardelli (45°29′843″N″−13°14′662″E″).

## Geomorphic Features and Habitats

The San Pietro outcrop lies at a distance of about 9 km from the coast, at 15 m depth. The study of this structure was first performed through an SSS survey (Edgetech DF-1000/DCI, 100–500 kHz; data processing: Coda Octopus Geokit Mosaics; cell size, 50 cm), which covered a 1,500 × 2,500 m area (*ca.* 4 km$^2$; Figure 9.2). The SSS mosaic consists of 13 profiles, 100 m spaced and acquired with a 75 m wide swath, which allowed an overlap of 20%.

The data highlights that the seabed is almost flat, locally showing the occurrence of rock outcrops, with a range of sizes, shapes, and spatial orientations. On the SSS data, they appear as high backscatter features. The seabed is mainly composed of sands. The rock outcrops can be grouped into two blocks with 40 smaller (0.6 up

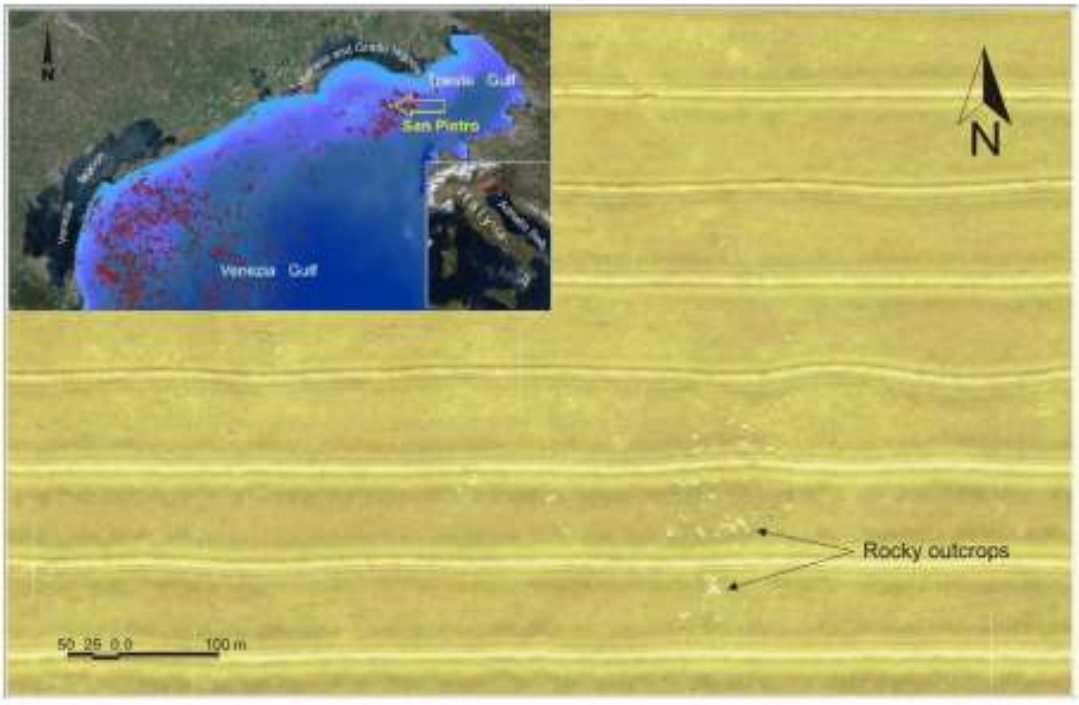


**Figure 9.2** San Pietro SSS mosaic. Data reveal that the seabed, with a dominant sandy component, is almost flat, with local high backscatter features, indicating the occurrence of rock outcrops.

to 6 m in length) outcrops in the surroundings, covering an area of 7,000 $m^2$ (about 175 m × 75 m; E–W oriented). The larger block is 260 $m^2$ large (29 m × 11 m).

In order to obtain a better morphological characterization of the rock outcrops, a multibeam survey has also been performed (Multibeam Reson SeaBat 8125, 455 kHz; processing: Reson PDS2000; grid cell size: 20 cm) in an area of 1.6 $km^2$. The surveyed area shows a NW–SE, 1.5‰ dipping seafloor, with a depth ranging from 15 to 1 m. The rock outcrops have a pinnacle morphology and are 1.5–1.9 m high, and 1–5 m wide (Figure 9.3).

In addition, a Chirp survey (Edgetech 3200-XS/SB-216S, 2–16 kHz; data processing: Discover SB 3200-XS and Kingdom Suite; Figure 9.4) has been performed in the rock outcrop area.

Subbottom profiler data were characterized by a signal penetration of 10 m and a vertical resolution of about 20 cm; the seismostratigraphic setting is generally flat, and where four major sequences were recognizable. Based on a correlation with a 2 m long core collected in the area (GT1bis; see [8]), the uppermost sequence consists of medium to fine sand, with abundant organic matter (*Cymodocea nodosa* (Ucria) Ascherson), probably related to the TST system.

The lowermost sequence is interpreted as representing the LST top (silty sands with *Polmonata* spp. and *Pisidium* spp. and littoral organic matter).

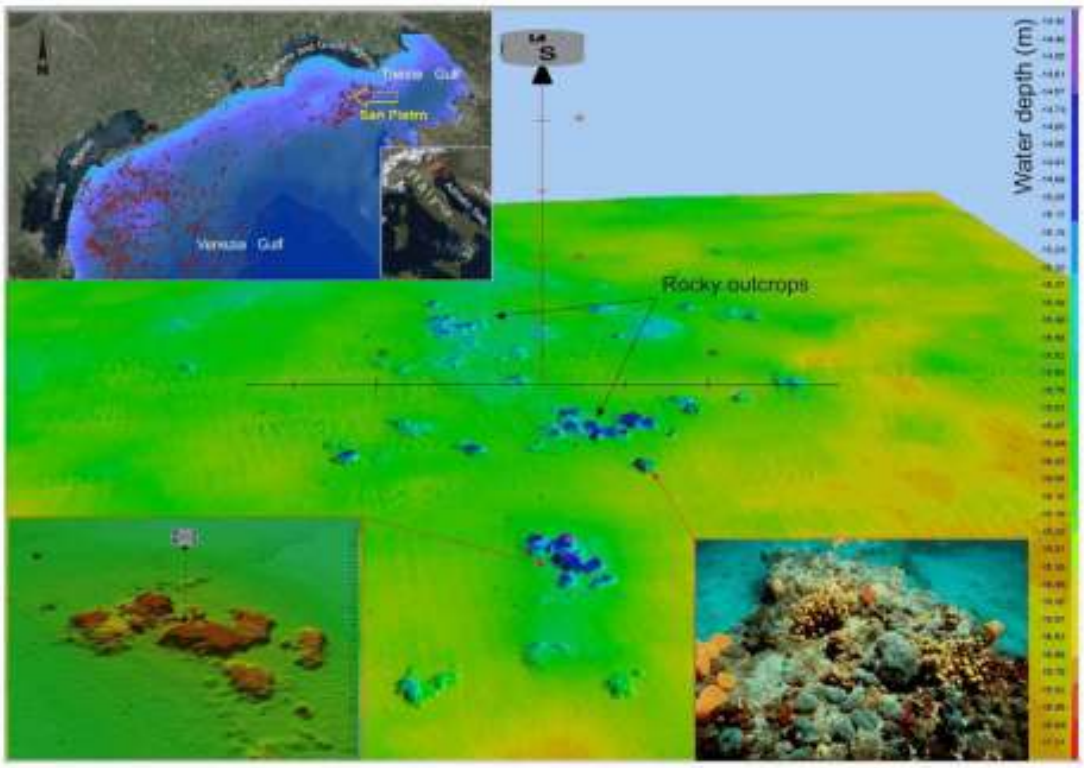


**Figure 9.3** Multibeam sonar bathymetric map showing a 3D perspective view of San Pietro outcrop area, 1.6 $km^2$ wide. The surveyed area shows a NW–SE, 1.5‰ dipping seafloor, with a depth ranging from 15 to 17 m. The rock outcrops have a pinnacle morphology and are 1.5–1.9 m high.

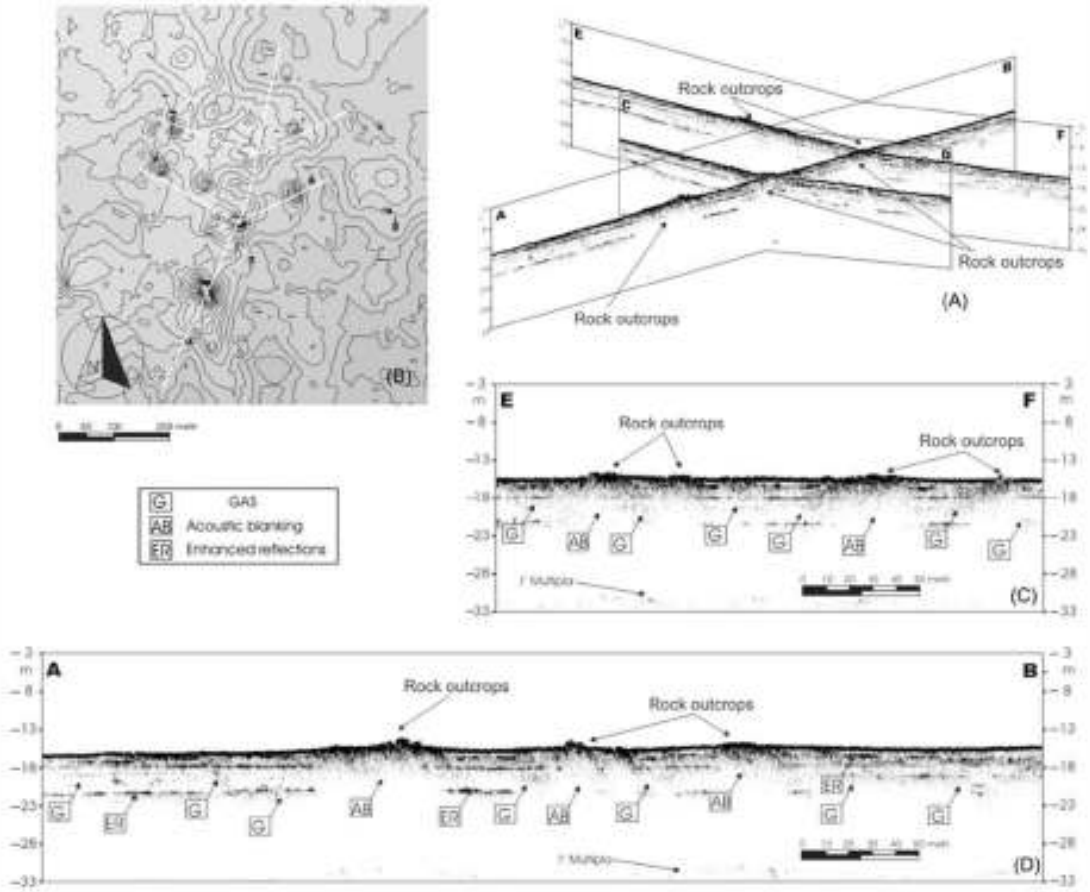


**Figure 9.4** Subbottom profiler Chirp (2–7 kHz) survey on the San Pietro outcrop: (A) 3D sketch; (B) seafloor map (digital echosounder survey); (C, D) high-resolution Chirp, interpreted profiles performed along the direction of maximum development of the rock outcrops (A, B) and across them (E–F). The investigated outcrops, represented by a seismic acoustic blanking, are clearly recognizable on the seismic data and appear to be partially buried within the superficial sediments. The signal penetration is primarily influenced by the presence of sandy-silty sand superficial sediments.

The occurrence of gas has also been identified in both the stratigraphic sequence and the water column (Figure 9.7).

The rock outcrops appear on the seismic profiles as semitransparent *facies* embedded down to about 1 m from the seafloor within the sedimentary sequence.

SSS data acquired in the Bardelli outcrop area, which lies at about 19 km away from the coast, covers 600 m × 800 m (Figure 9.5). The SSS mosaic consists of five profiles, 100 m spaced, and acquired with a 75 m wide swath, which allowed an overlap of 20%. The mosaic shows a predominantly sandy seafloor; locally pelitic sediments are evidenced as lighter backscatter.

The Bardelli outcrop consists of two main groups, which have an E–W orientation (Figure 9.5). They cover an area of 250 m × 90 m (6,300 $m^2$) and are separated by a flat sandy seafloor morphology, where minor rock outcrops are present. The larger group is 95 m × 80 m wide (4,100 $m^2$), shows an almost round shape, and

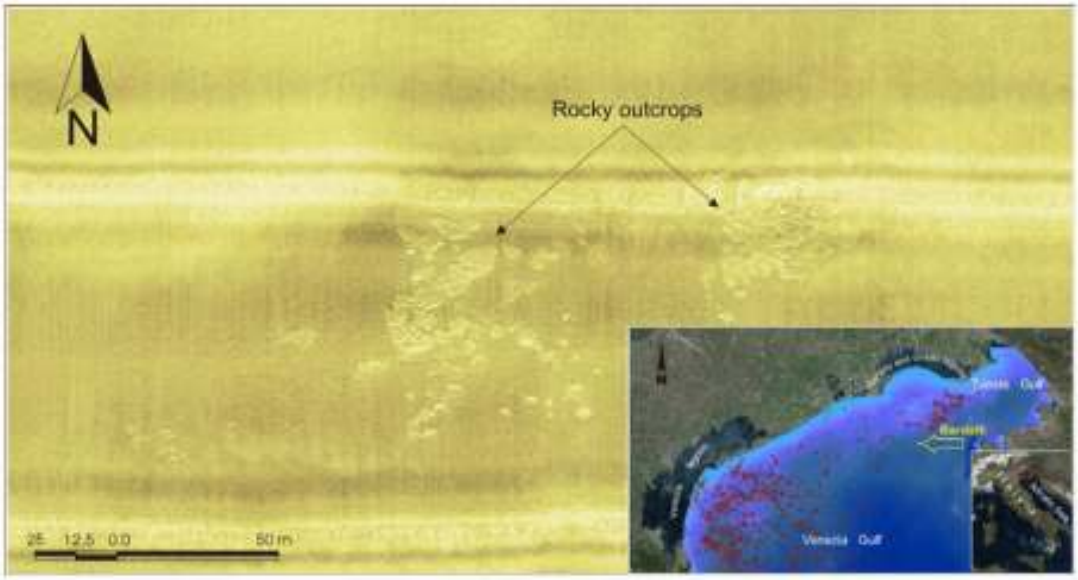


**Figure 9.5** Bardelli SSS mosaic showing a predominant flat, sandy seafloor; locally pelitic sediments are evident as lighter backscatter, whereas the outcrops appear as high backscatter features.

is formed by smaller blocks, separated by sandy to gravelly deposits. The second group, composed of closely spaced rock slabs, reveals an ENE–WSW orientation and is 55 m × 38 m wide (2,200 $m^2$). The slabs are separated by vertical fractures smaller than 0.2–0.3 m.

In order to obtain a better morphological characterization of this outcrop, a single-beam survey (Kongsberg-Simrad EA400, 38–200 kHz; processing: Reson PDS2000; grid cell size: 2 m; Figure 9.6) was performed over the Bardelli outcrop in an area of about 0.2 $km^2$. The analysis of 2D and 3D bathymetric data highlighted that the outcrop lies at a depth ranging from 20.2 to 22.5 m (dip, 4‰). Three morphological highs can be identified at 20.2, 20.4, and 20.6 m, the latter two being located in correspondence to the Bardelli outcrop. In the eastern sector of the surveyed area, a bathymetric low (maximum depth 22.5 m) is recognizable. The rock outcrops have a maximum elevation above the seafloor of 1.2 m.

A Chirp subbottom profiler survey was also conducted; one example is shown in Figure 9.7D. The maximum signal penetration was about 10 m. The high-resolution seismic profiles show the occurrence of a highly reflective *facies* on the seafloor indicative of the presence of the Bardelli outcrop. The sedimentary sequence consists of four depositional units (Figure 9.7D). The lowermost unit is composed of a tabular horizon geometry, locally affected by upward migrating gas.

The uppermost unit, which extends up to the seafloor, is onlapping against the outcrops. It can easily be noted that the two outcrop groups are not laterally connected and that two major plumes are recognizable just above the outcrops. They may represent fluids seeping from the sediments and the outcrops in the water column. Both the Chirp subbottom profiler investigations show, as regards the previous described outcrops, an embedding of only 1 m within the stratigraphic sequence and

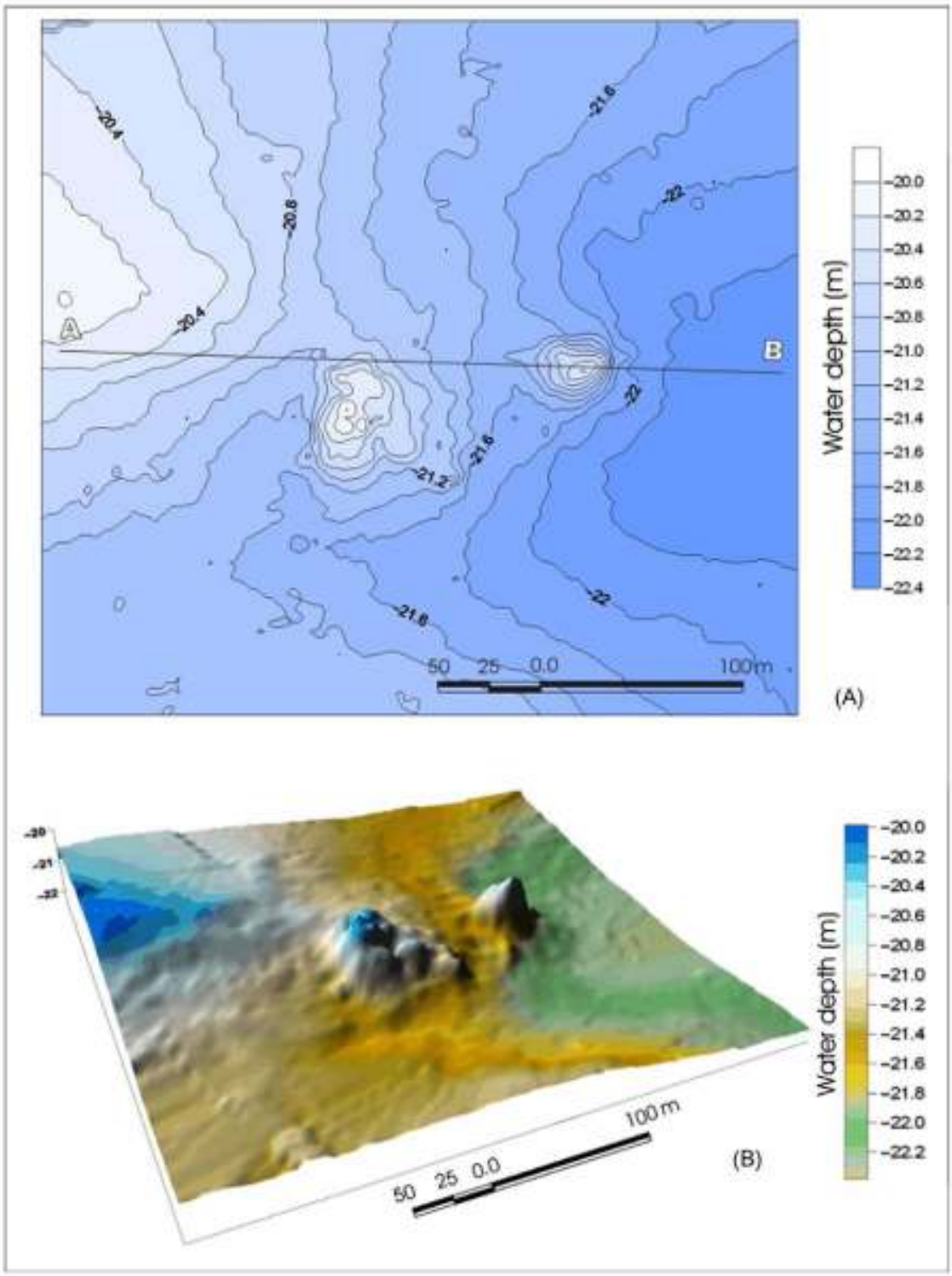


**Figure 9.6** Singlebeam data above Bardelli outcrop. (A) Seafloor contour map where the two blocks constituting the outcrop are recognizable; (A, B) Chirp subbottom profiler profile. (B) 3D perspective view; the outcrop lies at a depth of 20.2–22.5 m, with a maximum elevation above the seafloor of 1.2 m.

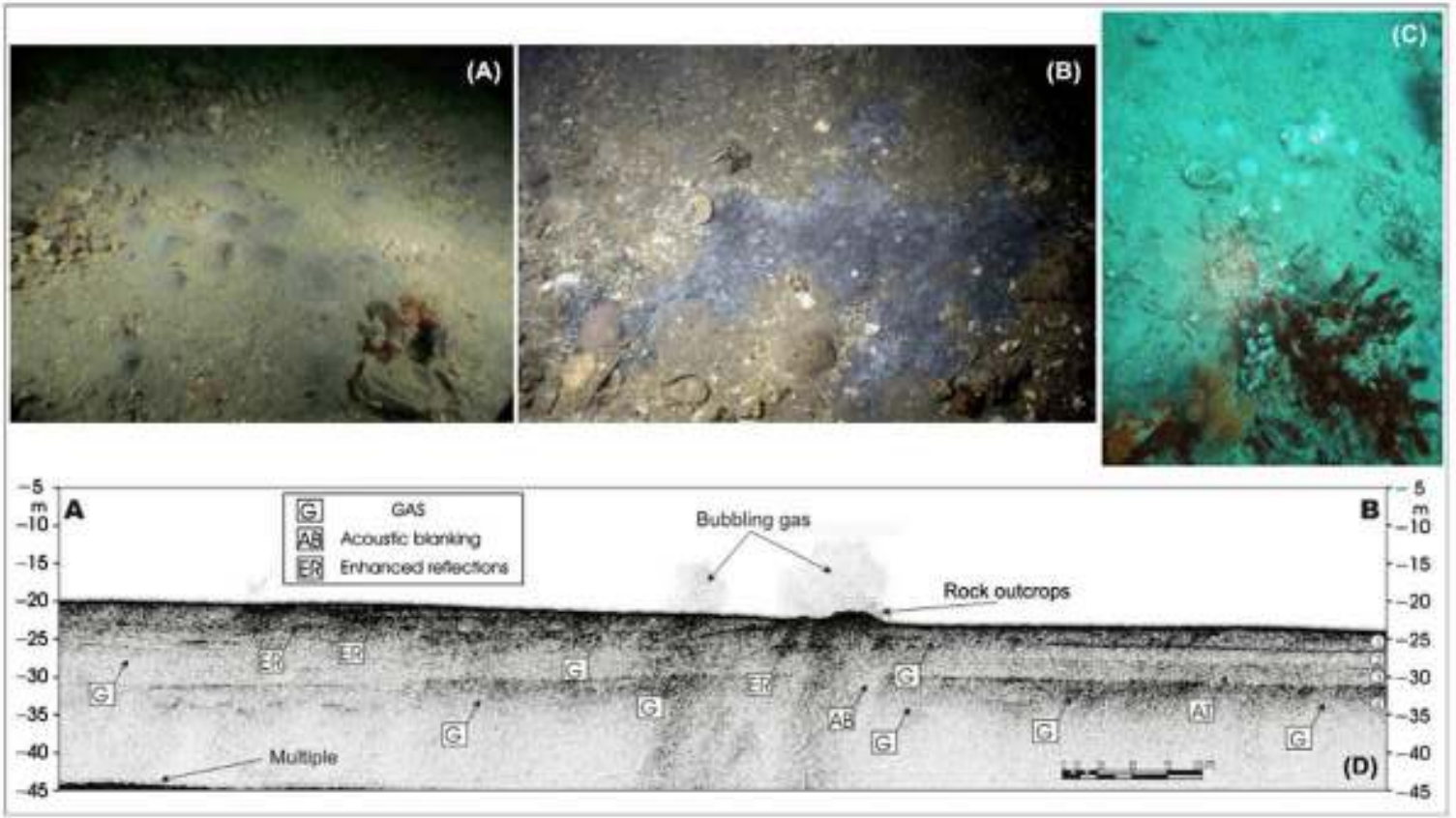


**Figure 9.7** (A) Small-scale (cm) mud volcanoes, (B) microbial mats, (C) bubbling gas from the water–sediments interface, (D) Chirp subbottom profiler (2–7 kHz) survey on the Bardelli outcrop. High-resolution seismic profile showing the occurrence of four depositional units. The highly reflective facies on the seafloor is indicative of the presence of the Bardelli outcrop. Numerous gas accumulations in the proximity of the outcrop can also be recognized; their occurrence is testified by bubbling gas seeping in the water column from the sediments and from the outcrops.

numerous gas accumulations in the proximity of the outcrop, for example, bubbling gas from the water–sediments interface (Figure 9.7C), small-scale mud volcanoes (Figure 9.7A), and microbial mats (Figure 9.7B) around the seepage site.

Four outcrop samples have been collected in correspondence to each outcrop during several diver surveys, at the outcrop top and bottom, and in peculiar areas, such as the gas seepages. SEM-EDX image analysis of eight thin sections of such samples of both the San Pietro and Bardelli outcrops confirmed that their origin is related to marine precipitation cements. Microstructural and petrographical observations were fundamental for the distinction of the different types of authigenic carbonates. Aragonite characterizes the Bardelli outcrop and is primarily associated with shell accumulation in the sediments. Calcite was mostly observed in correspondence to the San Pietro outcrop, in the calcareous sandstones. The mineralogical composition of the rocks reveals a high percentage of carbonates (calcite, aragonite, dolomite, and fragments of carbonate rocks), which may sum up to 80% of the sample. The remaining 20% is made of quartz, feldspar, biotite, chlorite, glauconite, phosphates, and small inclusions of pyrite. The composition of the examined samples on the whole proves the alluvial and marine origin of the deposits, which commonly characterize the study area.

Geochemical analyses, performed through the method described in [27] with a "dual inlet" mass spectrometer (Europa Scientific GEO 20-20), were also carried out to investigate the possible relationships of the rocks with the seepage of $CH_4$ fluids. The geochemical signatures performed on 16 bulk samples at different sampling sites (mixed marine sediments, shells, and carbonate cements) showed that they are depleted in $^{13}C$ with $\delta^{13}C$ values ranging between $-10.28‰$ and $-26.30‰$ V-PDB. More specifically, two samples of authigenic, acicular, aragonite carbonate cement alone revealed strong negative $\delta^{13}C$ values (e.g., $-49.80‰$ to $-39.40‰$ V-PDB), thus showing that methane is the primary source of the carbonate cement carbon.

$^{14}C$ data gave apparent radiocarbon ages of about 21,700 ± 2,265 and 15,940 ± 360 years BP for two aragonitic cement samples, and an age of about 4,990 ± 45 years BP for shells of gastropod and bivalve specimens embedded in the rock (Analyses performed at the Angstrom Laboratory of Uppsala University: the samples are ultrasonically cleaned in boiled distilled water [pH = 3]; each sample is leached with 0.5 M HCl, giving rise to separate fractions of $CO_2$; the desired fraction of $CO_2$ is graphitized using an Fe-catalyst reaction prior to the accelerator measurement). It would then suggest that the carbonate cement ages are compatible with the youngest ages for the fossil methane source, that is, the late Quaternary peat, which age is 16,000 to 22,000 years BP [8,28]. Instead, the ages from the shells would suggest that the cementation processes are recent (Holocene). However, the hypothesis on the age attribution to the outcrops remains at the moment speculative; in fact, we are going to perform an evaluation of the gas age also.

## Biological Communities

Macroalgal assemblages were seasonally investigated from 2008 to 2009 on the San Pietro and Bardelli outcrops by means of a 30 × 30 cm frame arranged randomly

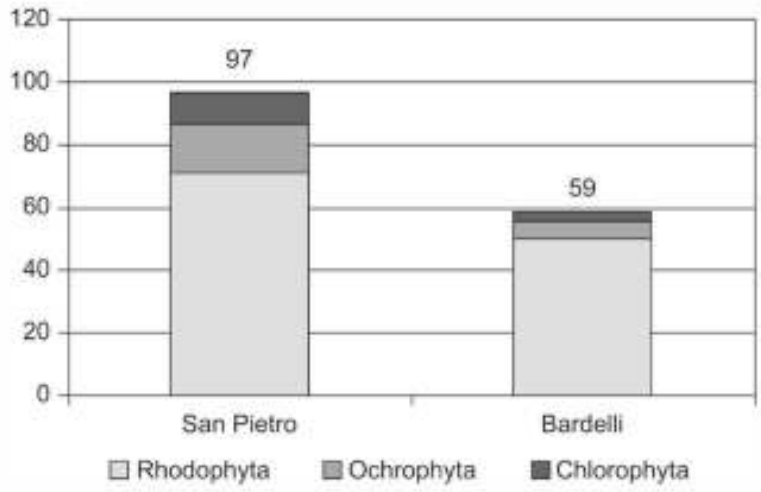


**Figure 9.8** Number of taxa assessed on the two rock outcrops.

on the bottom, within which the substratum was scrubbed clean. Algae collection was supported by underwater photography [29]. Furthermore, on the nearby soft bottoms, SCUBA surveys were made along two 10 m long radial transects across the reef structure. Samples were collected on three quadrates (50 × 50 cm) randomly selected along each transect.

A total of 114 taxa were recorded: 87 Rhodophyta, 17 Ochrophyta, and 10 Chlorophyta. The different number of species recorded at the San Pietro and Bardelli sampling sites (Figure 9.8) may be related to the different distances from the coast (3 and 18 miles, respectively) and depth (16 and 22 m). In particular, at Bardelli, the dim-light conditions favored the development of a greater relative percentage of red algae (84.7% versus 73.1% at San Pietro). These observations are in accordance with [30,31] results on nearby similar outcrops. Among the most conspicuous bioconstructors are the crustose red algae, with 21 Corallinales and 5 Peyssonneliaceae, which at Bardelli showed a coverage up to 70–80%. Nevertheless, these rock outcrops are characterized by a high spatial and temporal variability, even on a small to medium scale of observation. As suggested by Casellato et al. [30], in the Northern Adriatic, the unpredictability of the oceanographical conditions drive the observed variability in benthic communities.

On both outcrops, the most frequent species is the nongeniculate coralline red alga [32] *Lithophyllum pustulatum* (J.V. Lamouroux) Foslie (Figure 9.9B), while *Lithothamnion philippii* Foslie and the genus *Peyssonnelia* showed the higher coverage. Bardelli was also characterized by *Pneophyllum confervicola* (Kützing) Y.M. Chamberlain (Figure 9.9C–D), *Mesophyllum alternans* (Foslie) Cabioch & Mendoza, and *Neogoniolithon mamillosum* (Hauck) Setchell & L.R. Mason. The latter two species are acknowledged as important corallinegous bioconstructors distinctive of the Mediterranean [33–35]. It has been suggested that the calcareous organisms had an important role in the origin of the rock outcrops [30]: the precipitation of carbonate due to methane seeps formed the hard substrate on which the benthic building organisms developed. Such calcareous organisms act as bioconstructors, providing a

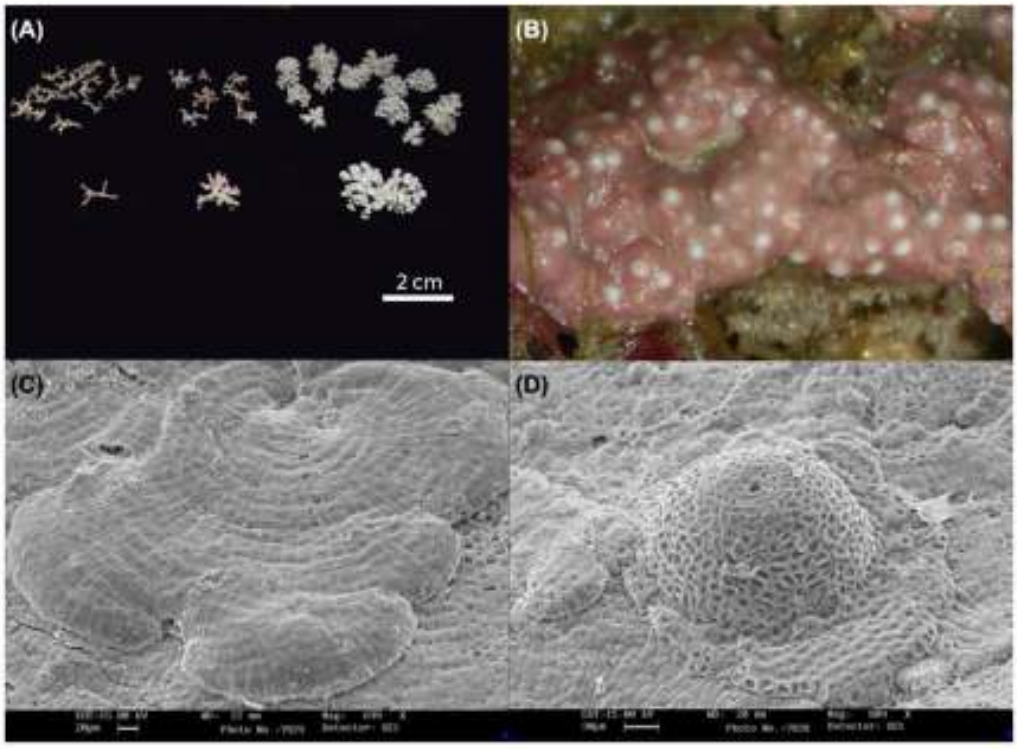


**Figure 9.9** (A) Rhodoliths specimens. From left to right: *L. corallioides*, *P. calcareum*, and *L. racemus*; (B) thallus in reproduction with conceptacles of *L. pustulatum*; (C) habitus of *P. confervicola*; (D) conceptacle of *P. confervicola.*

secondary substratum for further colonization and promoting the construction of the coralligenous reefs [35]. Furthermore, calcareous organisms represent a major contributor to coastal sediments and fossil deposits of biogenic calcium carbonate [36,37].

Finally, on the seabed surrounding the outcrops, free-living, unattached nodules of coralline algae [38,39] were identified. These assemblages represent complex and heterogenous substrata on otherwise monotonous sedimentary bottoms, providing habitat for many associated organisms. They are recognized worldwide as one of the most important benthic communities dominated by marine algae [40].

In particular, the sandy seabed at San Pietro was characterized by the rhodolith *Lithophyllum racemus* (Lamarck) Foslie, while on the pelitic–sandy sediments at Bardelli, a maërl association (Figure 9.9A) with two species characteristic, *Lithothamnion corallioides* (P.L. Crouan & H.M. Crouan) P.L. Crouan & H.M. Crouan and *Phymatolithon calcareum* (Pallas) W.H. Adey & D.L. McKibbin, along with *Lithothamnion minervae* Basso and *Lithophyllum racemus* (Lamarck) Foslie, were detected. Living rhodoliths are crucial for the survival of beds and their associated biodiversity [41]. The assessed ratio of living (pigmented)/nonliving thalli was higher at San Pietro ($L/nL = 10$) than at Bardelli ($L/nL = 1.64$). Following [42–44], the rhodoliths' sphericity was also assessed. The analyzed specimens are mostly likely spheroidal and ellipsoidal (Figure 9.10). As far as the density of branching is concerned, in accordance with the scale proposed by [42], the dominance of thalli with

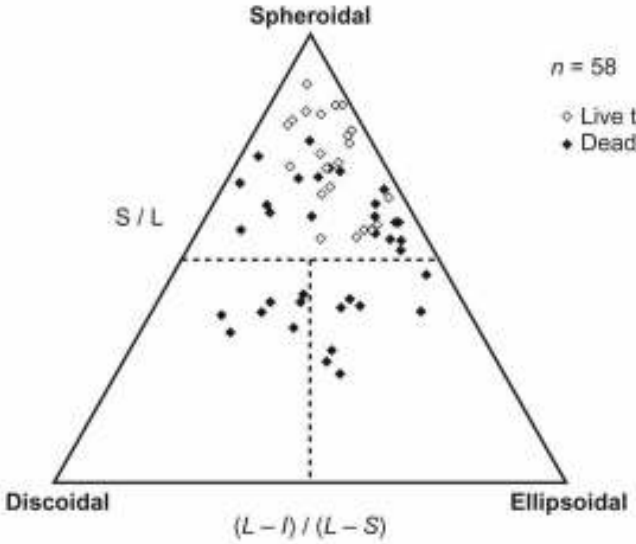


**Figure 9.10** Ternary diagram of *L. racemus* shape ($L$ = long axis; $I$ = intermediate axis; $S$ = short axis).

low-density branches (Classes II–III) was observed. In literature, the sphericity and branching density of rhodoliths have often been correlated to environmental factors, such as hydrodynamic features (currents, water turbulence, wave action) and sedimentation rate [39,42,45,46]. Sphericity has also been used as an indicator of frequency of movement and overturning [42,45]. On Bardelli, the lack of a dominant form, together with the almost total absence of fleshy epiphytic algae, seems to delineate a situation highly variable in local conditions. Nevertheless, the relationships linking the algal morphology and the environmental conditions are still questionable and mainly based on few correlative studies on living beds; therefore, more experimental data are imperative to better predict such correlations.

With reference to the EU Habitat Directive (Natura 2000, 92/43/EEC), the rock outcrops of the Northern Adriatic are regarded as "reef habitat" (Habitat: 1170), characterized by biogenic/geogenic concretions. None of the species until now reported are included in Annex II of the Habitat Directive, while two Mollusca (*Lithophaga lithophaga* Linnaeus, 1758, and *Pinna nobilis* Linnaeus, 1758), and two macroalgae (*L. corallioides* and *P. calcareum*) are respectively reported in Annexes IV and V.

The high biodiversity recorded, together with the occurrence of ecological gradients, represent valuable elements on the rather monotonous coastal bottoms of the Northern Adriatic Sea. In addition, the rock outcrops play a pivotal role as nurseries for demersal and pelagical species reproduction and spawning. The fragile biological equilibrium of these structures, the slow-growing calcareous organisms considered as nonrenewable resources, and the dredging and bottom trawling pressure that strongly threatens the physical characteristics of the habitat and negatively affect the associated biota, all motivate the need to protect the Trezze and their surrounding seabed.

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# FIRST CONTRIBUTION TO THE KNOWLEDGE OF CORALLINE ALGAE DISTRIBUTION IN THE SLOVENIAN CIRCALITTORAL ZONE (NORTHERN ADRIATIC)

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## *ABSTRACT*

*Authors present new data on the coralline algal flora from Slovenia. They come from a recent inspection of the Slovenian part of the Gulf of Trieste where peculiar communities, such as the biocoenosis of the coastal detritic bottom, the agglomeration of bioconcretions known in the area under the name of »trezze« or »tegnue«, and the bank of Mediterranean stony coral* Cladocora caespitosa, *occur. In such communities 11 coralligenous red algae were found. Five of them,* Hydrolithon boreale, Lithothamnion minervae, L. philippii, L. sonderi *and* Neogoniolithon brassica-florida *are newly recorded for Slovenia.*

**Key words:** coralline algae, circalittoral, *Cladocora caespitosa*, northern Adriatic, Slovenia

# PRIMO CONTRIBUTO ALLA CONOSCENZA DELLA DISTRIBUZIONE DELLE ALGHE CORALLINE NEL CIRCALITORALE SLOVENO (ADRIATICO SETTENTRIONALE)

## *SINTESI*

*Gli autori presentano nuovi dati sulla flora delle alghe coralline della Slovenia. I risultati provengono da una recente ispezione della parte slovena del Golfo di Trieste, dove vivono peculiari comunità, come la biocenosi del fondo detritico costiero, gli agglomerati di bioconcrezioni conosciute nell'area come »trezze« o »tegnue«, e i banchi madreporici di* Cladocora caespitosa. *In queste comunità sono state trovate 11 specie di alghe rosse coralligene. Cinque specie,* Hydrolithon boreale, Lithothamnion minervae, L. philippii, L. sonderi *e* Neogoniolithon brassica-florida *sono nuove segnalazioni per la Slovenia.*

**Parole chiave:** alghe coralline, circalitorale, *Cladocora caespitosa*, Adriatico settentrionale, Slovenia

## INTRODUCTION

Among the eight action plans adopted by the Contracting Parties of the Barcelona Convention, one is devoted to the coralligenous habitat: the Action plan for the conservation of the coralligenous and other calcareous bio-concretions in the Mediterranean Sea, UNEPMAP-RAC/SPA (Ballesteros, 2008). Within this document, the coralligenous formations are considered a typical Mediterranean underwater seascape, comprising coralline algal frameworks that grow in dim light conditions and in relatively calm waters (Ballesteros, 2006). Data concerning the coralligenous biocoenosis occurring in the Mediterranean Sea are sparse and mostly regarding the north-western part of the basin, southern Italy and the Alboran Sea, while other regions are poorly known (Pergent, 2009). Therefore, the available lists of species, as well as the main engineering species, are mainly known from those areas, and they cannot be considered constant in the rest of the Mediterranean (UNEP-MAP-RAC/SPA, 2008).

The Gulf of Trieste, even if characterized by shallow bottoms, displays a high number of both species and habitats. The circalittoral of the Gulf of Trieste is mostly composed by the biocoenosis of the muddy detritic bottom (Lipej *et al.*, 2006). A patch of the biocoenosis of the coastal detritic bottom is present in the Piran Bay (Lipej *et al.*, 2006) and a solitary temperate reef made of the Mediterranean Stony coral *(Cladocora caespitosa)* is located off Cape Ronek. More recently, some studies have shown the presence of some peculiar and rather uncommon habitats in the Slovenian area. Among them, the precoralligenous bioformation is one of the most interesting, since it also hosts great fish diversity (Lipej *et al.*, 2003; Orlando-Bonaca & Lipej, 2005). In Slovenian waters, the precoralligenous bioformation is distributed in the lower infralittoral rocky zone, in the depth range from 3 to 14 m, within the area between Cape Ronek and Cape Madona Nature Monument in Piran (Fig. 1).

The aim of this paper is to present new data on coralline algal species obtained from recent sampling in the circalittoral zone of the Slovenian coasts. Special attempt was given to a peculiar habitat such as the coral reef and to the biocoenosis of the coastal detritic bottom. A description of the recorded species is also given.

## MATERIAL AND METHODS

The sampling for the present study was done according to the requirements of the Marine Strategy Framework Directive (2008/56/ES). The circalittoral zone was sampled during the spring and autumn period in 2010 (Tab. 1) in 4 Slovenian areas (Fig.1): open waters off Cape Madona NM in Piran (1), open waters off Strunjan (2), near Cape Ronek (3), and the Bay of Piran (4).

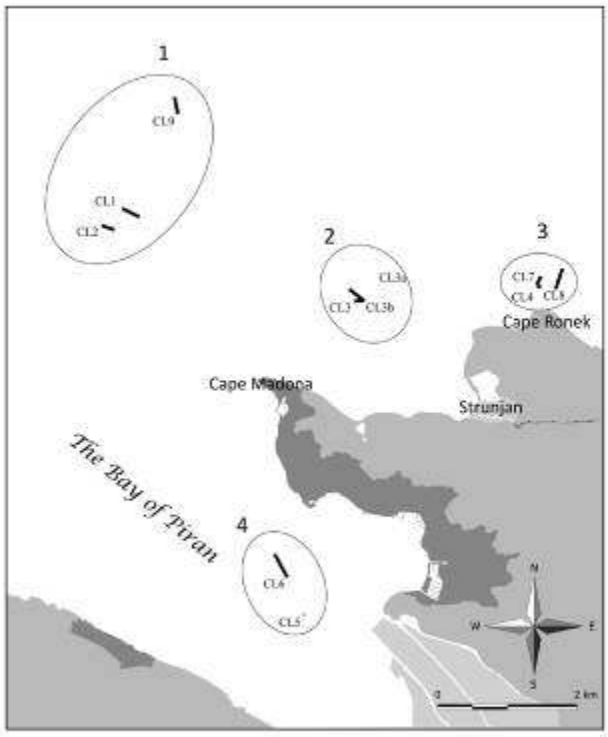


***Fig. 1: The study area with sampling sites.***
***Sl. 1: Obravnavano območje z lokalitetami vzorčevanj.***

The sampling was done by a benthos dredge (Pérés & Picard, 1964; Castelli *et al.*, 2003), more appropriate than grabs and cores for estimating the densities of little abundant benthic species. It is considered a semi-quantitative sampling method, owing to the problem of estimating the sampled area accurately (Holme & McIntyre, 1984).

On selected sampling areas, the dredge was trawled at a constant velocity of the research vessel (between 0.8 and 1.1 knots), for 5 to 8 minutes. The transect-lines dredged varied from 150 in 250 m in length. At the end, the dredge was raised on the vessel and the content was preserved in big sinks with seawater, while transported to the coast.

Only the transect CL8 located off Cape Ronek was not dredged, but surveyed with non-destructive visual methods, since it is located on the reef of *C. caespitosa*. Observations were made by divers in order to determine the algal species growing within this reef.

Algal samples were sorted in laboratory and fragments of material were air dried, mounted on aluminium stubs with acrylic adhesive and then analysed by scanning electron microscopy (SEM). Stubs were sonicated with a Vitec sonicator to remove sediments and diatoms and then coated with gold/palladium (with S150 Sputter Coater, Edwards) prior to viewing in a LEICA Steroscan 430i at 20 kV.

***Tab. 1: Samplings and sites characterization. *CL8 was only visual censused.***
***Tab. 1: Podatki o vzorčevanju in lokalitetah. Na lokaliteti *CL8 je bilo izvedeno le vzorčevanje z opazovalnimi tehnikami.***

| Site | Date | Start of the dredging | | End of the dredging | | Depth (m) |
|---|---|---|---|---|---|---|
| | | Lat (N) | Long (E) | Lat (N) | Long (E) | |
| CL1 | 1.6.2010 | 45°33.067' | 13°32.433' | 45°33.132' | 13°32.247' | 22.0-24.0 |
| CL2 | 1.6.2010 | 45°32.963' | 13°32.163' | 45°32.997' | 13°32.023' | 22.0-24.0 |
| CL3 | 10.6.2010 | 45°32.448' | 13°34.915' | 45°32.445' | 13°34.815' | 27.0 |
| CL4 | 10.6.2010 | 45°32.592' | 13°36.828' | 45°32.660' | 13°36.873' | 19.8-21.6 |
| CL5 | 14.6.2010 | 45°29.992' | 13°34.323' | 45°29.992' | 13°34.323' | 14.0 |
| CL6 | 14.6.2010 | 45°30.285' | 13°34.138' | 45°30.462' | 13°33.992' | 16.6 |
| CL1 | 22.10.2010 | 45°33.067' | 13°32.433' | 45°33.132' | 13°32.247' | 22.0-24.0 |
| CL2 | 22.10.2010 | 45°32.963' | 13°32.163' | 45°32.997' | 13°32.023' | 22.0-24.0 |
| CL7 | 22.10.2010 | 45°32.591' | 13°36.828' | 45°32.578' | 13°36.877' | 20.0 |
| CL8* | 5.11.2010 | 45°32.567' | 13°37.032' | 45°32.723' | 13°37.101' | 16.1-27.0 |
| CL3a | 15.11.2010 | 45°32.448' | 13°34.915' | 45°32.445' | 13°34.815' | 14.0-22.1 |
| CL3b | 15.11.2010 | 45°32.446' | 13°34.930' | 45°32.536' | 13°34.765' | 27.0 |
| CL9 | 15.11.2010 | 45°33.872' | 13°32.839' | 45°34.005' | 13°32.798' | 23.2 |

* visual count sampling

Anatomical terminology follows Woelkerling (1988) and growth-form terminology follows Woelkerling *et al.* (1993). Herbarium abbreviations follow Thiers (2011). Descriptions and terminology follow Irvine and Chamberlain (1994).

## RESULTS AND DISCUSSION

During the present study, 11 species of coralline algae were found in the circalittoral, 5 of which, *Hydrolithon boreale, Lithothamnion minervae, Lithothamnion philippii, Lithothamnion sonderi, Neogoniolithon brassica-florida* were first recorded in Slovenia (Tab. 2).

In samples from sites CL1 and CL2 the encrusting forms prevailed in autumn, while the rhodoliths, both living and fossil, were more abundant in spring (75% and 55% respectively). The most frequently collected species were: *Lithothamnion philippii* (encrusting, rarely rhodolith), *L. sonderi* (encrusting), *L. minervae* (rhodolit and encrusting) and *Pneophyllum confervicola* (encrusting), followed by *L. pustulatum* (encrusting and rhodolit) and *Neogoniolithon brassica-florida* (rhodolit and encrusting). In site CL9 the algal composition was similar, but with a greater abundance of not living thalli of *L. minervae*. The CL8 site was characterised by a large presence of not living rhodolits of *L. racemus* and *L. minervae*, and by encrusting forms of *L. minervae, L. philippii, L. sonderi*, and *P. fragile*, mainly as epiphytes on *C. caespitosa*. However, most of the thalli collected were partially depigmented, infertile and with evident signs of bioeroding activity.

### Species survey

***Hydrolithon boreale* (Foslie) Y. M. Chamberlain**
Basionym: *Melobesia farinosa* f. *borealis* Foslie
Lectotype locality: Roundstone, Co. Galway, Ireland

Only encrusting bisporangial thalli were observed (Fig. 2). The plants were 10 mm in diameter and 15 µm in thickness and presented a smooth surface with grainy texture, while the thin margin frequently showed orbital rings. Trichocytes were frequent. The domed chambers of conceptacles measured 60–85 µm in diameter and were 55–85 µm high. This alga was rarely seen in the study area, with few specimens found only in CL1 and CL2 sites (spring sampling) at ca. 22–24 m of depth.

***Lithophyllum pustulatum* (J. V. Lamouroux) Foslie**
Basionym: *Melobesia pustulata* J. V. Lamouroux
Type locality: France

Bisporangial plants were adherent on the substrate with entire margin (diameter up to 20 mm). The uniporate bisporangial conceptacles, convex and crowded with a developed columella at the base (Fig. 3), had chambers of 134–326 µm in diameter and 82–233 µm height. This species was observed in all the sampling sites, except in CL8. It was more abundant in CL2 and CL9.

***Tab. 2: Check-list of crustose coralline algae from the Slovenian part of the Gulf of Trieste. The 11 species in bold were found during the present study in the circalittoral belt. Taxa indicated with * are first records.***
***Tab. 2: Seznam skorjastih koraligenih alg iz slovenskega dela Tržaškega zaliva. 11 vrst, izpisanih krepko, je bilo najdenih tekom pričujoče raziskave v cirkalitoralnem pasu. Taksoni, označeni z *, se beležijo kot nove najdbe.***

| Taxa | Synonyms and records |
|---|---|
| *Amphiroa kuetzingiana* Trevisan | **as *Amphiroa verruculosa* Kützing**: Trieste: Giaccone, 1978: Slovenia: Vukovič, 1984. North Adriatic - Rovinj: Giaccone, 1978. |
| *Amphiroa rigida* J.V.Lamouroux | Trieste: Giaccone, 1978; Bressan *et al.*, 2000. Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980; Turk & Vukovič, 1994. North Adriatic: Rovinj: Giaccone, 1978; Munda, 1979; Gulf of Kvarner: Giaccone, 1978. |
| *Boreolithon van-heurckii* (Heydrich) A.S.Harvey & Woelkerling | **as *Melobesia van-heurckii*** (Heydrich) Cabioch: Trieste: Giaccone, 1978; Slovenia: Vukovič, 1980, 1984. |
| *Choreonema thuretii* (Bornet) F.Schmitz | Trieste: Giaccone, 1978; Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980. Adriatic: Bressan, 1974; North Adriatic- Gulf of Kvarner: Giaccone, 1978. |
| *Corallina officinalis* Linnaeus | **as *Corallina officinalis* Linnaeus**: Gulf of Trieste: Giaccone & Pignatti, 1967; Pignatti & Giaccone, 1967; Giaccone, 1970; Bressan, 1974; Giaccone, 1978; Franzosini *et al.*, 1983/84; Franzosini & Bressan, 1988; Bressan *et al.*, 1991; Bussani & Vukovič, 1992; Bressan *et al.*, 2000; Falace, 2000; Falace *et al.*, 2005; Slovenia: Avčin *et al.*, 1973; Matjašič *et al.*, 1975; Vukovič, 1980; Turk & Vukovič, 1994. North Adriatic - Rovinj: Giaccone, 1978; Munda, 1979; Gulf of Kvarner: Giaccone, 1978. **As *Corallina officinalis* var. *flabellifera* Schiffner:** Slovenia: Vukovič, 1980, 1984; Turk & Vukovič, 1994; Munda, 1991. |
| *Fosliella farinosa* f. *solmsiana* (Falkenberg) Foslie | Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980, 1982a. |
| *Haliptilon virgatum* (Zanardini) Garbary & H.W.Johansen | **as *Corallina granifera* J.Ellis & Solander**: Trieste: Giaccone, 1978; Bressan *et al.*, 1991; Falace, 2000; Falace *et al.*, 2005. Slovenia: Avčin *et al.*, 1973; Matjašič *et al.*, 1975; Vukovič, 1980, 1982b; Vrišer *et al.*, 1981; Turk & Vukovič, 1994. |
| *** *Hydrolithon boreale* (Foslie) Y.M.Chamberlain** | Trieste: Falace, 2000; Bressan *et al.*, 2006. North Adriatic - Rijeka: Zavodnik & Zavodnik, 1992. |
| *Hydrolithon farinosum* (J.V.Lamouroux) D.Penrose & Y.M.Chamberlain | **as *Hydrolithon farinosum* (J.V.Lamouroux) D.Penrose & Y.M.Chamberlain:** Trieste: Falace, 2000; Bressan *et al.*, 2006. Slovenia: Orlando & Bressan, 1998. **as *Fosliella farinosa* (J.V.Lamouroux) M.A.Howe:** Trieste: Bressan, 1974; Bressan *et al.*, 1977; Giaccone, 1978; Franzosini *et al.*, 1983/84. Slovenia: Avčin *et al.*, 1973, 1974; Matjašič *et al.*, 1975; Vukovič, 1980, 1982a. North Adriatic: - Gulf of Venezia - Rovinj - Gulf of Kvarner: Giaccone, 1978. **as *Melobesia farinosa* J.V.Lamouroux:** Trieste: Schiffner (1916); Giaccone & Pignatti, 1967; Pignatti & Giaccone, 1967; Giaccone, 1970. |
| *Hydrolithon cruciatum* (Bressan) Y.M.Chamberlain | Trieste as **Fosliella cruciata** Bressan: Bressan *et al.*, 1977; Giaccone, 1978. Slovenia: Orlando & Bressan, 1998. |
| *Jania longifurca* Zanardini | Trieste: Giaccone, 1978; Bressan *et al.*, 2000; Falace *et al.*, 2005. Slovenia: Matjašič *et al.*, 1975. North Adriatic - Rovinj: Giaccone, 1978. |
| *Jania rubens* (Linnaeus) J.V.Lamouroux | Trieste: Giaccone & Pignatti, 1967, 1972; Pignatti & Giaccone, 1967; Giaccone, 1970; Ghirardelli *et al.*, 1973; Giaccone, 1978; Bressan *et al.*, 1991; 2000; Falace, 2000; Falace *et al.*, 2005; Bressan *et al.*, 2006. Slovenia: Avčin *et al.*, 1973; Matjašič *et al.*, 1975; Vukovič, 1980. North Adriatic - Rovinj: Giaccone, 1978; Munda, 1979. Gulf of Kvarner: Giaccone, 1978. |
| *Lithophyllum corallinae* (P.L.Crouan & H.M.Crouan) Heydrich | Adriatic: as **Dermatolithon corallinae** (P.L.Crouan & H.M.Crouan) Foslie: Giaccone, 1978; Munda, 1979. As ***Titanoderma corallinae* (P.L.Crouan & H.M.Crouan) Woelkerling, Y.M.Chamberlain & P.C.Silva:** Slovenia: Orlando & Bressan, 1998. |

| Taxa | Synonyms and records |
|---|---|
| *Lithophyllum cystoseirae* (Hauck) Heydrich | **as *Dermatolithon cystoseirae* (Hauck) H.Huvé:** Trieste: Giaccone, 1978. Slovenia: Avčin *et al.*, 1973, Matjašič *et al.*, 1975; Vukovič, 1980, 1982a, 1982b; Turk & Vukovič, 1994. North Adriatic - Rovinj: Giaccone, 1978. **as *Dermatolithon papillosum* var. *cystoseirae* (Hauck) M.Lemoine:** Trieste: Giccone & Pignatti, 1967. **as *Titanoderma cystoseirae* (Hauck) Woelkerling, Y.M.Chamberlain & P.C.Silva:** Trieste: Bressan & Babbini, 2003. |
| *Lithophyllum decussatum* (J.Ellis & Solander) Philippi | as ***Lithophyllum decussatum* (J.Ellis & Solander) Philippi:** Slovenia: Turk & Vukovič, 1994. |
| *Lithophyllum incrustans* Philippi | Trieste: Giaccone, 1978; Franzosini & Bressan, 1988; Falace, 2000; Falace *et al.*, 2005; Bressan *et al.*, 2006. Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980; Munda 1991. North Adriatic - Rovinj: Giaccone, 1978; Munda, 1979. |
| *Lithophyllum papillosum* Zanardini | Trieste: Giaccone, 1970. **As *Goniolithon papillosum* (Zanardini ex Hauck) Foslie:** Slovenia: Vukovič, 1984. North Adriatic - Rovinj: Giaccone, 1978. |
| ***Lithophyllum pustulatum* (J.V.Lamouroux) Foslie** | Trieste: Pignatti & Giaccone, 1967; Curiel *et al.*, 2000-2001; Gordini *et al.*, in press. **As *Dermatolithon hapalidiodes* (P.L.Crouan & H.M.Crouan) Foslie:** Trieste: Giaccone & Pignatti, 1967; Pignatti & Giaccone, 1967; Giaccone, 1970, 1978; Franzosini *et al.*, 1983/84; Franzosini & Bressan, 1988; Falace & Bressan, 1990, 1994. Slovenia: Avčin *et al.*, 1979. North Adriatic - Rovinj: Giaccone, 1978. As ***Dermatolithon pustulatum* (J.V.Lamouroux) Foslie:** Trieste: Schiffner, 1916; Giaccone, 1970, 1978. North Adriatic: Rovinj - Gulf of Kvarner: Giaccone, 1978. As ***Titanoderma pustulatum* (J.V.Lamouroux) Nägeli:** Trieste: Falace & Bressan, 2002; Falace, 2000; Falace *et al.*, 2005; Bressan & Giaccone, 2005. Slovenia: Orlando & Bressan, 1998. As ***Titanoderma pustulatum* var. *canellatum* (Kützing) Y.M.Chamberlain:** Trieste: Bressan *et al.*, 2006. |
| ***Lithophyllum racemus* (Lamarck) Foslie** | Trieste: Giaccone & Pignatti, 1967; Pignatti & Giaccone, 1967; Giaccone, 1970; Giaccone, 1978; Bressan, 1988; Bussani & Vukovič, 1992; Gordini *et al.*, in press. Slovenia: Matjašič *et al.*, 1975; Avčin *et al.*, 1979; Vukovič, 1980; Turk & Vukovič, 1994. North Adriatic - Rovinj: Giaccone, 1978. |
| *Lithophyllum stictaeforme* (Areschoug) Hauck | Slovenia: Matjašič *et al.*, 1975; Avčin *et al.*, 1979; Vukovič, 1980, 1982b; Turk & Vukovič, 1994; Munda, 1991. North Adriatic: - Rovinj - Gulf of Kvarner: Giaccone, 1978. |
| *Lithothamnion corallioides* (P.L.Crouan & H.M.Crouan) P.L.Crouan & H.M.Crouan | Trieste: Bressan, 1974; Giaccone, 1978; Bressan & Nichetto, 1994; Bressan & Giaccone, 2005; Gordini *et al.*, in press; **as *Lithophyllum solutum* (Foslie) M.Lemoine:** Slovenia: Avčin *et al.*, 1979. |
| *** *Lithothamnion minervae* Basso** | Trieste: Bressan & Giaccone, 2005; Bressan *et al.*, 2006; Gordini *et al.*, in press |
| *** *Lithothamnion philippii* Foslie** | Trieste: Pignatti & Giaccone, 1967; Giaccone, 1970, 1978; Bressan & Giaccone, 2005; Gordini *et al.*, in press. North Adriatic - Rovinj: Foslie, 1905; Giaccone, 1978 |
| *** *Lithothamnion sonderi* Hauck** | Trieste: Giaccone, 1978 |
| *Melobesia membranacea* (Esper) J.V.Lamouroux | Trieste: Giaccone, 1978. Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980. **As *Epilithon membranaceum* (Esper) Heydrich:** Trieste: Schiffner, 1916; Pignatti & Giaccone, 1967; Giaccone, 1970. North Adriatic - Rovinj: Giaccone, 1978; Munda, 1979. Gulf of Kvarner: Giaccone, 1978. |
| *** *Neogoniolithon brassica-florida* (Harvey) Setchell & Mason** | Trieste: Falace, 2000. As ***Neogoniolithon notarisii* (Dufour) G.Hamel & M.Lemoine:** Trieste: Giaccone & Pignatti, 1967; Pignatti & Giaccone, 1967; Giaccone, 1970, 1978. North Adriatic - Rovinj: Giaccone, 1978. |
| ***Neogoniolithon mamillosum* (Hauck) Setchell & L.R.Mason** | Trieste: Giaccone & Pignatti, 1967; Giaccone, 1978; Gordini *et al.*, in press. Slovenia: Avčin *et al.*, 1973, 1979; Matjašič *et al.*, 1975; Vukovič, 1980. North Adriatic - Rovinj - Gulf of Kvarner: Giaccone, 1978. |

| Taxa | Synonyms and records |
|---|---|
| ***Phymatolithon lenormandii* (J.E. Areschoug) W.H.Adey** | Trieste: Giaccone, 1978; Falace, 2000; North Adriatic - Rovinj: Giaccone, 1978. **As *Lithothamnion lenormandii* (J.E.Areschoug) Foslie:** Trieste: Pignatti & Giaccone, 1967; Giaccone, 1970. Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980; Munda, 1991. |
| ***Pneophyllum confervicola* (Kützing) Y.M.Chamberlain** | Trieste: Falace, 2000; Bressan & Babbini, 2003; Gordini *et al.*, in press. **as *Fosliella minutula* (Foslie) Ganesan:** Trieste: Giaccone, 1978. Slovenia: Matjašič *et al.*, 1975; Vukovič, 1980. North Adriatic - Rovinj: Giaccone, 1978. |
| ***Pneophyllum fragile* Kutzing** | Trieste: Falace, 2000; Bressan & Babbini, 2003; Bressan *et al.*, 2006. Slovenia: Orlando & Bressan, 1998. **As *Fosliella lejolisii* (Rosanoff) M.A.Howe:** Trieste: Simonetti, 1972; Bressan *et al.*, 1977; Giaccone, 1978; Franzosini *et al.*, 1983/84. Slovenia: Vukovič, 1980, 1984. North Adriatic: - Rovinj - Gulf of Kvarner: Giaccone, 1978. **As *Melobesia lejolisii* Rosanoff:** Trieste: Giaccone & Pignatti, 1967; Pignatti & Giaccone, 1967; Giaccone, 1970; Grado: Simonetti, 1971. As ***Pneophyllum lejolisii* (Rosanoff) Y.M.Chamberlain:** Trieste: Della Valle *et al.*, 1993. |
| *Spongites fruticulosa* Kützing | as **Spongites fruticulosus**: Trieste: Bressan & Giaccone, 2005. As ***Lithothamnium fruticulosum* (Kützing) Foslie:** Trieste: Giaccone & Pignatti, 1972; Giaccone, 1978. Slovenia: Matjašič *et al.*, 1975; Avčin *et al.*, 1979; Vukovič, 1980. North Adriatic - Rovinj: Giaccone, 1978. As ***Spongites fruticulosa* f. *clavulatum* Foslie** Trieste: Giaccone, 1970; Pignatti & Giaccone, 1967; Bussani & Vukovič, 1992. |

***Lithophyllum racemus* (Lamarck) Foslie**

Basionym: *Millepora racemus* Lamarck

Type locality: Sicily

The observed plants were unattached, forming branched sub-globular spheres with branches not densely crowded (Fig. 4). Thalli measured up to 23 mm in diameter and were smaller than standard specimens (up to 80 mm). Only old tetrasporangial uniporate conceptacles immersed in the protuberances were found. Chambers, with a pronounced columella at the base (Fig. 5), had a diameter of 236–327 µm and height of 72–196 µm. Few living thalli were found only in CL1 spring sampling, whilst some not living samples were observed also in CL8.

***Lithothamnion minervae* Basso**

Type locality: Pontian Islands, Tyrrhenian Sea

Both encrusting and sub-globular thalli were found (Fig. 6). The encrusting thalli measured up to 20 mm, with short protuberances (0.5–1 mm), while rhodolits were up to 35 mm with longer protuberances (1–3 mm). Only tetrasporangial plants were found with multiporate conceptacles developing in groups at the apices of the branches. The elliptical chambers had a diameter of 248–487 µm and were 123–218 µm high. Living and not-living thalli were collected in CL1, more rarely in CL2 and CL8, where thalli without reproductive structures and with grazing signs were observed.

***Lithothamnion philippii* Foslie**

Type locality: Funafuti, Ellice Islands

The encrusting thalli were up to 5 cm in diameter and to 6 mm thick. The plant surface was flat or with small mounds, while the margin was thick. The hemispherical or conical gametangial conceptacles were raised (Fig. 7), measuring up to 1000 µm in diameter. The diameter of the chamber was 398–436 µm, and the height was 146–189 µm (Fig. 8). The multiporate conceptacles were convex or with flat roof (Fig. 9), with elliptical chamber of 60–85 µm in diameter and 55–85 µm in height. Old conceptacles were buried in thallus. Tetrasporangial plants were commonly collected in all the examined sites, while the gametangial thalli were observed only in CL2.

***Lithothamnion sonderi* Hauck**

Holotype locality: Helgoland, Germany

The encrusting thalli were thin or up to 3 mm thick, with a diameter of 3–5 cm. The plant surface was smooth, the margin entire, thin or sometimes lobed. Confluences of adjacent thalli formed small crests. The multiporate conceptacles were slightly raised (Fig. 10), with flat roof and elliptical chamber (Fig. 11) of 140–418 µm in diameter and 88–137 µm in height.

This species was observed in all the sampling sites.

***Neogoniolithon brassica-florida* (Harvey) Setchell & L. R. Mason**

Basionym: *Melobesia brassica-florida* Harvey

Type locality: Algoa Bay, Cape Province, South Africa

The plants were encrusting, with diameter up to 36 mm and thickness up to 1 mm. The surface of thalli was smooth, sometimes glossy, with margin entire and thick. Gametangial conceptacles were numerous and flask--shaped with chambers measuring 290–380 µm in diameter and 340–567 µm in height. Tetrasporangial conceptacles were uniporate, hemispherical or conical (Fig. 12). The chambers measured 330–657 µm in diameter and were 211–267 µm high. Old conceptacles were buried in thallus. Trichocytes were common.

Few samples of this species were observed only in spring sampling in CL1 and CL2 sites.

***Neogoniolithon mamillosum* (Hauck) Setchell & L. R. Mason**

Basionym: *Lithothamnion mamillosum* Hauck

The encrusting thalli were frequently mamillate (Fig. 13), reaching up to 6 cm in diameter and 0.5–0.8 mm of thickness. The margin was entire and thin. Gametangial conceptacles were raised, flask-shaped, with chambers measuring 316–540 µm in diameter and 187–370 µm in height. Tetrasporangial conceptacles were uniporate, raised, hemispherical or conical. Chambers were 269–390 µm in diameter and 100–188 µm in height. Few samples were observed in all sites, except for CL8.

***Phymatolithon lenormandii* (Areschoug) W. H. Adey**

Basionym: *Melobesia lenormandii* Areschoug

Type locality: Arromanches-les-Bains, Calvados, France

The encrusting thalli had a diameter up to 4.5 cm and thickness up to 190 µm. All the collected thalli had flat surface and entire margin, with or without orbital ridges.

Only tetrasporangial plants with multiporate conceptacles were observed (Fig. 14), slightly raised and with a flat roof. Chambers measured 135–223 µm in diameter, and 67–134 µm in height. Specimens were observed only at CL2, and one single specimen was found at CL9.

***Pneophyllum confervicola* (Kützing) Y. M. Chamberlain**

Basionym: *Phyllactidium confervicola* Kützing

Type locality: Trieste, Italy

Thalli were encrusting, orbicular or partially unconsolidated, with diameter of 12 mm and 8 µm of thickness. The surface had a mat texture and the margin was thin. Trichocytes were common (Fig. 15). Only tetra/bisporangial uniporate bubble-like conceptacles (Fig. 16) were observed, with domed chambers measuring 54–93 µm in diameter and 31–77 µm in height. Sometimes, at the base of the chambers a small *columella* was present.

***Pneophyllum fragile* Kützing**

Type locality: Mediterranean Sea

Type species (holotype) of the genus *Pneophyllum*

The encrusting thalli were orbicular with a diameter up to 6 mm and thickness up to 15 µm. The surface of the plant had a grainy texture and the margin was lobed and thin (Fig. 17). Trichocytes were common. Only tetra/bisporangial plants were observed. The elliptical conceptacles had a chambers diameter of 52–110 µm and height of 26–67 µm. It was observed in all the sampling sites, except in spring in CL1 and CL2.

## Coralline algal flora in the circalittoral zone

So far, 31 species of coralline algae have been reported in the literature for the Slovenian coast (Tab. 2). However, some of these species were observed only once (Tab. 2) and have not been detected in more recent studies, so their presence should be reinvestigated.

During the present study, the faunistic and floristic aspects of the biocoenosis of coastal detritic bottom in the circalittoral were analysed. Eleven species of coralline algae were recorded in circalittoral samples. Five of them represent a new record for the Slovenian part of the Gulf of Trieste, while they have already been recorded in the Italian part. In particular, *H. boreale* is a very common species, both as an epilith and epiphyte, mainly in the littoral but also at the '»Dosso of S. Croce«' at the depth of about 11 m (Bressan *et al.*, 2006). In the Gulf of Trieste, *P. fragile* is present as an epilith or epiphyte, in particular on *Corallina* and *Jania* species, and on seagrasses, while *L. minervae* and *L. philippii* are important coralline algae of the »Tegnùe« (Gordini *et al.*, in press). *L. minervae*, which is endemic in the Mediterranean Sea (Basso *et al.*, 2004), is commonly found in the Gulf of the Trieste as rhodolith on the detritic bottoms or as an encrusting species on rocks or shells, also near the »Dosso of Santa Croce«. Few specimens of *P. confervivola* were found only in the CL8 site, while in other parts of the Gulf of Trieste it is common as an epiphyte on algae and molluscs. *N. brassica-florida* is quite common, especially near fresh water springs as an epilith, while *L. sonderi* was rarely found (Giaccone, 1978). During the present research, *L. sonderi* was found widespread in all study sites, while *N. mamillosum* was less frequent. In the Gulf of Trieste it was found in the coralligenous of some »Tegnùe« (Gordini *et al.*, in press). These species are mentioned as important builders of coralligenous in the *»Draft Lists of coralligenous/ maërl populations and of main species to be considered by the inventory and monitoring«* of the RAC-SPA (UNEP(DEPI)/ MED WG.362/3, 2011). Never-

theless, *L. minervae* and *L. philippii,* abundant in all sampling sites, were not reported in this list even if they were previously mentioned as the main algal builders in the »Proposal of a Work Programme on Protecting the Coralligenous and other Calcareous Bio-Concretions in the Mediterranean« (UNEP(DEC)/MED WG. 308/9, 2007). These species can significantly contribute to the bioconstruction process (Bressan & Babbini, 2003; Bressan *et al.*, 2009; Giaccone *et al.*, 2009) in particular in the Northern Adriatic, where *L. minervae* represents one of the main reef forming algae on the »Tegnùe« of Chioggia (Fava *et al.*, 2008; Ponti *et al.*, 2011). Moreover, *L. philippii* seems to be one of the most important building species on the »Tegnùe« in the Gulf of Trieste (Gordini *et al.,* in press) and in the Gulf of Venice (ARPAV-MSN Venezia, 2008).

In the biocoenosis of the coastal detritic bottom (sites CL1 and CL2) the encrusting forms prevailed in autumn, while in spring a conspicuous presence of prâline rhodoliths (sensu Basso, 1998) was observed. The site CL9 revealed a similar algal composition, but with a greater abundance of *L. minervae* subfossil thalli. The endemic Mediterranean *L. racemus* is particularly frequent under constant and important current action (Basso, 1996). Few living thalli were found only in sites CL1 and CL2, while fossil thalli were abundant in site CL8 (on the *Cladocora caespitosa* bank). These observations seem to indicate that the rhodolith forming species *L. racemus* and *L. minervae* are occasionally forced to the Slovenian shore by currents from the central-western area of the Gulf of Trieste where these species are common (Orel *et al.*, 81/82; Bressan & Giaccone, 2005; Bressan *et al.*, 2006).

### Banks of stony corals

The site located off Cape Ronek (CL8) is characterised by the presence of the Mediterranean Stony coral reef with dead basal colonies and fossil rhodoliths, as well as encrusting thalli. To our knowledge, such habitat types are not common in the studied area nor were they in the past. Banks of *C. caespitosa* are not frequent in the rest of the Mediterranean Sea either, since they are reported only in the Ligurian Sea (Morri *et al.*, 1994), the Adriatic Sea (Kružić & Požar-Domac, 2003) and the Aegean Sea (Kühlmann, 1996). Seven coralline algal species were found in such bioconcretions. However, the number of studied samples is rather small, so that the number of the recorded species could probably increase following new planned surveys in the studied area.

It seems that the Mediterranean stony coral is undergoing a rapid decrease in both size and spatial distribution in the Mediterranean Sea (Morri *et al.*, 2001); hence it would be of great importance to study and analyse biological and ecological aspects of such banks in the Slovenian part in order to establish possible measures of protection as well. We also believe that the bank of the Mediterranean stony coral of the northern Adriatic offers possibilities for new records of coralline algae.

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## PRISPEVEK K POZNAVANJU RAZŠIRJENOSTI KORALIGENIH ALG V SLOVENSKEM CIRKALITORALNEM PASU (SEVERNI JADRAN)

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*POVZETEK*

*Avtorji poročajo o novih najdbah koraligenske flore alg za Slovenijo, pridobljenih v slovenskem delu Tržaškega zaliva tekom recentnih vzorčevanj nekaterih posebnih habitatnih tipov, kot so biocenoza obrežnega detritnega dna, biokonkrecije iz koraligenih alg znane pod imenom »trezze« oziroma »tegnue« in koralnega grebena sredozemske kamene korale* Cladocora caespitosa. *Izmed teh je bilo pet vrst prvič ugotovljenih za slovenski del Tržaškega zaliva, in sicer vrste* Hydrolithon boreale, Lithothamnion minervae, L. philippii, L. sonderi *in* Neogoniolithon brassica-florida.

**Ključne besede:** koraligene alge, cirkalitoral, *Cladocora caespitosa*, severni Jadran, Slovenija

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***PLATE 1 / TABLA 1***

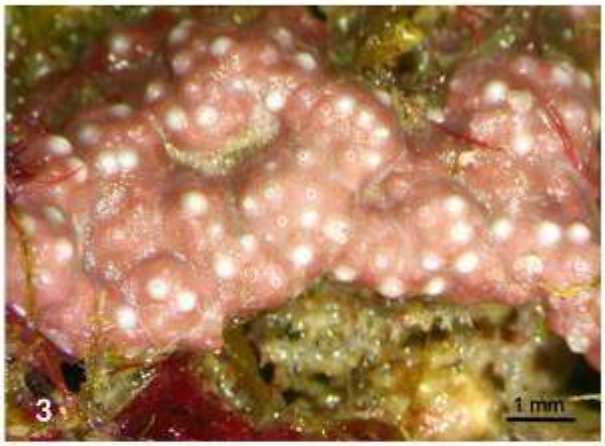
***Fig. 2:*** *Hydrolithon boreale.*
***Sl. 2:*** *Hydrolithon boreale.*
***Fig. 3:*** *Lithophyllum pustulatum* ***(uniporate sporangial conceptacles).***
***Sl. 3:*** *Lithophyllum pustulatum* ***(enoporni konceptakli na sporangijih).***
***Fig. 4:*** *Lithophyllum racemus.*
***Sl. 4:*** *Lithophyllum racemus.*
***Fig. 5:*** *Lithophyllum racemus* ***(conceptacle chamber with columella).***
***Sl. 5:*** *Lithophyllum racemus* ***(komora konceptakla z kolumelo).***
***Fig. 6: Free-living plant of*** *Lithothamnion minervae.*
***Sl. 6: Prosto živeča*** *Lithothamnion minervae.*
***Fig. 7:*** *Lithothamnion philippii* ***(gametangial conceptacle).***
***Sl. 7:*** *Lithothamnion philippii* ***(konceptakel na gametangiju).***

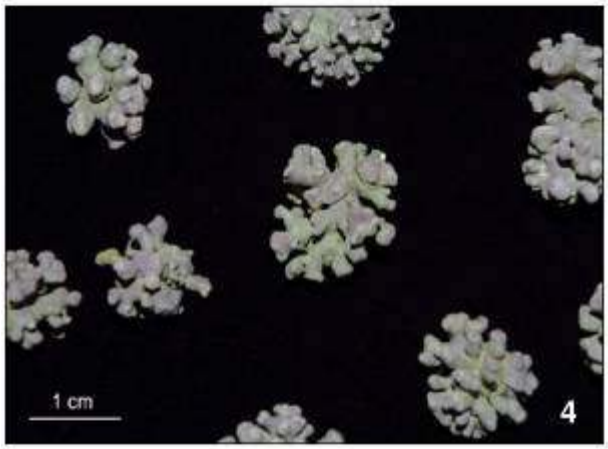
***PLATE 2 / TABLA 2***

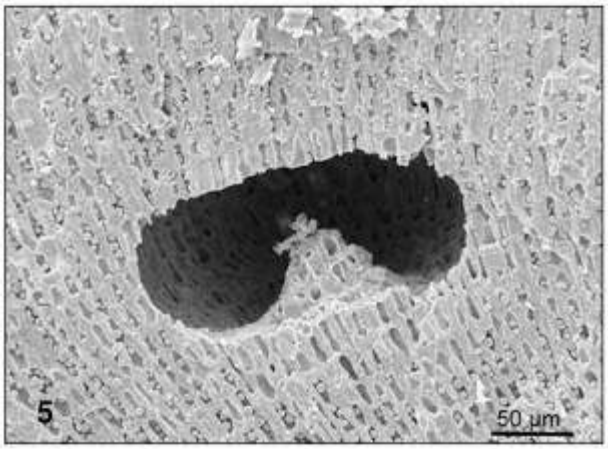
***Fig. 8:*** *Lithothamnion philippii* ***(chamber of a gametangial conceptacle).***
***Sl. 8:*** *Lithothamnion philippii* ***(komora konceptakla na gametangiju).***
***Fig. 9:*** *Lithothamnion philippii* ***(sporangial multiporate conceptacle).***
***Sl. 9:*** *Lithothamnion philippii* ***(večporni konceptakel na sporangiju).***
***Fig. 10:*** *Lithothamnion sonderi* ***(multiporate conceptacles).***
***Sl. 10:*** *Lithothamnion sonderi* ***(večporni konceptakli).***
***Fig. 11:*** *Lithothamnion sonderi* ***(sporangial conceptacle).***
***Sl. 11:*** *Lithothamnion sonderi* ***(konceptakel na sporangiju).***
***Fig. 12:*** *Neogoniolithon brassica-florida* ***(tetrasporangial conceptacles).***
***Sl. 12:*** *Neogoniolithon brassica-florida* ***(konceptakli na tetrasporangiju).***
***Fig. 13:*** *Neogoniolithon mamillosum* ***(conceptacles grouped on the protuberances).***
***Sl. 13:*** *Neogoniolithon mamillosum* ***(konceptakli združeni v izbokline).***

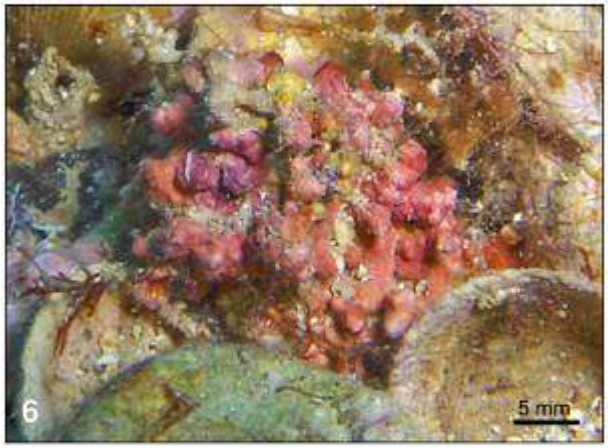
***PLATE 3 / TABLA 3***

***Fig. 14:*** *Phymatolithon lenormandii* ***(multiporate conceptacles).***
***Sl. 14:*** *Phymatolithon lenormandii* ***(večporni konceptakli).***
***Fig. 15:*** *Pneophyllum confervicola* ***(trichocytes on thallus surface).***
***Sl. 15:*** *Pneophyllum confervicola* ***(trihocite na površini stelke).***
***Fig. 16:*** *Pneophyllum confervicola* ***(sporangial plant with uniporate conceptacle).***
***Sl. 16:*** *Pneophyllum confervicola* ***(sporangij z enopornim konceptaklom).***
***Fig. 17:*** *Pneophyllum fragile.*
***Sl. 17:*** *Pneophyllum fragile.*



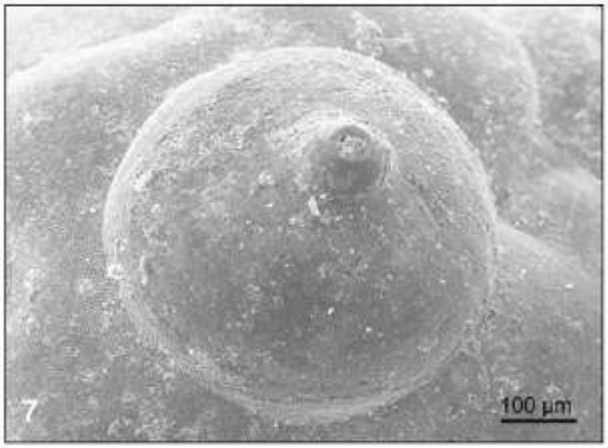
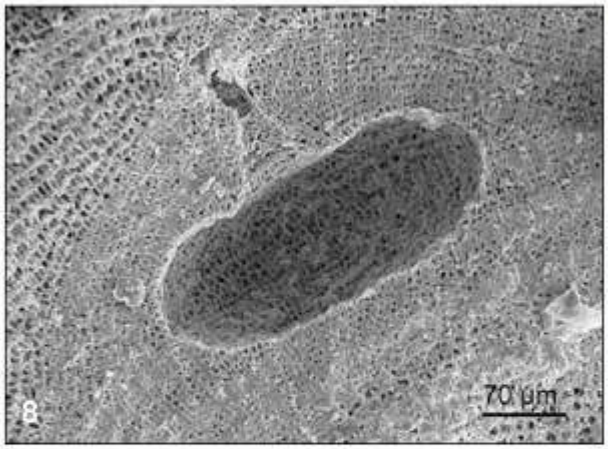
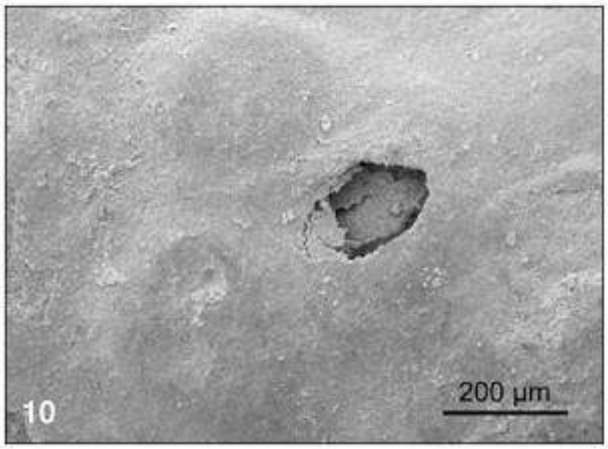
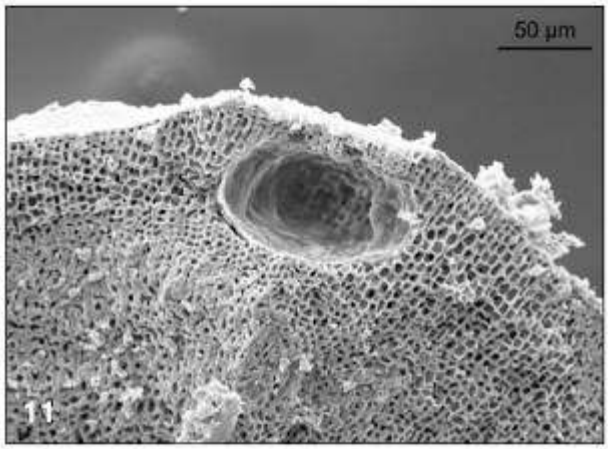




***PLATE 1 / TABLA 1***





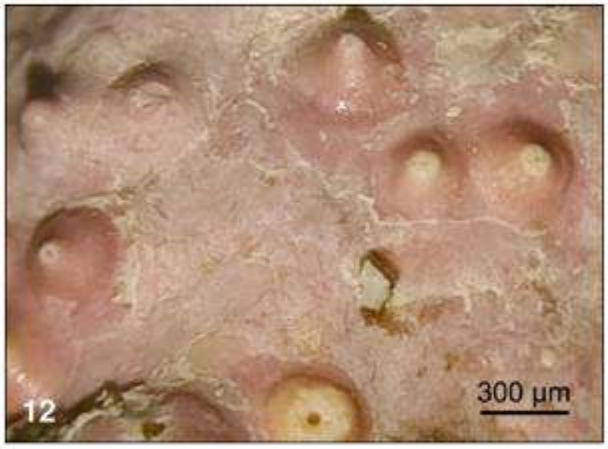
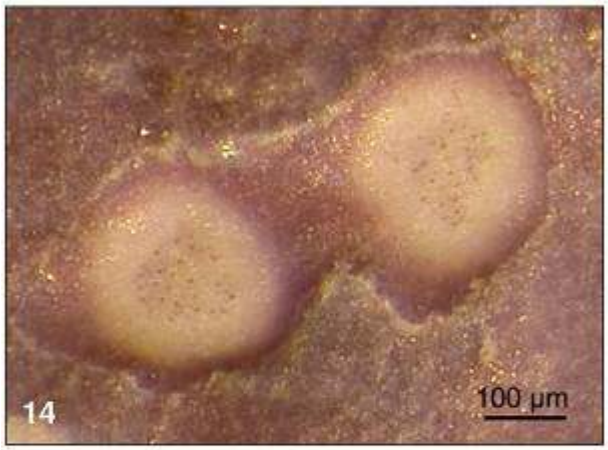
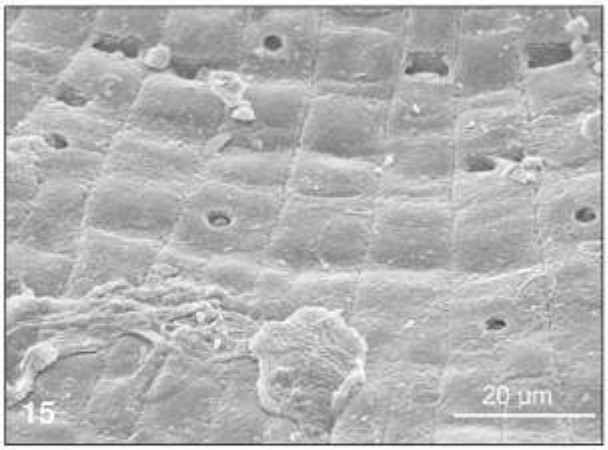
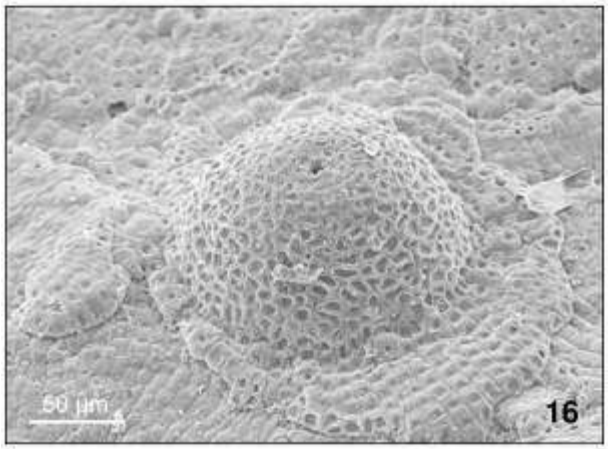



***PLATE 2 / TABLA 2***



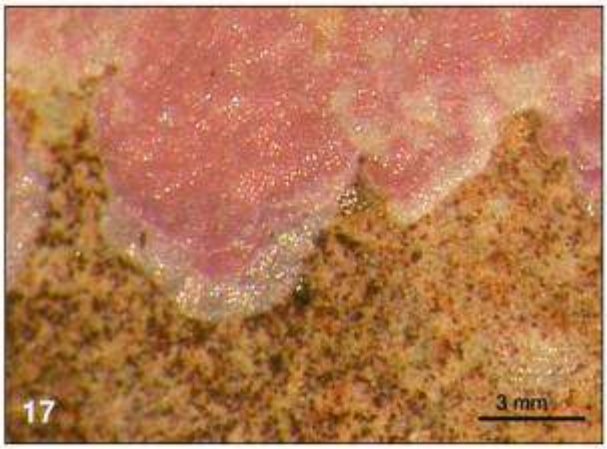




***PLATE 3 / TABLA 3***

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Daniele Curiel, Annalisa Falace*, Vinko Bandelj, Sara Kaleb, Cosimo Solidoro and Enric Ballesteros

# Species composition and spatial variability of macroalgal assemblages on biogenic reefs in the northern Adriatic Sea

**Abstract:** We sampled macroalgal assemblages on 37 rocky outcrops in the northern Adriatic over the last 2 decades by SCUBA. Macroalgal assemblages were rich (173 taxa), but there was high variability in the number of species and coverage. The morphology of the outcrops, the distance from the coast and the depth were identified as the main factors accounting for this variability. Both the mean total algal coverage (14.8%) and encrusting layer coverage (8.0%) were low when compared to typical Mediterranean coralligenous habitats. Four main groups of algal assemblages were distinguished on the basis of their species composition and coverage. Groups 1 and 3 were located inshore off the Lido inlet and south of it, and had, respectively, low or intermediate total algal cover. Group 2 included outcrops situated offshore from the Venice lagoon along with all outcrops off the Grado-Marano lagoon; these had the highest total algal cover. Finally, group 4 included assemblages comprising algae that were widespread on outcrops in the inshore habitats of the Venice lagoon, between Malamocco and Chioggia inlets. Offshore outcrops subject to low turbidity and eutrophication levels had several characteristic Mediterranean coralligenous taxa.

**Keywords:** coralligenous assemblages; macroalgae; Mediterranean; Northern Adriatic Sea; rocky outcrops.

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## Introduction

Coralline algal bioconstructions constitute key habitats in the complex mosaic of Mediterranean biodiversity; among them, coralligenous assemblages are the most widespread and are considered an important hot spot of biodiversity (Ballesteros 2006). Coralligenous reefs can be defined as a biogenic substratum produced by accumulation of both calcareous encrusting algae growing in dim light conditions and fauna (mainly bryozoans, serpulids, corals and sponges) that contribute to developing and consolidating the framework formed by the calcareous algae (Hong 1980, Ballesteros 2006). The northern Adriatic Sea is scattered with hundreds of rocky outcrops, initially interpreted as beach rocks (Braga and Stefanon 1969, Stefanon 1970, Newton and Stefanon 1975), but current knowledge suggests that they are most likely related to seeping methane and cementation and lithification processes (Colantoni et al. 1998, Stefanon and Zuppi 2000, Conti et al. 2002, Gordini et al. 2004). The assemblages developing over these structures are similar to those reported for coralligenous outcrops outside the northern Adriatic (Casellato and Stefanon 2008), but they have some striking differences that make them unique (Falace, unpublished data).

Location, depth, topography and geological structure of the northern Adriatic rocky outcrops are well known (Braga and Stefanon 1969, Newton and Stefanon 1975), as are biodiversity and spatio-temporal variability of zoobenthic assemblages (Mizzan 1992, Gabriele et al. 1999, Casellato et al. 2005, 2007, Casellato and Stefanon 2008, Ponti and Mescalchin 2008, Molin et al. 2010, Ponti et al. 2011). However, phycological studies started recently, and only partial results have been published (Curiel et al. 2001, Curiel and Molin 2010, 2010a,b, Kaleb et al. 2011, Gordini et al. 2012).

The aims of this study were (1) to broaden knowledge of species composition and structure of macroalgal assemblages growing on rocky outcrops of the northern Adriatic, (2) to investigate their spatial variability and

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(3) to search for main environmental variables and geo-morphological features that could account for the observed variability.

## Materials and methods

### Study area

The rocky outcrops studied are located in the northern Adriatic Sea in an area extending from the Gulf of Venice to the Gulf of Trieste, in the proximity of the Venice and the Grado-Marano lagoons (45°13′–45°39′ N; 12°20′–13°28′ E). The reefs have a rocky base (local calcareous sediments cemented by seeping methane, Stefanon and Zuppi 2000) that hosts the growth of calcareous bio-concretions. These reefs are surrounded by sedimentary bottoms (Trincardi et al. 1994) in which the sandy fraction prevails in offshore locations, with mud and clay dominant in the inshore localities. The distance from the coast is 0.5 to 21 km and depths range from 7 to 25 m (Figure 1, Table 1). Dominant sea currents are driven by cyclonic geostrophic circulation (Artegiani et al. 1997a,b, Solidoro et al. 2009). Strong seasonal halocline and thermocline are present, and the light is estimated to be 1%–2% of the mean surface irradiance (Franco 1984, Bernardi-Aubry et al. 2004) at all depth ranges.

The morphology of northern Adriatic rocky outcrops may be classified as "banks with more or less horizontal substrata" (*sensu* Pérès and Picard 1964, Laborel 1987), and their dimensions vary from 1–2 m² to 1000 m² (Casellato and Stefanon 2008). Their extent and morphology are very diverse, but may be categorized into three basic typologies: i) type 1: widespread rocks with low relief (0.5–1 m); ii) type 2: clustered rocks with low relief (0.5–1 m); iii) type 3: wide structures, with relief up to 3–4 m (Table 1).

### Sampling and laboratory analyses

We collated and re-analyzed the data collected over approximately 15 years on 37 rocky outcrops (Figure 1, Table 1), and partial results have been published (Curiel et al. 2001, 2010a,b, Curiel and Molin 2010, Falace et al. 2010a,b, Gordini et al. 2012). Samples were collected in spring through early summer on the upper horizontal surfaces of the outcrops by scraping and collecting all macroalgae with a vacuum lift on three randomly selected quadrats of 2500 cm². Species compositions and coverage (Boudouresque 1971) were determined in the laboratory. When possible, all the macroalgae were identified to specific or lower levels using the most recent taxonomic literature. For species with insignificant

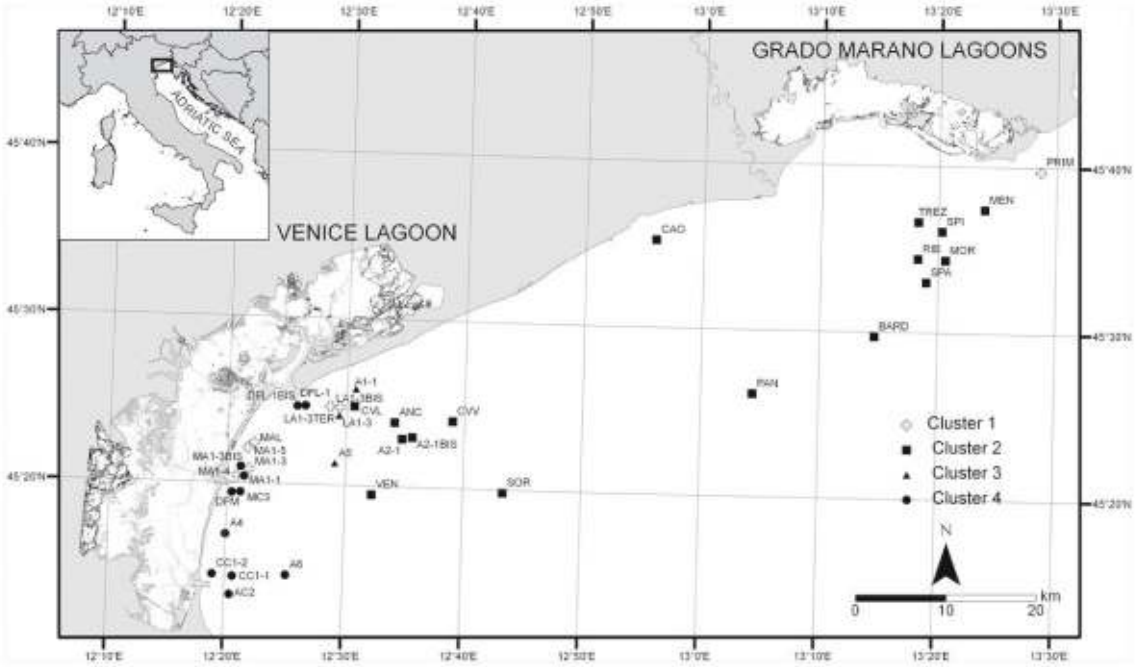


**Figure 1** Geographical distribution of the rocky outcrops sampled. Different symbols correspond to clusters obtained in Figure 3.

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| Site | Morphology (type) | Depth (m) | Distance to coast (km) | Site | Morphology (type) | Depth (m) | Distance to coast (km) |
|---|---|---|---|---|---|---|---|
| A1-1 | 3 | 14 | 3 | LA1-3TER | 3 | 14 | 3.9 |
| A2-1 | 2 | 19 | 9.7 | MA1-1 | 1 | 10 | 1 |
| A2-1BIS | 2 | 19 | 9.8 | MA1-3 | 2 | 10 | 1.9 |
| A4 | 2 | 10 | 1.9 | MA1-3BIS | 2 | 10 | 1.9 |
| A5 | 1 | 17 | 8.5 | MA1-4 | 1 | 8 | 1 |
| A6 | 1 | 20 | 8.3 | MA1-5 | 1 | 7 | 1.4 |
| AC2 | 1 | 15 | 2.2 | MAL | 1 | 9 | 1.7 |
| ANC | 3 | 18 | 7.5 | MC3 | 1 | 12 | 1 |
| BARD | 3 | 19 | 19 | MEN | 1 | 14 | 4.8 |
| CAO | 2 | 10 | 2.8 | MOR | 3 | 19 | 10.9 |
| CC1-1 | 1 | 16 | 1.2 | PAN | 3 | 25 | 21.2 |
| CC1-2 | 1 | 9 | 2.5 | PRIM | 3 | 10 | 2.5 |
| CVL | 3 | 20 | 9.9 | RIB | 2 | 21 | 11.5 |
| CVV | 3 | 15 | 4.3 | SPI | 3 | 15 | 7.4 |
| DFL-1 | 1 | 10 | 0.5 | SOR | 3 | 22 | 19.3 |
| DFL-1BIS | 1 | 10 | 0.5 | SPA | 3 | 19 | 13.8 |
| DFM | 1 | 9 | 0.7 | TREZ | 2 | 13 | 7.6 |
| LA1-3 | 3 | 14 | 3.9 | VEN | 2 | 20 | 13.3 |
| LA1-3BIS | 3 | 14 | 3.9 | | | | |

**Table 1** Rocky outcrops morphology and main environmental variables.
See Figure 1 for locations of sites. Morphology categories: type 1, widespread rocks with low relief (0.5–1 m); type 2, clustered rocks with low relief (0.5–1 m); type 3, wide structures with relief up to 3–4 m.

abundances, a nominal coverage value of 0.01% was assigned.

The number of species, total algal coverage, Shannon index, coverages of encrusting, turf and erect algae and coverages of Chlorophyta, Rhodophyta and Ochrophyta (Phaeophyceae) were estimated for every sample, and relationships of these parameters and environmental variables, such as type of substratum, depth and distance from the coast, were evaluated by non-parametric Spearman rank order correlations.

Ordination and cluster analysis were performed to explore the variability of macroalgal assemblages between the different outcrops and identify discrete groups of samples with similar species composition and abundances. We used a two-step procedure based on self-organizing maps (SOMs), a neural network, unsupervised, iterative numerical algorithm (Kohonen 2001) for non-linear projection and ordination of multidimensional data onto a lower dimensional (usually 2D) lattice made by map units, to which model vectors are associated. Based on their multi-dimensional similarity, original data are projected on the map units so that similar data are grouped in the same or neighboring map units. Model vectors of map units may be further analyzed by classical hierarchical or partitive clustering methods (Solidoro et al. 2007a, Bandelj et al. 2008) to obtain a smaller number of easily described clusters. For the clustering of map units, we used the Ward's minimum variance method (Legendre and Legendre 1998). SOM has already been successfully applied in other ecological studies (Lek and Guégan 1999, Giraudel and Lek 2001, Park et al. 2004, Bandelj et al. 2008). The original algal cover data were first transformed by $\chi^2$ metric transformation (Legendre and Gallagher 2001) to prevent the "double zero" problem (Legendre and Legendre 1998) and to give higher weight to rare species. The transformed data were then analyzed with the SOM Toolbox for Matlab routines. The SIMPER test (Clarke 1993) was used to determine species responsible for multivariate patterns.

## Results

A total of 173 macroalgal taxa were collected and identified, of which 124 were Rhodophyta, 25 Ochrophyta and 24 Chlorophyta (Appendix I). The species richness per sample was 25.6±17.0 (±SD), with a minimum of six taxa (LA1 3 BIS) and a maximum of 97 taxa (SPI) per sample (Table 2). The mean macroalgal coverage was 14.8%±29.2%, with the lowest values found on the outcrops close to the Venice lagoon and the highest on the outcrop SPI offshore the Gulf of Trieste (Table 2).

Rhodophyta were the most frequent and abundant taxa (Figure 2A, Table 2), although a high variability was

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| | Number of species | Coverage (%) | H' | Encrusting (cover %) | Erect (cover %) | Turf (cover %) | Chlorophyta (cover %) | Ochrophyta (cover %) | Rhodophyta (cover %) |
|---|---|---|---|---|---|---|---|---|---|
| A1-1 | 21 | 1.9 | 1.7 | 0.5 | 1.2 | 0.2 | 0.0 | 0.0 | 1.8 |
| A2-1 | 33 | 4.4 | 1.3 | 3.9 | 0.2 | 0.3 | 0.0 | 0.2 | 4.2 |
| A2-1BIS | 32 | 5.6 | 1.3 | 4.7 | 0.1 | 0.8 | 0.0 | 0.2 | 5.4 |
| A4 | 16 | 2.0 | 0.9 | 0.0 | 1.9 | 0.1 | 0.5 | 0.0 | 1.5 |
| A5 | 8 | 0.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| A6 | 11 | 4.4 | 0.2 | 0.1 | 4.3 | 0.1 | 4.3 | 0.0 | 0.1 |
| AC2 | 23 | 6.0 | 0.4 | 0.0 | 5.9 | 0.1 | 5.5 | 0.3 | 0.2 |
| ANC | 38 | 2.1 | 1.6 | 1.9 | 0.1 | 0.1 | 0.0 | 0.0 | 2.0 |
| BARD | 61 | 100.8 | 2.4 | 82.9 | 14.4 | 3.4 | 3.2 | 15.9 | 81.7 |
| CAO | 39 | 4.1 | 1.8 | 1.3 | 2.7 | 0.1 | 0.0 | 0.3 | 3.9 |
| CC1-1 | 12 | 4.5 | 0.7 | 0.0 | 4.3 | 0.2 | 3.8 | 0.3 | 0.5 |
| CC1-2 | 20 | 9.5 | 1.4 | 0.0 | 5.0 | 4.5 | 4.2 | 0.2 | 5.1 |
| CVL | 18 | 1.1 | 1.7 | 0.9 | 0.2 | 0.1 | 0.0 | 0.0 | 1.1 |
| CVV | 18 | 0.6 | 1.6 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 |
| DFL-1 | 42 | 3.0 | 1.8 | 0.0 | 2.3 | 0.7 | 2.1 | 0.1 | 0.9 |
| DFL-1BIS | 27 | 2.9 | 1.3 | 0.0 | 2.3 | 0.6 | 2.2 | 0.1 | 0.7 |
| DFM | 37 | 24.5 | 1.8 | 0.0 | 19.3 | 5.2 | 13.3 | 4.4 | 6.8 |
| LA1-3 | 21 | 0.4 | 2.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.4 |
| LA1-3BIS | 6 | 0.1 | 1.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| LA1-3TER | 8 | 0.2 | 1.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 |
| MA1-1 | 35 | 10.2 | 1.6 | 0.2 | 8.6 | 1.5 | 3.0 | 0.1 | 7.2 |
| MA1-3 | 31 | 12.2 | 1.4 | 0.2 | 11.2 | 0.9 | 2.4 | 0.0 | 9.8 |
| MA1-3BIS | 27 | 4.6 | 2.2 | 0.0 | 2.1 | 2.4 | 0.7 | 0.0 | 3.8 |
| MA1-4 | 22 | 4.0 | 1.5 | 0.1 | 2.4 | 1.5 | 0.2 | 0.0 | 3.8 |
| MA1-5 | 36 | 9.2 | 1.7 | 0.2 | 6.5 | 2.5 | 0.3 | 0.0 | 8.9 |
| MAL | 13 | 2.5 | 1.4 | 0.0 | 1.5 | 1.1 | 0.0 | 0.0 | 2.5 |
| MC3 | 22 | 7.3 | 1.3 | 0.0 | 3.7 | 3.6 | 6.2 | 0.2 | 0.9 |
| MEN | 7 | 11.1 | 0.6 | 10.6 | 0.0 | 0.5 | 0.0 | 0.0 | 11.1 |
| MOR | 12 | 14.4 | 0.5 | 14.2 | 0.2 | 0.1 | 0.1 | 0.2 | 14.1 |
| PAN | 17 | 34.6 | 1.9 | 30.6 | 2.7 | 1.3 | 0.2 | 0.9 | 33.5 |
| PRIM | 21 | 3.7 | 1.4 | 0.2 | 0.6 | 2.9 | 0.0 | 0.0 | 3.7 |
| RIB | 16 | 53.0 | 1.4 | 49.0 | 0.5 | 3.6 | 0.0 | 1.7 | 51.4 |
| SPI | 97 | 147.9 | 3.0 | 70.7 | 48.4 | 28.9 | 17.8 | 46.3 | 83.8 |
| SOR | 35 | 3.3 | 1.6 | 3.2 | 0.0 | 0.1 | 0.0 | 0.1 | 3.1 |
| SPA | 22 | 21.3 | 1.9 | 13.6 | 0.3 | 7.4 | 1.8 | 0.2 | 19.3 |
| TREZ | 14 | 16.1 | 1.8 | 5.9 | 0.8 | 9.5 | 0.3 | 0.0 | 15.8 |
| VEN | 13 | 1.4 | 1.6 | 1.3 | 0.0 | 0.0 | 0.0 | 0.4 | 0.9 |
| Min | 6 | 0.04 | 0.2 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.04 |
| Max | 97 | 147.9 | 3.0 | 82.9 | 48.4 | 28.9 | 17.8 | 46.3 | 83.8 |
| Mean±SD | 25.6±17.0 | 14.8±29.2 | 1.5±0.5 | 8.2±19.3 | 4.2±8.6 | 2.3±5.0 | 2.0±3.8 | 2.0±8.0 | 10.8±20.2 |

**Table 2** Number of species per sample, total percentage coverage, Shannon diversity, coverage of encrusting, erect and turf algae and coverage of green, brown and red algae at each of the sampling stations.
Data are averages of three replicates. See Table 1 and Figure 1 for sampling sites.

detected, with the Rhodophyta ranging from 50% to 100% of total taxa from each outcrop, the Chlorophyta from 0% to 33% and the Ochrophyta from 0% to 19%. Rhodophyta had a mean coverage of 10.8%±20.2%, the Ochrophyta of 2%±8.0% and the Chlorophyta of 2%±3.8% (Table 2). The coverage by phylum also varied greatly among the outcrops, ranging from 0% to 84% of the total coverage for the Rhodophyta, from 0% to 18% for the Chlorophyta and from 0% to 46% for the Ochrophyta (Table 2). The more abundant taxa were coralline algae and Peyssonneliaceae (*Peyssonnelia dubyi*, *P. harveyana*, *P. polymorpha*, *P. rosa-marina*, *P. squamaria*, *Lithothamnion philippii* and *Lithophyllum pustulatum*) and foliose Rhodophyta (*Rhodymenia ardissonei* and *Cryptonemia lomation*). Amongst the Ochrophyta and Chlorophya *Zanardinia typus* and *Ulva laetevirens* were, respectively, the most abundant species.

The number of turf algae (13.4±9.0 taxa) was higher than the encrusting (6.4±5.6 taxa) and the erect ones

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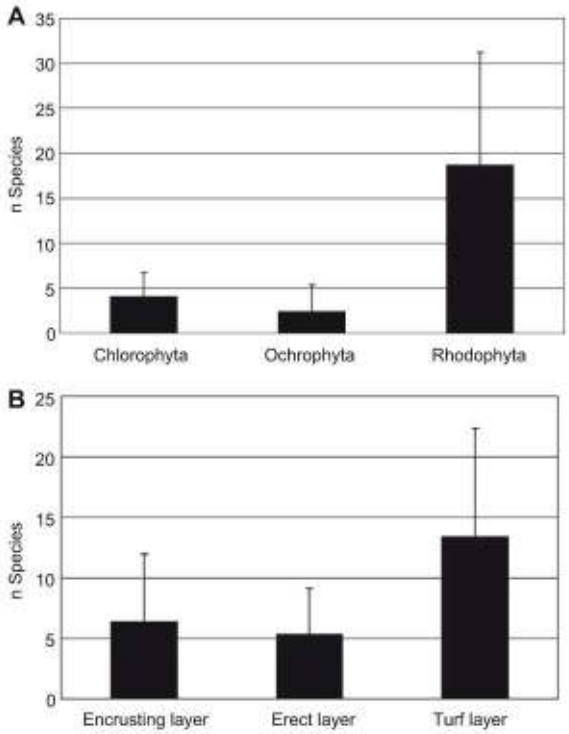


**Figure 2** (A, B) Total number of taxa in each algal phylum (A) and each vegetation stratum (means+SD, n=3). n, number.

(5.4±3.8 taxa) (Figure 2B). Different results were obtained considering the mean coverage values: 8.2%±19.3% for encrusting algae, which prevailed over the erect (4.2%±8.6%) and turf algae (2.3%±5.0%) (Table 2).

Type 1 outcrops had high coverage of Chlorophyta and erect algae, low values of the Shannon index and low coverage of encrusting algae (Table 3). In contrast, outcrops of type 3 had high values of Shannon index and high coverage of encrusting algae, but low values of Chlorophyta coverage. Moreover, type 1 outcrops were mostly situated in shallow waters near the coast, whereas type 3 outcrops were located in the deeper offshore waters. Depth was negatively correlated with erect algal coverage, but positively correlated with encrusting algal coverage. Distance from coast, which is well correlated with depth (R=0.86, $p<0.05$), had the same correlation pattern, plus a significant negative correlation with Chlorophyta coverage.

The SOM non-linear ordination analysis resulted in a map of 5×6 units (Figure 3). A partitioning into four clusters was identified as most appropriate for further considerations based on visual inspection of sample ordinations on the map and on the levels of diversity between clusters in the dendrogram (Figure 1), taking into account similarity percentage (SIMPER) analysis of species abundances (Table 4).

First, the outcrops were divided between those on the right part of the SOM (clusters 2 and 4), where the majority of the sampling sites are projected, and those on the left part of the SOM, with fewer outcrops (clusters 1 and 3). The outcrops of clusters 1 and 3, mainly substratum type 1 and type 3, had a restricted number of significant taxa: the encrusting *Peyssonnelia* sp. in cluster 3 and *Aglaothamnion tenuissimum*, *A. tripinnatum* and *Rhodophyllis divaricata* in cluster 1 (Table 4). The species defining cluster 3 are common in northern Adriatic shallow rocky outcrops, both over natural and artificial substrata. Cluster 3 grouped only three rocky outcrops at intermediate distances (mean 4 km) off the Lido inlet (Figure 1) at a mean depth of 14 m; these are characterized by very low total algal cover (Figure 4). Cluster 1 comprised outcrops located near to shore (mean distance from coast 1.9 km) off the Lido inlet and south of it, with the exception of PRIM off the Grado-Marano lagoon (Gulf of Trieste) (Figure 1). Outcrops in cluster 1 occurred in shallow waters (mean depth 10 m) and had intermediate values of total algal cover (mean 15%) (Figure 4).

The rocky outcrops included in cluster 2 were mainly of substratum types 2 and 3 and were largely characterized by the red algae *Peyssonnelia dubyi*, *P. harveyana*, *P. rosa-marina*, *P. squamaria*, *Lithothamnion philippii*, *Lithophyllum pustulatum* and the brown algae *Cutleria chilosa*, *Halopteris filicina* and *Sphacelaria plumula*

| | nsp | Cover | H' | Enc. | Erect | Turf | Chl | Och | Rho |
|---|---|---|---|---|---|---|---|---|---|
| Type1 | -0.04 | 0.06 | -0.34* | -0.62* | 0.37* | 0.17 | 0.41* | -0.02 | -0.25 |
| Type2 | 0.06 | 0.11 | 0.00 | 0.21 | -0.09 | 0.04 | -0.07 | 0.15 | 0.25 |
| Type3 | -0.01 | -0.16 | 0.34* | 0.43* | -0.29 | -0.21 | -0.34* | -0.12 | 0.03 |
| Depth | -0.21 | 0.05 | -0.04 | 0.56* | -0.43* | -0.31 | -0.26 | 0.31 | 0.03 |
| Dist. coast | -0.20 | 0.12 | 0.15 | 0.78* | -0.49* | -0.18 | -0.39* | 0.21 | 0.28 |

**Table 3** Non-parametric Spearman rank order correlations between site characteristics (see Table 1 for site details) and algal variables. Nsp, number of species; cover, total coverage; H', Shannon diversity index; Enc, encrusting algae; erect, erect algae; turf, turf algae; Ch, Chlorophyta; Och, Ochrophyta; Rho, Rhodophyta; dist. coast, distance to coast. Correlations marked with * are significant at $p<0.05$.

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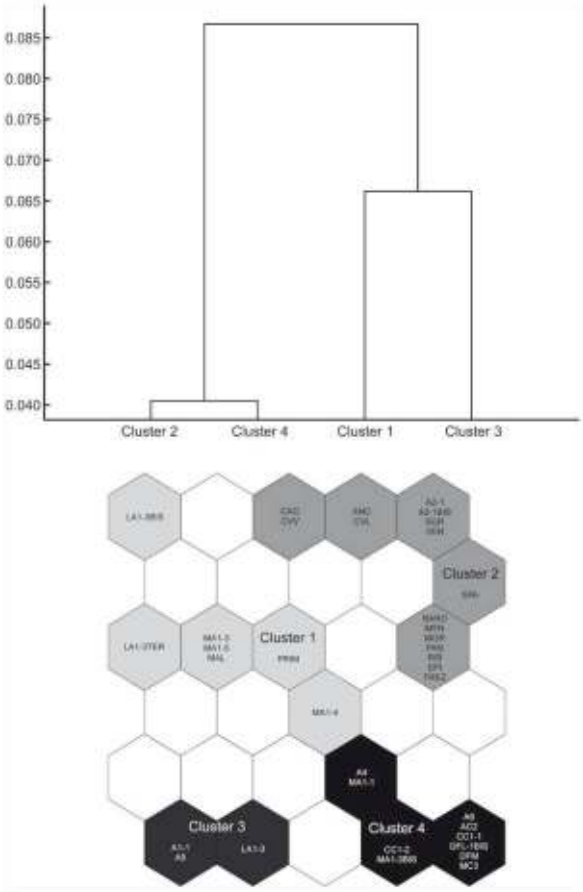


**Figure 3** Dendrogram obtained using Ward's minimum variance method of frequency (upper graphic) and self-organizing maps (SOMs) (lower graphic). For the geographical location of the stations, see Figure 1.

(Table 4). Cluster 2 grouped the rocky outcrops situated offshore (mean distance 10 km) from the Venice lagoon, along with all sampling sites off the Grado-Marano Lagoon found in deeper water (mean 19 m) (Figure 1) and characterized by the highest total algal cover (mean 33%), with some extreme values for stations BARD and SPI. In particular, these last two outcrops were characterized by a high number of taxa (61–97), total coverage (100%–148%), encrusting algae (71%–83% coverage), erect algae (15%–48% coverage), Ochrophyta (16%–4% coverage) and Rhodophyta (82%–84% coverage). Finally, cluster 4 comprised rocky outcrops characterized by algae that are widespread in the inshore habitats of the Venice lagoon, between the Malamocco and Chioggia inlets (Figure 1): the red algae *Chondria capillaris, Dasya baillouviana, D. hutchinsiae, Gracilariopsis longissima, Polysiphonia morrowii, Radicilingua reptans* and *R. thysanorhizans*, the brown alga *Dictyota dichotoma* v. *intricata* and the green algae *Ulva laetevirens* and *Chaetomorpha linum* (Table 4). Outcrops grouped in cluster 4 were mainly of substratum type 1 situated at depths of 10 m (Figure 1) at a mean distance of only 1.2 km from the shore. They had intermediate total coverages of algae (mean 19%).

## Discussion

The present number of macroalgal taxa reported for northern Adriatic rocky outcrops amounts to 190 (Solazzi and Tolomio 1981, Ponti et al. 2011, this study), with red algae being dominant, both in species number and abundance. Boudouresque (1973) reported 315 macroalgal species for deep-water macroalgal Mediterranean sciaphilic assemblages, whereas a total of 187 epiphytic macroalgal species were observed on the coralligenous assemblages off Tuscany's coasts and islands (northwestern Mediterranean Sea) (Piazzi et al. 2011). Thus, the algal assemblages growing in these Adriatic outcrops can be considered to have a high species richness. Moreover, they include a high percentage of the flora of the region as the total number of macrophytes reported for the Gulf of Trieste amounts to 220 taxa (Falace 2000). Nevertheless, the mean total algal coverage (14.8%±29.2%, with an encrusting algal cover of 80%±193%) was low when compared to values reported in coralligenous assemblages (total cover >120%, with an encrusting algal cover >90%, Piazzi et al. 2004, Ballesteros 2006). These differences are difficult to explain, but they may be attributable to the high environmental variability in the physico-chemical and trophic parameters of the water column (Stefanon and Boldrin 1982, Soresi et al. 2004, Casellato et al. 2005, Solidoro et al. 2009, Ponti et al. 2011), the reduced extension of the outcrops, the surrounding muddy sediments (AA. VV. 2010, Ponti et al. 2011) and the reduced depth at which they develop. Moreover, the particulate organic matter enhances the colonization on the rocky outcrops of filter feeders, such as sponges, tunicates, bryozoans and some polychaetes (Mizzan 1992, Gabriele et al. 1999, Casellato et al. 2005, 2007, Ponti and Mescalchin 2008, AA. VV. 2010, Ponti et al. 2011), which can outcompete macroalgae and perhaps explain the low percentage of algal cover observed. Only some encrusting species or taxa that grow attached to the substratum, such as *Peyssonnelia* spp., *Lithothamnion philippii, Lithophyllum pustulatum* and *Zanardinia typus*, attained a large coverage.

The total cover of algal taxa had great variability in relation to the morphology of the outcrops, distance from the coast, depth and geographical location. On the

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**Simper classification**

| Cluster 1 | Contr. % | Cluster 3 | Contr. % | Cluster 2 | Contr. % | Cluster 4 | Contr. % |
|---|---|---|---|---|---|---|---|
| *Cryptonemia lomation* | 21 | *Rhodymenia ardissonei* | 26 | *Rhodymenia ardissonei* | 15 | *Ulva laetevirens* | 40 |
| *Rhodophyllis divaricata* | 18 | *Peyssonnelia* sp. 1 | 26 | *Peyssonnelia harveyana* | 15 | *Radicilingua thysanorhizans* | 10 |
| *Rhodymenia ardissonei* | 16 | *Cryptonemia lomation* | 13 | *Peyssonnelia rosa-marina* | 13 | *Gracilariopsis longissima* | 10 |
| *Lithophyllum pustulatum* | 13 | *Aglaothamnion* sp. | 13 | *Lithophyllum pustulatum* | 12 | *Dictyota dichotoma v. intricata* | 9 |
| *Rhodymenia pseudopalmata* | 6 | *Lithophyllum pustulatum* | 10 | *Lithothamnion philippii* | 7 | *Chondria capillaris* | 5 |
| *Aglaothamnion tenuissimum* | 5 | *Radicilingua thysanorhizans* | 3 | *Gelidium pusillum* | 7 | *Radicilingua reptans* | 4 |
| *Aglaothamnion* sp. | 4 | | | *Cutleria chilosa* | 7 | *Chaetomorpha linum* | 4 |
| *Radicilingua thysanorhizans* | 4 | | | *Peyssonnelia dubyi* | 6 | *Rhodymenia ardissonei* | 4 |
| *Aglaothamnion tripinnatum* | 3 | | | *Sphacelaria plumula* | 2 | *Dasya hutchinsiae* | 3 |
| *Antithamnion cruciatum* | 2 | | | *Peyssonnelia squamaria* | 2 | *Nitophyllum punctatum* | 2 |
| | | | | *Cryptonemia lomation* | 1 | *Ceramium diaphanum* | 2 |
| | | | | *Radicilingua thysanorhizans* | 1 | | |
| | | | | *Peyssonnelia* sp. | 1 | | |

**Table 4** SIMPER (similarity percentage analysis) output of macroalgal classification into four clusters of rocky outcrops obtained in SOM (self-organizing map) analysis.
Contr. %, % contribution to differentiation of clusters.

inshore outcrops situated near the fluvial inflows (Po, Brenta, Piave, Tagliamento) and the Venice and Grado-Marano lagoons, the algal coverage was almost zero and the substratum was mainly covered by sediment; in contrast, rocky outcrops situated further offshore attained total algal coverages of 70%–80%. At intermediate distances from the coast, the calcified taxa of the genus *Peyssonnelia* prevailed, while offshore rocky outcrops were dominated by species of the genus *Lithophyllum* and *Lithothamnion*. This shift in species abundances is in accordance with the findings of Hong (1980), who observed that with increasing degree of disturbance, the Corallinales are replaced by the Peyssonneliaceae, which have a much lower building capacity (Sartoretto 1996). On the rocky outcrops, even where the turf-forming and filamentous algae were numerically dominant, there was always low coverage, with the exception of *Pseudochlorodesmis furcellata*. In contrast, the encrusting algae, such as *Lithophyllum incrustans, Lithothamnion minervae, L. philippii, Peyssonnelia harveyana, P. polymorpha,* and *P. rosa-marina*, had reduced coverage on the inshore rocky outcrops, but they were abundant on the offshore ones characterized by low turbidity and sedimentation. Our results are in agreement with others authors (Morganti et al. 2001, Balata et al. 2004, 2005, 2007), who described a varying structure of coralligenous assemblages and a great spatial and temporal variability between areas characterized by different water turbidity and sediment deposition. Furthermore, as we sampled only on the horizontal surfaces, rocky outcrops are not very high (up to 4 m) and are surrounded by muddy substrata, the effect of sediment deposition should be important. In fact, as observed by Balata et al. (2005, 2007), turf-forming species become abundant on high sediment deposition horizontal surfaces whereas the abundance of encrusting algae is strongly reduced as a consequence of the combined effects of low light levels, burial and scouring (Balata et al. 2007). In particular among the turf-forming species, *P. furcellata* is considered one of the most tolerant taxa in coralligenous assemblages of both sediment and nutrient enrichment (Balata et al. 2005, 2007, Piazzi et al. 2011). However, in contrast to Balata et al. (2011), we observed a high coverage of the prostrate ochrophyte *Zanardinia typus* on the inshore outcrops.

Differences between outcrops of clusters 2 and 4 could be related to water quality. Indeed, a low concentration of

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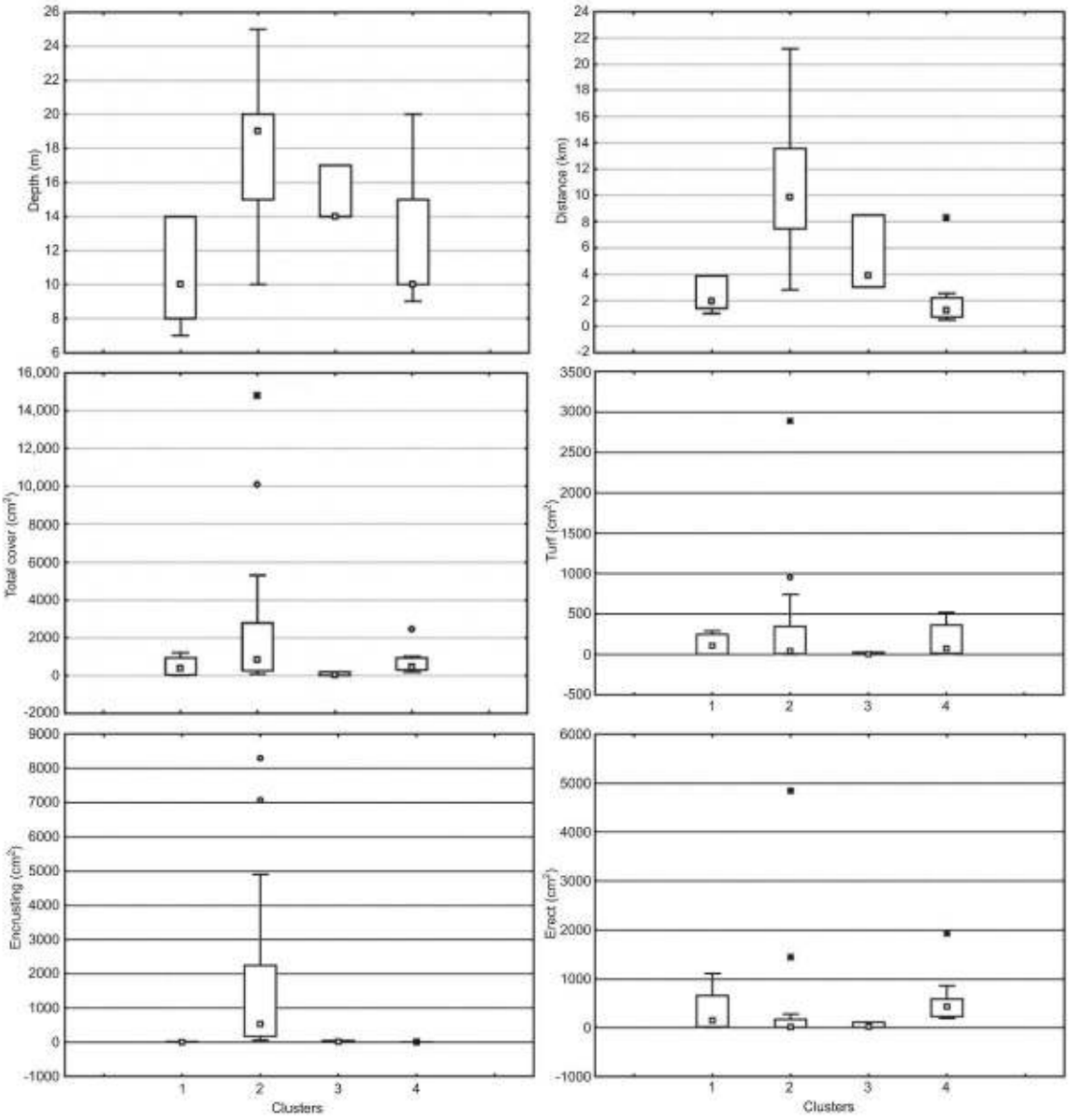


**Figure 4** Box-and-whisker plots of depth, distance from coast, total cover, covers of turf and encrusting and erect algae for the four clusters identified in self-organizing map (SOM) analysis. Boxes include the median, the inter-quartile range with the 25th and 75th percentiles; the upper and lower whiskers mark the maximum and minimum values, hollow dots the outliers and asterisks the extreme values.

inorganic nutrients and chlorophyll *a* distinguish offshore stations of cluster 2 from the others (Bernardi-Aubry et al. 2006, ARPAV 2008, Solidoro et al. 2009). Cluster 2, which includes deep and offshore rocky outcrops situated eastward of the Venice lagoon up to the Gulf of Trieste, was characterized by a high mean number of species (29.5) total coverage (26.3%) and Rhodophyta coverage (20.8%). Moreover, these rocky outcrops were characterized by taxa that are also common on typical Mediterranean coralligenous assemblages, such as *Peyssonnelia rosa-marina*, *P. harveyana*, *P. polymorpha*, *P. squamaria*, *Lithophyllum pustulatum*, *L. incrustans*, *L. racemus*, *Lithothamnion philippii*, *L. minervae*, *Mesophyllum macroblastum*, *M. alternans* and *Neogoniolithon mamillosum*. Cluster 4 grouped the shallow inshore rocky outcrops that were almost all located between the sea inlets of Malamocco and Chioggia; they were characterized by a medium-high number of taxa and a low total coverage and included

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species that are commonly found on both coastal natural and artificial hard substrata (Curiel et al. 1999, Falace 2000, Falace et al. 2010c). Cluster 1 included rocky outcrops situated between the sea inlets of Lido and Malamocco at intermediate depths and distances from the coast. These outcrops had reduced mean numbers of taxa and coverage and a prevalence of *Cryptonemia lomation*, *Rhodophyllis divaricata*, *Rhodymenia ardissonei* and *Lithophyllum pustulatum*. Finally, the three rocky outcrops that define cluster 3 bore assemblages and characteristics that were intermediate between those found in cluster 2 and clusters 1 and 4. The reduced total algal coverage, the shallow depth and the habitat preferences of algal species characterizing the assemblages included in clusters 1, 3 and 4 suggest a great influence of coastal-related pressures. Indeed, all of them are situated off the Venice lagoon, where erosion dominates over deposition processes, and there is a tendency for sediment loss (Bianchi et al. 2004, Defendi et al. 2010) through the inlets (Gačić et al. 2004). Sediment transport reaches $385\times10^3$ t year$^{-1}$ through the Lido inlet, $48\times10^3$ t year$^{-1}$ through the Malamocco inlet and $140\times10^3$ t year$^{-1}$ through the Chioggia inlet (Defendi et al. 2010). Limited transparency of water and high loads of total suspended matter in the sea inlets have also been reported (Bianchi et al. 2004), which most probably limit the development of sensitive algal taxa and, in particular, the growth of the erect algae in areas close to the inlets. A similar effect can be hypothesized for the site PRIM situated off Grado Lagoon in an area affected not only by the outflow from the lagoon, but also by the plume of the Isonzo river flowing along the northwestern coast of the Gulf of Trieste (Solidoro et al. 2007a). The mathematical models of water fluxes of the Venice lagoon (D'Alpaos and Martini 2005) stress that the long dams favor the transport of dissolved and particulate matter to the sea at several km distance, with a consequent fall out over the outcrops located at reduced or intermediate distances from the coast. Furthermore, these rocky outcrops also receive many visits from recreational fishermen and shellfish collectors, which indicates that they are often physically disturbed. The area south of the Lido inlet is also characterized by high salinity and lower nutrient concentrations and chlorophyll (Solidoro et al. 2007b), thus showing oligotrophic characteristics.

Rocky outcrops situated off the Lido inlet are very diverse, indicating that it is an area of great environmental complexity and/or strong gradients. Indeed, there is a change in algal assemblages from cluster 4 to 1, 3 and 2 going offshore (Figure 4). The complexity is most probably due to the high hydrodynamism of this area, with Venice lagoon waters mixing with currents flowing along the coast from northeast to southwest, bringing nutrient-enriched waters from the estuaries of several rivers (Piave, Livenza, Sile). The Lido inlet also concentrates the highest vessel traffic, thus possible effects of physical disturbance and species translocation on hulls or in ballast waters on structure and composition of macroalgal communities on rocky outcrops cannot be disregarded.

Little information is available in the literature on the effects of nutrient enrichment on coralligenous assemblages (Piazzi et al. 2011), and, in the northern Adriatic, the response of algal subtidal communities to nutrients should be the subject of further in-depth investigations.

Among the rocky outcrops, BARD and SPI deserve closer inspection because they were characterized by the highest number of taxa (61–97) and total coverage (100%–148%). Encrusting algal coverage (71%–83% coverage) was also high and was represented by some of the main coralligenous builders, such as such as *Mesophyllum alternans*, *Neogoniolithon mamillosum* and *Lithophyllum stictaeforme* (Falace et al. 2011, Gordini et al. 2012). On these two outcrops, we also found *Lithothamnion philippii*, *L. minervae* and *Lithophyllum pustulatum*, which significantly contribute to the bioconstruction process in these and other biogenic reefs of the northern Adriatic (Falace et al. 2010a, 2011, 2012, Gordini et al. 2012). Moreover, *Mesophyllum macroblastum*, which is characteristic of the Mediterranean coralligenous flora, was identified for the first time in the Adriatic on the SPI outcrop (Kaleb et al. 2011). Some erect algae, such as *Arthrocladia villosa*, *Cryptonemia lomation*, *Dictyota dichotoma* v. *dichotoma*, *Halymenia elongata*, *H. floresii*, *Nithophyllum punctatum*, *Rhodymenia ardissonei*, *Scinaia complanata* and *Taonia atomaria*, were also abundant. The surrounding sediments comprised sandy to muddy bottoms with maërl-forming free-living coralline algae, such as *Lithothamnion corallioides*, *Phymatolithon calcareum*, *Lithothamnion minervae* and *Lithophyllum racemus* (Falace et al. 2010a, Gordini et al. 2012). These two outcrops have recently been designated as Sites of Community Interest (SCI) for the Friuli Venezia Giulia, together with some outcrops in the area of Chioggia in Veneto, because of their high biodiversity and ecological interest (Falace et al. 2009).

Northern Adriatic rocky outcrops show striking differences from typical Mediterranean coralligenous assemblages. Articulated coralline algae are not present in northern Adriatic rocky outcrops, but the most outstanding absence is that of the green erect alga *Halimeda tuna* (J. Ellis *et* Solander) J.V. Lamouroux, one of the most significant species in Mediterranean coralligenous assemblages (Ballesteros 1991, 2006). Moreover, *Flabellia petiolata* was found only in four samples, with a very low coverage

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(<1%). *Flabellia petiolata* and *H. tuna* have been reported as species sensitive to sediment and nutrient enrichments (Balata et al. 2005, 2011), and there has been an upward migration of these two species from the lower sublittoral zone to the eulittoral zone in relation to increasing turbidity in the Gulf of Trieste (Falace 2000, Falace et al. 2010c).

None of the endangered species reported by Ballesteros (2006) were observed in our samples. In contrast, up to seven alien species (*Antithamnion hubbsii, Desmarestia viridis, Heterosiphonia japonica, Neosiphonia harveyi, Polysiphonia morrowii, Polysiphonia stricta, Solieria filiformis*) (Zenetos et al. 2010) were identified in our samples.

In summary, this contribution is the first extensive review on macroalgal assemblages on rocky outcrops in the northern Adriatic Sea. Although this whole area is subject to strong environmental (river mouths, sedimentation, exchanges with coastal lagoons) and anthropogenic pressures (overfishing, coastal eutrophication, maritime tourism and commercial traffic), these submerged rocky habitats have a high macroalgal species diversity, similar to that already observed for the macrozoobenthic assemblages. The results obtained in this study may be used as a baseline for the macroalgal assemblages of the rocky outcrops from the northern Adriatic Sea within the context of the future enforcement by the EU maritime policy of the Marine Strategy Framework Directive, which is aimed at the promotion of the sustainable use of the seas and the conservation of marine ecosystems.

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# Appendix

## Appendix I Floristic list

**Rhodophyta**

Acrochaetiaceae
*Acrochaetium microscopicum* (Nägeli ex Kützing) Nägeli
*Acrosorium ciliolatum* (Harvey) Kylin
*Aglaothamnion* sp.
*Aglaothamnion tenuissimum* (Bonnemaison) Feldmann-Mazoyer
*Aglaothamnion tripinnatum* (C. Agardh) Feldmann-Mazoyer
*Anotrichium furcellatum* (J. Agardh) Baldock
*Antithamnion cruciatum* (C. Agardh) Nägeli
*Antithamnion hubbsii* E.Y. Dawson
*Antithamnion tenuissimum (*Hauck) Schiffner
*Apoglossum ruscifolium* (Turner) J. Agardh
*Asparagopsis armata* Harvey [*Falkenbergia rufolanosa* (Harvey) F. Schmitz]
*Bangia fuscopurpurea* (Dillwyn) Lyngbye
*Botryocladia boergesenii* Feldmann
*Botryocladia botryoides* (Wulfen) Feldmann
*Botryocladia chiajeana* (Meneghini) Kylin
*Botryocladia microphysa* (Hauck) Kylin
*Callithamnion corymbosum* (Smith) Lyngbye
*Calosiphonia dalmatica* (Kützing) Bornet *et* Flahault
*Caulacanthus ustulatus* (Mertens ex Turner) Kützing
*Centroceras clavulatum (*C. Agardh) Montagne
*Ceramium ciliatum* (J. Ellis) Ducluzeau
*Ceramium cimbricum* H.E. Petersen
*Ceramium codii* (H. Richards) Feldmann-Mazoyer
*Ceramium comptum* Børgesen
*Ceramium diaphanum* (Lightfoof) Roth
*Ceramium siliquosum* (Kützing) Maggs *et* Hommersand
*Ceramium virgatum* Roth
*Champia parvula* (C. Agardh) Harvey
*Chondracanthus acicularis* (Roth) Fredericq
*Chondria capillaris* (Hudson) M.J. Wynne
*Chondria dasyphylla* (Woodward) C. Agardh
*Compsothamnion thuyoides* (Smith) Nägeli
*Crouania attenuata* (C. Agardh) J. Agardh
*Cryptonemia lomation* (Bertoloni) J. Agardh
*Dasya baillouviana* (S.G. Gmelin) Montagne
*Dasya corymbifera* J. Agardh
*Dasya hutchinsiae* Harvey
*Dudresnaya verticillata* (Withering) Le Jolis
*Erythrocladia irregularis* Rosenvinge
*Erythrotrichia carnea* (Dillwyn) J. Agardh
*Eupogodon planus* (C. Agardh) Kützing
*Gastroclonium reflexum* (Chauvin) Kützing
*Gastroclonium clavatum* (Roth) Ardissone
*Gelidiella nigrescens* (Feldmann) Feldmann *et* Hamel
*Gelidium pusillum* (Stackhouse) Le Jolis
*Gracilaria bursa-pastoris* (S.G. Gmelin) P.C. Silva
*Gracilariopsis longissima* (S.G. Gmelin) Steentoft et al.
*Griffithsia schousboei* Montagne
*Gulsonia nodulosa* (Ercegovic) Feldmann *et* G. Feldmann

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*Halymenia elongata* C. Agardh
*Halymenia floresii* (Clemente) C. Agardh
*Halymenia floresii* v. *ulvoidea* Codomier
*Herposiphonia secunda* (C. Agardh) Ambronn
*Heterosiphonia japonica* Yendo
*Hydrolithon boreale* (Foslie) Y.M. Chamberlain
*Hydrolithon farinosum* (J.V. Lam.) D. Penrose *et* Y.M. Chamberlain
*Hypnea musciformis* (Wulfen) J.V. Lamouroux
*Hypoglossum hypoglossoides* (Stackhouse) Collins *et* Hervey
*Kallymenia* sp.
*Laurencia obtusa* (Hudson) J.V. Lamouroux
*Lithophyllum corallinae* (P.L. Crouan *et* H.M. Crouan) Heydrich
*Lithophyllum cystoseirae* (Hauck) Heydrich
*Lithophyllum incrustans* Philippi
*Lithophyllum pustulatum* (J.V. Lamoroux) Foslie
*Lithophyllum racemus* (Lamarck) Foslie
*Lithophyllum stictaeforme* (J.E. Areschoug) Hauck
*Lithothamnion corallioides* (P.L. Crouan *et* H.M. Crouan) P.L. Crouan *et* H.M. Crouan
*Lithothamnion minervae* Basso
*Lithothamnion philippii* Foslie
*Lithothamnion sonderi* Hauck
*Lomentaria chylocladiella* Funk
*Lomentaria clavellosa* (Turner) Gaillon
*Lomentaria verticillata* Funk
*Melobesia membranacea* (Esper) J.V. Lamouroux
*Meredithia microphylla* (J. Agardh) J. Agardh
*Mesophyllum alternans* (Foslie) Cabioch *et* Mendoza
*Mesophyllum macroblastum* (Foslie) Adey
*Monosporus pedicellatus* (Smith) Solier
*Myriogramme minuta* Kylin
*Neogoniolithon brassica-florida* (Harvey) Setchell *et* L.R. Mason
*Neogoniolithon mamillosum* (Hauck) Setchell *et* L.R. Mason
*Neosiphonia harveyi* (J.W. Bailey) M.S. Kim, H.G. Choi, Guiry *et* G.W. Sanders
*Nitophyllum punctatum* (Stackhouse) Greville
*Palisada perforata* (Bory de Saint-Vincent) K.W. Nam
*Parviphycus tenuissimus* B. Santelices
*Peyssonnelia dubyi* P. *et* H. Crouan
*Peyssonnelia harveyana* P. *et* H. Crouan ex J. Agardh
*Peyssonnelia polymorpha* (Zanardini) F. Schmitz
*Peyssonnelia rosa-marina* Boudouresque *et* Denizot
*Peyssonnelia rubra* (Greville) J. Agardh
*Peyssonnelia squamaria* (S.G. Gmelin) Decaisne
*Phyllophora sicula* (Kützing) Guiry *et* L.M. Irvine
*Phymatolithon calcareum* (Pallas) W.H. Adey *et* D.L. McKibbin
*Phymatolithon lenormandii* (J.E. Areschoug) W.H. Adey
*Pleonosporium borreri* (Smith) Nägeli
*Plocamium cartilagineum* (Linnaeus) P.S. Dixon
*Pneophyllum confervicola* (Kützing) Y.M. Chamberlain
*Pneophyllum fragile* Kützing
*Polysiphonia denudata* (Dillwyn) Greville ex Harvey
*Polysiphonia elongata* (Hudson) Sprengel
*Polysiphonia furcellata* (C. Agardh) Harvey
*Polysiphonia morrowii* Harvey
*Polysiphonia sanguinea* (C. Agardh) Zanardini
*Polysiphonia scopulorum* Harvey
*Polysiphonia stricta* (Dillwyn) Greville
*Predaea ollivieri* Feldmann
*Pterosiphonia pennata* (C. Agardh) Sauvageau
*Pterothamnion crispum* (Ducluzeau) Nägeli
*Pterothamnion plumula* (J. Ellis) Nägeli
*Ptilothamnion pluma* (Dillwyn) Thuret
*Radicilingua reptans* (Kylin) Papenfuss
*Radicilingua thysanorhizans* (Holmes) Papenfuss
*Rhodophyllis divaricata* (Stackhouse) Papenfuss
*Rhodymenia ardissonei* (Kuntze) Feldmann
*Rhodymenia pseudopalmata* (J.V. Lamouroux) P.C. Silva
*Scinaia complanata* (F.S. Collins) A.D. Cotton
*Seirospora interrupta* (Smith) F. Schmitz
*Solieria filiformis* (Kützing) P.W. Gabrielson
*Spermothamnion repens* (Dillwyn) Rosenvinge
*Spermothamnion strictum* (C. Agardh) Ardissone
*Sphondylothamnion multifidum* (Hudson) Nägeli
*Spyridia filamentosa* (Wulfen) Harvey
*Stylonema alsidii* (Zanardini) K.M. Drew

**Ochrophyta (Phaeophyceae)**
*Arthrocladia villosa* (Hudson) Duby
*Cladosiphon zosterae* (J. Agardh) Kylin
*Cutleria chilosa* (Falkenberg) P.C.Silva
*Cutleria multifida* (Turner) Greville [*Aglaozonia parvula* (Greville) Zanardini]
*Cystoseira* sp.
*Desmarestia viridis* (O.F. Müller) J.V. Lamouroux
*Dictyopteris polypodioides* (A.P. De Candolle) J.V. Lamouroux
*Dictyota dichotoma* (Hudson) J.V. Lamouroux v. *dichotoma*
*Dictyota dichotoma* (Hudson) J.V. Lamouroux v. *intricata* (C. Agardh) Greville
*Dictyota linearis* (C. Agardh) Greville
*Dictyota spiralis* Montagne
*Ectocarpus siliculosus* (Dillwyn) Lyngbye v. *siliculosus*
*Halopteris filicina* (Grateloup) Kützing
*Hincksia ovata* (Kjellman) P.C. Silva
*Hincksia sandriana* (Zanardini) P.C. Silva
*Myriactula stellulata* (Harvey) Levring
*Myrionema orbiculare* J. Agardh
*Nereia filiformis* (J. Agardh) Zanardini

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*Spermatochnus paradoxus* (Roth) Kützing
*Sphacelaria cirrosa* (Roth) C. Agardh
*Sphacelaria plumula* Zanardini
*Sporochnus pedunculatus* (Hudson) C. Agardh
*Stilophora tenella* (Esper) P.C. Silva
*Taonia atomaria (*Woodward) J. Agardh
*Zanardinia typus* (Nardo) P. C. Silva

**Chlorophyta**
*Acrochaete viridis (*Reinke) R. Nielsen
*Acrochaete flustrae* (Reinke) O'Kelly
*Bryopsis hypnoides* J.V. Lamouroux
*Bryopsis plumosa* (Hudson) C. Agardh
*Chaetomorpha ligustica* (Kützing) Kützing
*Chaetomorpha linum* (O.F. Müller) Kützing
*Cladophora coelothrix* Kützing
*Cladophora dalmatica* Kützing
*Cladophora hutchinsiae* (Dillwyn) Kützing
*Cladophora laetevirens* (Dillwyn) Kützing
*Cladophora pellucida* (Hudson) Kützing
*Cladophora sericea* (Hudson) Kützing
*Cladophora vagabunda* (Linnaeus) C. Hoeck
*Derbesia tenuissima* (Moris *et* De Notaris) P. *et* H. Crouan
*Flabellia petiolata* (Turra) Nizamuddin
*Gayralia oxysperma* (Kützing) K.L. Vinogradova ex Scagel et al.
*Pseudochlorodesmis furcellata* (Zanardini) Børgesen
*Tellamia contorta* Batters
*Ulva flexuosa* Wulfen
*Ulva intestinalis* Linnaeus
*Ulva laetevirens* Areschoug
*Ulvella lens* P. *et* H. Crouan
*Ulvella setchellii* P.J.L. Dangeard
*Valonia utricularis* (Roth) C. Agardh

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# Morphology-anatomy of *Mesophyllum macroblastum* (Hapalidiaceae, Corallinales, Rhodophyta) in the Northern Adriatic Sea and a key to Mediterranean species of the genus

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**Abstract** – The coralline red alga *Mesophyllum* (Hapalidiaceae) is recorded for the first time from the Gulf of Trieste (Northern Adriatic Sea) and gametangial plants of *M. macroblastum* are recorded for the first time from the Mediterranean Sea. A morphological-anatomical account is provided, including comparisons with specimens from the western coast of Italy and with published data. Distribution and habitat information, comparison with Mediterranean species of *Mesophyllum*, and a dichotomous key to Mediterranean species are included along with brief comments on other species in the genus known to produce volcano-like tetrasporangial conceptacles.

**Corallinales / Hapalidiaceae / Mediterranean Sea / *Mesophyllum macroblastum* / Northern Adriatic / taxonomy**

**Résumé** – Le genre *Mesophyllum* (Hapalidiaceae), est signalé pour la première signalisation pour le Gulf de Trieste (Nord Adriatique) et un pied gamétangial de *Mesophyllum macroblastum* (Foslie) Adey est observé pour la première fois en Méditerranée. *M. macroblastum* est décrit et comparé avec des spécimens récoltés sur le littoral occidental de l'Italie. La distribution et des informations sur l'habitat, autant que la comparaison avec les espèces Méditerranéen de *Mesophyllum* sont reportées. Une clé dichotomique des espèces de *Mesophyllum* connues jusqu'au présent pour la Méditerranée est proposée avec des commentaires sur les autres espèces du genre qui produisent des conceptacles tétrasporangiaux en forme de volcan.

**Corallinales / Hapalidiaceae / Mer Méditerranée / *Mesophyllum macroblastum* / Adriatique Nord / taxonomie**

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## INTRODUCTION

All five species of the coralline red algal genus *Mesophyllum* (Hapalidiaceae, Corallinales, Rhodophyta) reported from European waters by Cabioch & Mendoza (2003) are also reported to occur in the Mediterranean Sea. *Mesophyllum expansum* (Philippi) Cabioch & Mendoza is based on a type from an unknown locality in Sicily; *M. macroblastum* (Foslie) Adey was originally described from the Gulf of Naples (Tyrrhenian Sea); *M. alternans* (Foslie) Cabioch & Mendoza is typified by a specimen from Tangiers, Morocco, and *M. macedonis* Athanasiadis is based on a type from the Aegean Sea in Greece. The fifth species, *M. lichenoides* (J. Ellis) Marie Lemoine, is epitypified with a specimen from southern England (Woelkerling & Irvine 2007). Based on data in Cabioch & Mendoza (2003) and Bressan & Babbini (2003), *M. lichenoides* is distributed throughout the Mediterranean Sea, but Athanasiadis & Neto (2010: 337, 340) suggest that its occurrence in the Mediterranean requires confirmation. *M. expansum*, *M. macroblastum* and *M. alternans* are restricted to the western Mediterranean, and *M. macedonis* is reported only from its type locality (Pidgeon Cave, near Sarti, Greece). There is no published key to Mediterranean species of *Mesophyllum*.

Within the Adriatic Sea, there are unconfirmed records of *M. macroblastum* from an unspecified locality in the central Adriatic (Ercegovic, 1980; record repeated in Babbini & Bressan 1997 and in Furnari *et al.* 1999) and near Sušac Island in the southern Adriatic (Rac & Lovric, 2002). To date, however, no species of *Mesophyllum* has been reported from the Gulf of Trieste in the northern end of the Adriatic.

This paper presents an account on the first records of *Mesophyllum* from the Gulf of Trieste and the first record of gametangial plants of *M. macroblastum* from the Mediterranean Sea. Comparisons with recently collected specimens of *M. macroblastum* from the Tyrrhenian Sea (Pianosa Island) and with published data on the type (Gulf of Naples, Tyrrhenian Sea) and on specimens from Australia and New Zealand are included. Distribution and habitat data, along with comparisons with other Mediterranean species of *Mesophyllum*, a dichotomous key to Mediterranean species, and brief remarks on other species in the genus known to produce volcano-like conceptacles, are also provided.

## MATERIALS AND METHODS

Gulf of Trieste samples were collected in August 2008 and April 2009 at the Trezza San Pietro (Fig. 1). For comparison, two additional tetrasporophytic specimens from Pianosa Island in the Tyrrhenian Sea (west coast of Italy) were also examined. All specimens were preserved in a 4% formaldehyde-seawater. Fragments of Gulf of Trieste material were analysed by scanning electron microscopy (SEM) after being prepared by air drying and then mounting them on aluminium stubs with acrylic adhesive. Stubs were sonicated with a Vitec sonicator to remove sediment and diatoms and then coated with gold/palladium (with S150 Sputter Coater, Edwards) prior to viewing in a LEICA Steroscan 430i at 20 kV. Tyrrhenian Sea specimens were prepared for SEM by air-drying fertile fragments of the thallus or small pieces of longitudinally fractured material and

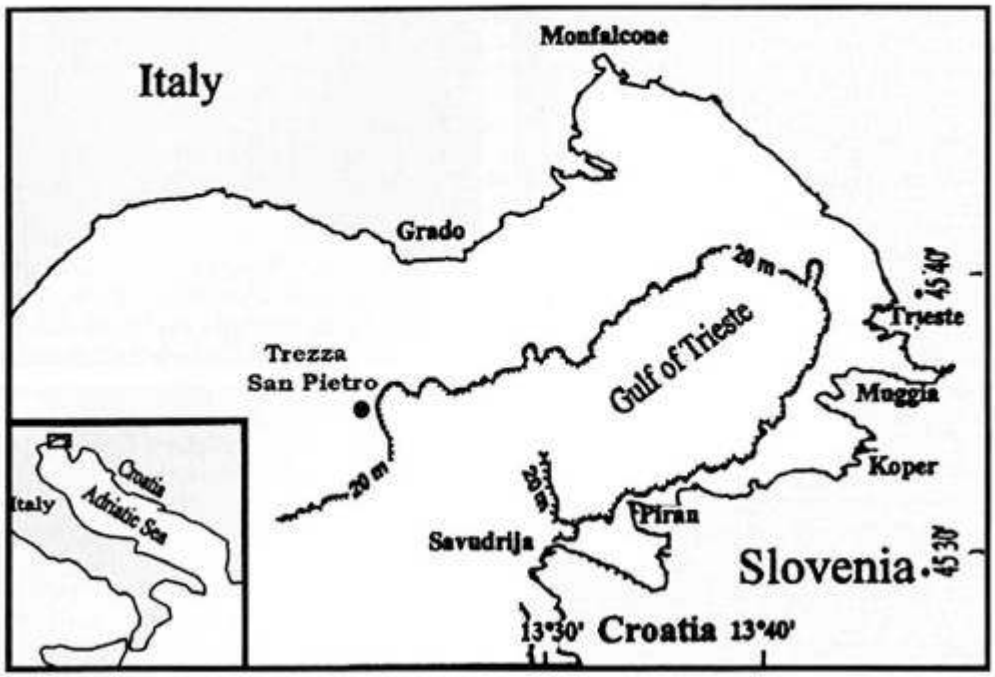



Fig. 1. Sampling site: Trezza San Pietro - Gulf of Trieste (45°36, 2237N – 13°20, 3007E).

then mounting on aluminium stubs with « Fotobond » acrylic adhesive (Agfa-Gevaert). The stubs and materials were the coated with gold (Emitech K550) and observed with a Philips XL 20 SEM operating at 15 kV.

Anatomical terminology follows Woelkerling (1988) and growth-form terminology follows Woelkerling *et al.* (1993). Herbarium abbreviations are those used in Index Herbarium, formerly in print (Holmgren *et al.* 1990) and more recently online electronically (Holmgren & Holmgren 1998, continuously updated). Voucher specimens have been lodged at PC [Département Systématique et évolution (bâtiment de Cryptogamie), Muséum national d'histoire naturelle, Paris].

## RESULTS AND DISCUSSION

***Mesophyllum macroblastum*** (Foslie) Adey, 1970: 25.
**Basionym:** *Lithothamnion macroblastum* Foslie, 1897: 16.
**Holotype:** TRH (Department of Botany, Museum of Natural History and Archaeology, University of Trondheim, Trondheim, Norway), Foslie Herbarium, B16-2435.
**Type locality:** Gulf of Naples, Italy.

**Specimens examined:**
**Gulf of Trieste (Northern Adriatic), Italy**: Trezza San Pietro (45°36, 2237N – 13°20, 3007E), *leg. D. Poloniato*, April 2009, 15 m depth, PC 0116485. Trezza San Pietro (45°36, 2237N – 13°20, 3007E), *leg. D. Poloniato*, April 2009, 15 m depth, PC 0116486. Trezza San Pietro, (45°36, 2237N – 13°20, 3007E); *leg. D. Poloniato*, August 2008, 15 m depth, PC 0116487.

**Tuscany (Tyrrhenian Sea), Italy:** La Scarpa, Pianosa Island (Tuscan Archipelago) (42°34.861' N - 10°05.905' E), *leg D. Racano*, October 2006, 30 m depth, PC 0116488. La Scarpa, Pianosa Island (Tuscan Archipelago) (42°34.861' N - 10°05.905' E), *leg D. Racano*, October 2006, 30 m depth, PC 0116489.

**Gulf of Trieste and Tyrrhenian Sea plants**

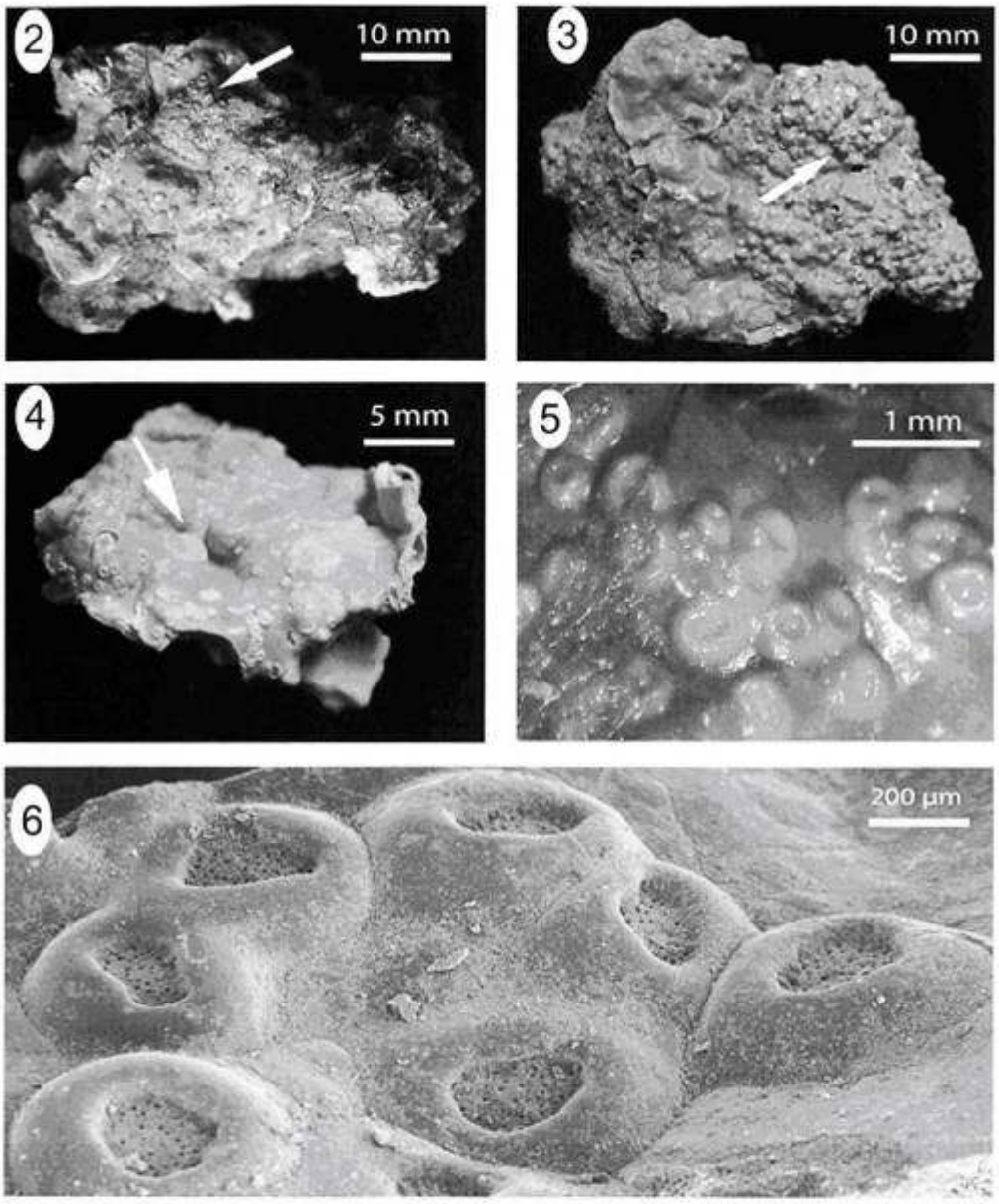
**Vegetative features:** Plants growing at Trezza San Pietro (Gulf of Trieste) are encrusting to warty or inconspicuously layered (applanate branching generally visible only in section) in growth form (Figs 2-3), grew attached to rock, and are up to 50 mm across and 0.2-0.8 mm thick. Pianosa Island (Tyrrhenian Sea) plants are similar, both epilithic and epizoic plants were collected, and several applanate branches are visible in surface view (Fig. 4).

Plants from both localities are pseudoparenchymatous and have a dorsiventral organization. They also have monomerous construction (Figs 9, 16, 17) with a single system of branched filaments forming a broad ventral or central core region and a perhiperal region in which core filaments or their derivatives curve outward towards the thallus surface. In the core region, filaments are coaxial, with cells of adjacent filaments aligned in arching tiers. Filaments terminate at the thallus surface in one or sometimes 2-3 epithallial cells with more or less flattened outer walls (Figs 11-12). When present, filaments with 2-3 epithallial cells occur in patches and are interspersed with patches of filaments with one epithallial cell. Epithallial cells are subtended by initials that are as long or longer than their immediate inward derivatives.

In surface view (Figs 10, 14, 15), cells (which may or may not be epithallial cells) are more or less polygonal. Like various other corallines (e.g. see Garbary & Veltkamp, 1980; Woelkerling & Irvine, 1986: 382; Wilks & Woelkerling, 1994: 200 & fig. 18; Wegeberg & Pueschel, 2002: 243, Table 1), distal walls of epithallial cells of *Mesophyllum* almost certainly are not calcified or are only lightly calcified. Consequently, in dried specimens and in specimens prepared for scanning electron microscopy, epithallial cells commonly collapse or are damaged or are lost. When this occurs, the underlying cell and the primary pit connection that originally linked that cell to the lost or damaged epithallial cell becomes visible (Figs 10, 14).

Within the thallus, cells of the same filament are always linked by primary pit-connections, while cells of adjacent thallus filaments (other than epithallial cells and subepithallial initials), are commonly but not always linked by cell fusions (Figs 9, 11).

Tentative evidence for the occurrence of a possible trichocyte (Fig. 14) was seen in a roof of a young multiporate conceptacle in a Tyrrhenian Sea plant. Trichocytes (see Woelkerling, 1988: 17) sometimes produce hair-like extensions that protrude above the thallus surface and eventually abscise or break off, leaving a pore-like hole that is visible in surface view. In the Tyrrhenian Sea plant, this pore like hole was about 3 µm in diameter and surrounded by 6 cells. By contrast, pores of tetrasporangial conceptacles are 10-12 µm in diameter and normally surrounded by 8-10 cells (compare Figs 14-15). We have not, however, seen trichocytes in sectional view, and no similar holes were seen in Gulf of Trieste plants. If confirmed by further study, this represents the first record of trichocytes in *Mesophyllum macroblastum*. Trichocytes have been recorded in several species of *Mesophyllum*, but their occurrence is not considered taxonomically significant (see Woelkerling & Harvey, 1993: 576-577).




Figs 2-6. *Mesophyllum macroblastum*. **2.** Encrusting tetrasporangial plants on rock. Note volkano-like conceptacles (arrow). **3.** Encrusting to warty plants on rock; note uniporate conceptacles (arrow). **4.** Tetrasporangial plant consisting of two main superimposed lamellae; note applanate branch (arrow). **5, 6.** Surface views of tetrasporangial conceptacles with sunken pore plates. (**2**, PC 0116486; **3**, PC 0116487; **4**, PC 0116488; **5-6**, PC 0116485).

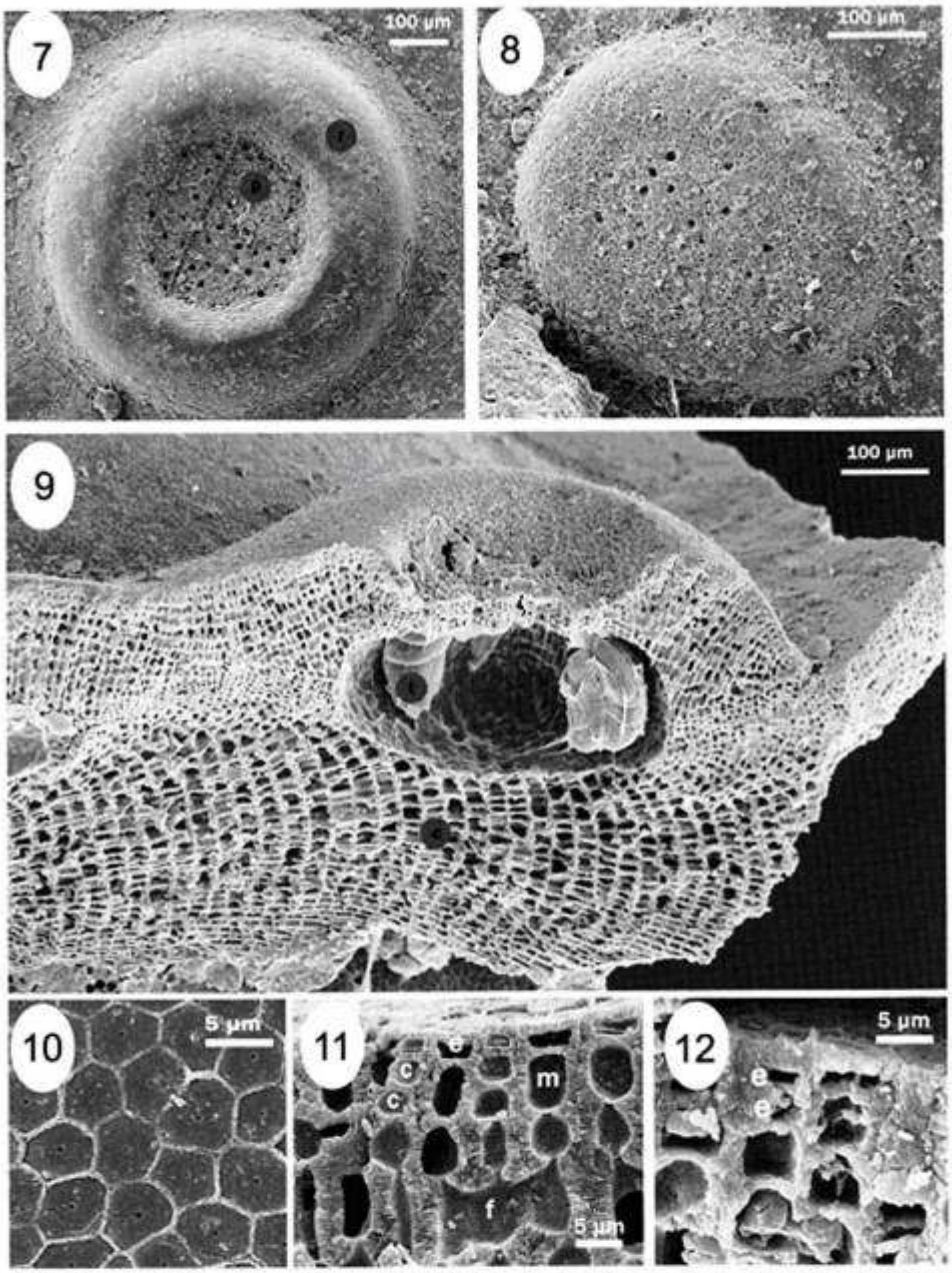
A comparative summary of data on vegetative features and measured characters for Gulf of Trieste and Tyrrhenian Sea specimens examined during this study appears in Table 1.

Table 1. Comparative data for *M. macroblastum*: vegetative features. Sources: **(a)** Foslie, 1897; **(b)** Present study; **(c)** Woelkerling and Harvey, 1993; **(d)** Woelkerling, 1996; **(e)** Cabioch & Mendoza 2003; **(f)** Harvey *et al.*, 2003; **(g)** Harvey *et al.*, 2005; **(h)** Volpi & Benvenuti (2009); i) Farr *et al.* 2009. nd = no data

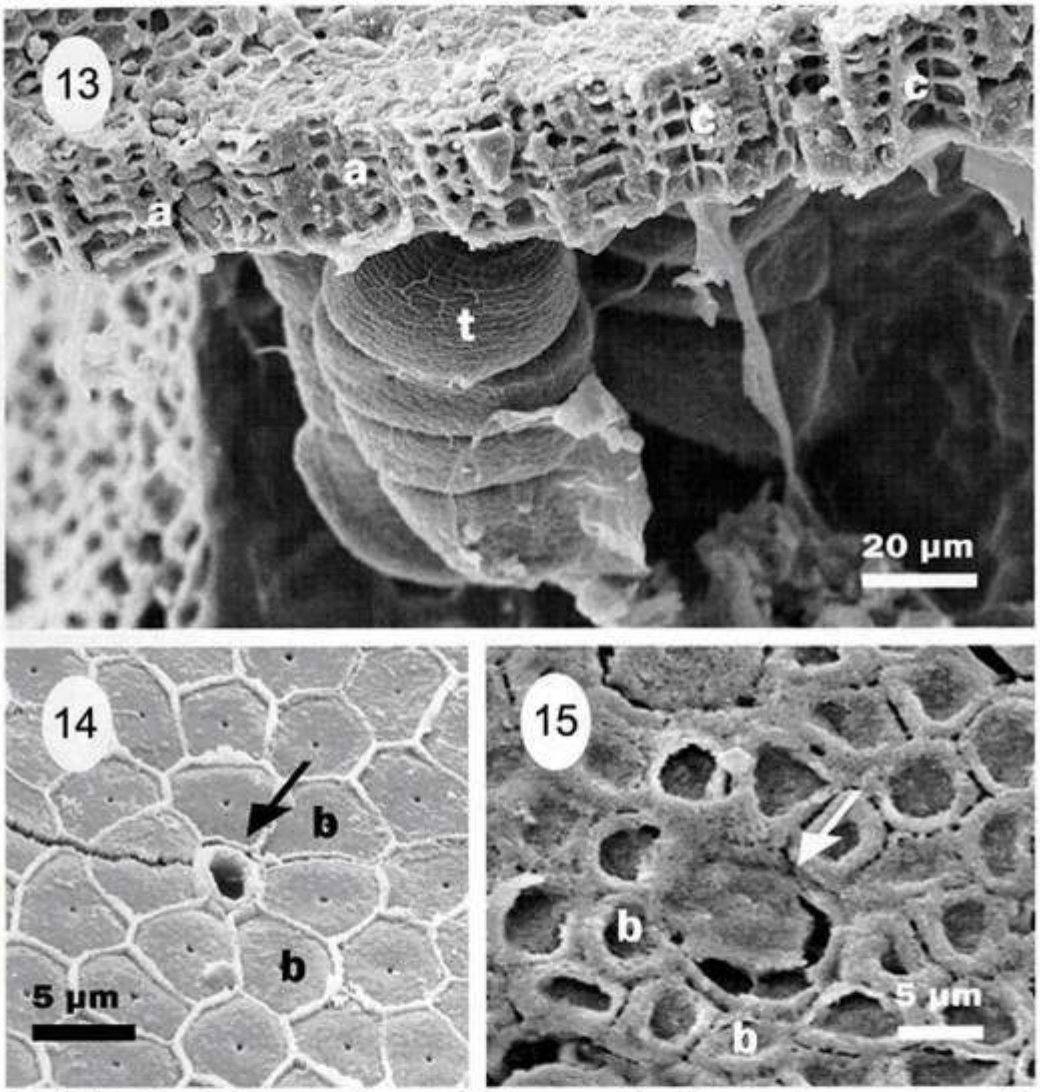
| *Locality* / *Feature* | *Gulf of Trieste (Trezza S. Pietro) (b)* | *Tyrrhenian Sea (b) (h)* | *Gulf of Naples (Holotype TRH) (a) (c)* | *France (Port Cros and Corsica) (e)* | *Southern and south-eastern Australia (c) (d) (f)* | *New Zeland (g) (i)* |
|---|---|---|---|---|---|---|
| Habitat substratum | epilithic | epilithic or epizoic | epilithic | epilithic | epilithic or epizoic, epiphytic | epilithic or epizoic |
| depth range | to depths of 15-16 m | subtidal from depths of 5 m to at least 30 m | 27-45 m | subtidal to 15, 30-40, 90 m | intertidal in pools and subtidal to 15 m (**c**), to depths of 27 m (**f**) | intertidal & subtidal to at least 18 m |
| Morphology thallus form | encrusting to warty | encrusting, layered to warty | earty | encrusting to warty, or lumpy | encrusting to layered, warty or lumpy (**c**) | encrusting to warty, layered or lumpy |
| thallus diameter | Up to 50 mm across | 35-50 mm | 40-50 mm | 80 mm | Up to 83 mm (**c**), 90 mm (**f**) | Up to 105 mm across |
| thallus thickness | 200-800 µm | 200-1000 µm | 100-450 µm (1000 µm) | nd | 0.1-20 mm 9 (**c**), 1-4 mm (**f**) | nd |
| adhesion | mainly attached | mainly attached, or with free margins | mainly attached | mainly attached or with partly free margins | mainly attached (**c**) | mainly attached, or with free margins |
| Vegetative anatomy | | | | | | |
| trichochytes | – | (+) | nd | – | – | – |
| cell fusions | + | + | + | + | + | + |
| core region | | | | | | |
| type of growth | coaxial | coaxial | coaxial or non coaxial | coaxial or non coaxial | coaxial or non coaxial (**c**) | nd |
| thickness | 190-220 µm | 100-300 µm | 200 µm | 150 µm | nd | nd |
| cell- length | 15-22 | (13) 15-22 µm | nd | nd | 8-42 µm (**c**) | nd |
| cell- breadth | 5-9 | 6-8 µm | nd | nd | 5-12 µm (**c**) | nd |
| peripheral region | | | | | | |
| thickness | up to 220 µm | 120-200 (630) µm | 150 µm | 500 µm | nd | nd |
| cell length | 5-11 4-8 µm | (5) 10-18 (22) µm | nd | nd | 5-12 µm (**c**) | nd |
| cell breadth | 4-8 µm | 4-8 µm | nd | nd | 4-9 µm (**c**) | nd |
| Epithallial region | | | | | | |
| cells in surface view | polygonal | polygonal | polygonal | polygonal | nd | nd |

Table 1. Comparative data for *M. macroblastum*: vegetative features. Sources: **(a)** Foslie, 1897; **(b)** Present study; **(c)** Woelkerling and Harvey, 1993; **(d)** Woelkerling, 1996; **(e)** Cabioch & Mendoza 2003; **(f)** Harvey *et al.*, 2003; **(g)** Harvey *et al.*, 2005; **(h)** Volpi & Benvenuti (2009); i) Farr *et al.* 2009. nd = no data *(continued)*

| *Locality* / *Feature* | *Gulf of Trieste (Trezza S. Pietro) (b)* | *Tyrrhenian Sea (b) (h)* | *Gulf of Naples (Holotype TRH) (a) (c)* | *France (Port Cros and Corsica) (e)* | *Southern and south-eastern Australia (c) (d) (f)* | *New Zeland (g) (i)* |
|---|---|---|---|---|---|---|
| outer walls in section | flattened | flattened | nd | rounded to flattened | rounded to flattened **(d)** | rounded to flattened |
| number of cell layers | 1-3 | 1 | nd | nd | (1) | nd |
| cell diameter in surface view | 6-9 µm | 5-6 µm | nd | nd | 5-7 µm **(f)** | nd |
| cell length | 2-3 µm | 2-3 µm | nd | nd | 3-6 µm **(b)** 2-5 µm **(f)** | nd |
| cell breadth | 5-8 µm | 3-6 µm | nd | nd | nd | nd |
| Subepithallial initials: length compared to subtending cells | as long or longer | as long or longer | nd | nd | as long or longer **(c)** | as long or longer |



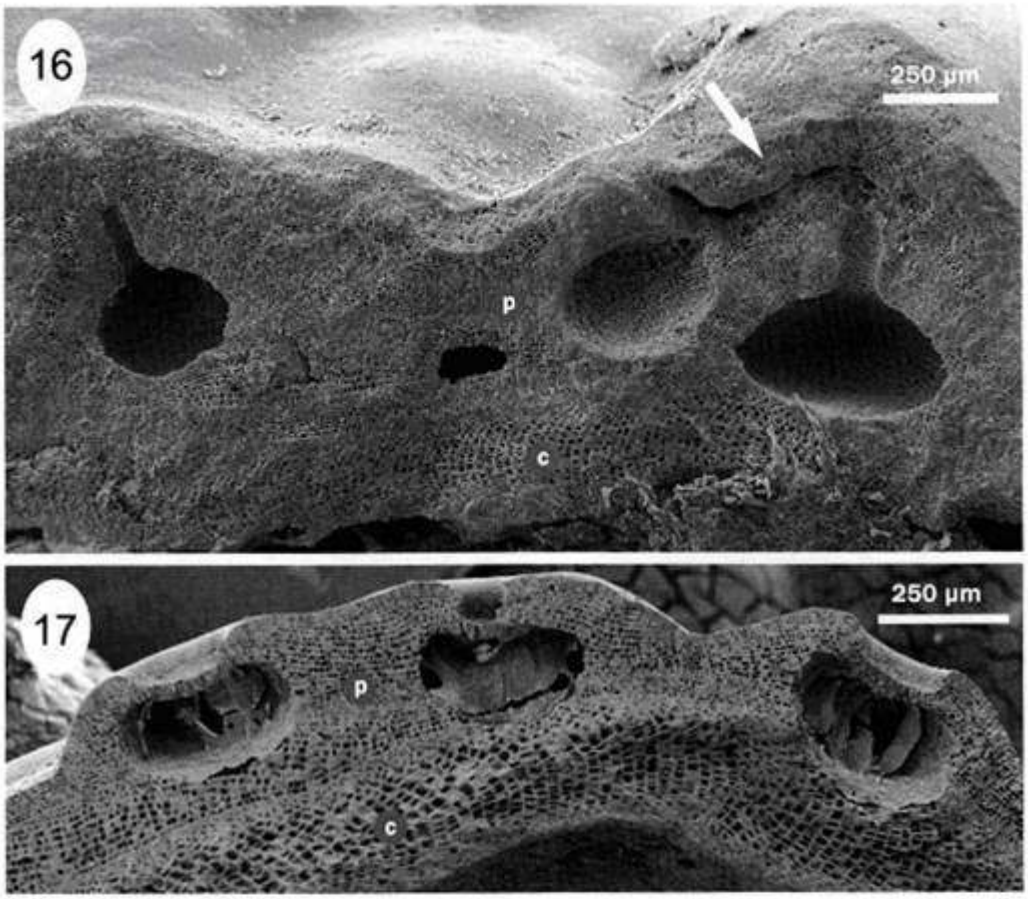

Figs 7-12. *Mesophyllum macroblastum*. **7.** Surface view of a tetrasporangial conceptacle with sunken pore plate (**p**) and peripheral rim (**r**). **8.** Surface view of a mound-like tetrasporangial conceptacle on same plant as conceptacle in Fig. 7. **9.** Longitudinal fracture through a plant showing a coaxial core region (**c**) with cells of adjacent filaments linked by cell fusions, and a mature conceptacle with tetraspores (**t**) and a sunken pore plate. **10.** Surface view of thallus showing polygonial cells. Note primary pit connections signifying where these cells were linked distally to epithallial cells (no longer present). **11.** Fracture showing flattened epithallial cells (**e**). Note subepithallial initials (**m**) slightly longer than their immediate inward derivatives, and cell-fusions (**f**) joining cells of adjacent filaments. Note also derivative cells (**c**) after division of initial cells. **12.** Fracture showing two layers of epithallial cells (**e**). (**7-9,** PC 0116485; **10, 11,** PC 0116486; **12,** PC 0116487).




Figs 13-15. *Mesophyllum macroblastum*. **13.** Tetrasporangia with zonately arranged spores (**t**). Note the pore plate showing rectangular cells lining pore canals (**c**), with thinner cell walls if compared to other pore plate cells (**a**). **14.** Surface view showing cells with primary pit connections; epithallial cells no longer present (see text for details). Note a possible trichocyte pore (arrow) smaller than the bordering initials cells (**b**). **15.** Pore of a tetrasporangial conceptacle that is much larger than the bordering epithallial cells (**b**) and is still blocked by a tetrasporangial plug. Note collapsed or broken distal walls of epithallial cells. (**13,** PC 0116486; **14, 15,** PC 0116488).

**Conceptacles:** Plants with multiporate conceptacles (Figs 2, 5, 6, 7-9, 13, 17) were found both in the Gulf of Trieste and the Tyrrhenian Sea during the present study, and in addition, plants with uniporate conceptacles (Figs 3, 16) were collected in the Gulf of Trieste. The latter represent the first record of uniporate plants of this species in the Mediterranean Sea.

Tetrasporangial plants in the Gulf of Trieste and Tyrrhenian Sea had scattered to densely grouped multiporate conceptacles protruding above the




Figs 16-17. *Mesophyllum macroblastum*. **16.** Fracture showing gametangial conceptacles immersed only in peripheral region (**p**) or with chamber partly in contact with core (**c**). Note lamellate branch (arrow) overgrowing conceptacle roof. **17.** Longitudinal section through a plant showing tetrasporangial conceptacles that are either immersed in the peripheral region (**p**), or with the chamber base more or less in contact with the core region (**c**). (**16,** PC 0116487; **17,** PC 0116489).

surrounding thallus surface. Conceptacle chamber floors commonly are situated just above the coaxial core region of the thallus. Roofs of mature conceptacles are volcano-like with a perhiperal rim and a more or less sunken central pore-plate perforated by a number of pore canals (Figs 6, 13, 17). In surface view (Fig. 15), pore canals are bordered by 8-10 cells similar in shape and similar or slightly smaller in size than other epithallial cells in the pore plate. In sectional view (Fig. 13) pore canals in Gulf of Trieste plants were lined with cells that looked more or less square, appear very slightly larger than other conceptacle roof cells, and appear to have slightly thinner walls. In the Tyrrhenian Sea plants, cells lining pore canals were more or less square in sectional view, and appeared similar to or slightly larger in size to other conceptacle roof cells, which were more thick-walled. Mature conceptacles contain tetrasporangia with zonately arranged spores and apical plugs that block pore canals prior to spore release (Figs 9, 14, 17). Older conceptacles can become buried in the thallus.

Numerical and other data on Gulf of Trieste and Tyrrhenian Sea plants relating to mature tetrasporangial conceptacles is summarized in Table 2.

One Gulf of Trieste specimen (PC 0116485) with mature volcano-like multiporate conceptacles also had one multiporate conceptacle which in surface view was mound-like and did not have a sunken pore-plate (Fig. 8). This conceptacle was smaller in external diameter (360 × 420 µm) than nearby volcano-like conceptacles (540-790 µm in greatest external diameter), and it had only 10-12 evident pores in the roof rather than the 22-43 pores of nearby volcano-like conceptacles. We suspect that the mound-like conceptacle either was not fully mature or possibly was aberrant.

Another Gulf of Trieste specimen (PC 0116487) possessed uniporate rather than multiporate conceptacles. The uniporate conceptacles were more or less densely crowded and protruding above the surrounding thallus surface (Fig. 3). Unfortunately, these conceptacles appeared empty (Fig. 16), and thus we cannot be certain whether they are old male or old female/carposporangial conceptacles, although the conceptacle chamber diameter and height (Table 3) makes it more likely that they are female/carposporangial. In southern and south-eastern Australian plants (Woelkerling & Harvey, 1993; Harvey *et al.*, 2003), carposporangial conceptacles have similar dimensions while male conceptacles are smaller (see data in Table 3). Buried uniporate conceptacles also were observed (Fig. 16). This is the first Mediterranean Sea record of gametangial conceptacles in *Mesophyllum macroblastum*. In southern Australia, gametangial plants can be monoecious or dioecious (Woelkerling & Harvey, 1993; Woelkerling, 1996).

**Comparisons with previous studies of *M. macroblastum***

Detailed studies of the type specimen, collected from the Gulf of Naples (Tyrrhenian Sea) have been published by Woelkerling & Harvey (1993), who also provided an account of the species in southern Australia, and by Cabioch & Mendoza (2003), who also provided an account of the species in the Mediterranean Sea. Gulf of Trieste and Tyrrhenian Sea specimens examined during the present study are largely concordant with the type material and other material studied by the above authors, leaving no doubt that these specimens belong to *Mesophyllum macroblastum*.

Woelkerling & Harvey (1993: 580, including table 5) concluded that the occurrence of volcano-like tetrasporangial conceptacles in which cells lining the pore canals were similar in size and shape to other cells in the conceptacle roof were diagnostic of *M. macroblastum*. Caboich & Mendoza (2003) reaffirmed that conclusion, and Gulf of Trieste and Tyrrhenian Sea specimens possess these characters.

Tables 1, 2 and 3 provide a summary comparison of data on *M. macroblastum* from the present study with available data on the type specimen and on the species from other recent studies. The extent of knowledge of the species varies from region to region. Thus, for example, gametangial plants are recorded only from the Gulf of Trieste, Australia and New Zealand, with most data coming from Australia. Not all studies include data for all characters listed in the Tables, and some variations are evident. In Table 1, for example, not all known growth-forms are reported for all regions, and non-coaxial as well as coaxial development is known in the holotype and plants from France and Australia, but non-coaxial growth was not evident in the Gulf of Trieste and Tyrrhenian Sea plants. Filaments terminating in more than 1 epithallial cell were observed in some Gulf of Trieste specimens but have not been explicitly reported from elsewhere. Filaments with more than one epithallial cell, however, are evident in scanning

Table 2. Comparative data for *M. macroblastum*: tetrasporangial features. Sources: **(a)** Foslie, 1897; **(b)** Present study; **(c)** Woelkerling and Harvey, 1993; **(d)** Woelkerling, 1996; **(e)** Cabioch & Mendoza 2003; **(f)** Harvey *et al.*, 2003; **(g)** Harvey *et al.*, 2005; **(h)** Farr *et al.* 2009. nd = no data

| *Locality* / *Feature* | *Gulf of Trieste (Trezza S. Pietro) (b)* | *Tyrrhenian Sea (b) (h)* | *Gulf of Naples (Holotype TRH) (a) (c)* | *France (Port Cros and Corsica) (e)* | *Southern and south-eastern Australia (c) (d) (f)* | *New Zeland (g) (i)* |
|---|---|---|---|---|---|---|
| Tetrasporangial conceptacles | | | | | | |
| shape | volcano-like[a] | volcano-like | volcano-like | volcano-like | volcano-like | volcano-like |
| external diameter | 540-790 µm | 560-760 µm | 550-700 µm | 550-570 µm | nd | nd |
| external height | 80-110 µm | up to 200 µm | nd | nd | nd | nd |
| pore plate | 170-330 µm | 230-300 µm | nd | nd | nd | nd |
| peripheral rim thickness | (110) 130-170 µm | 140-200 µm | nd | nd | nd | nd |
| peripheral rim height | 40-80 µm | 60-80 µm | nd | 35 µm[b] | nd | nd |
| number of pores | 22-43 | 39[b] | about 20 (a), nd (c) | nd | nd | nd |
| pore diameter | 10-12 µm | 11-13 µm | nd | nd | nd | nd |
| roof thickness | 30 µm[b] | 35-40 µm | 30 µm[b] | nd | 27-35 µm (**c**) | nd |
| number of cell layers in roof | 6[b] | 6-7 | 7-8 | nd | 4-5 (**c**), 6-7 (**f**) | nd |
| chamber diameter | 310 µm[b] | 300-400 µm | 230 µm[b] | to 350 µm | 145-270 µm (**c**) | (6) |
| chamber height | 200 µm[b] | 180-200 µm | 164 µm[b] | nd | 90-150 µm (**c**) | 165-355 µm |
| disposition in thallus | in peripheral region or in contact with core region | in peripheral region or in contact with core region | in peripheral region | in peripheral region | in peripheral region (**c**) (**f**) | nd |
| old conceptacles buried | none observed | sometimes | nd | nd | commonly (**c**) (**f**) | nd |

a. one mound-like conceptacle observed; b. based on one measurement.

Table 2. Comparative data for *M. macroblastum*: tetrasporangial features. Sources: **(a)** Foslie, 1897; **(b)** Present study; **(c)** Woelkerling and Harvey, 1993; **(d)** Woelkerling, 1996; **(e)** Cabioch & Mendoza 2003; **(f)** Harvey *et al.*, 2003; **(g)** Harvey *et al.*, 2005; **(h)** Farr *et al.* 2009. nd = no data *(continued)*

| *Locality* / *Feature* | *Gulf of Trieste (Trezza S. Pietro) (b)* | *Tyrrhenian Sea (b) (h)* | *Gulf of Naples (Holotype TRH) (a) (c)* | *France (Port Cros and Corsica) (e)* | *Southern and south-eastern Australia (c) (d) (f)* | *New Zeland (g) (i)* |
|---|---|---|---|---|---|---|
| Bordering pore cells | | | | | | |
| disposition | same level | same level | same level | same level | nd | nd |
| number of cells | 8-10 | 9-10 | nd | 8-9 | | nd |
| appearance in surface view | like other epithallial cells or slightly smaller | like other epithallia cellsl | nd | nd | like other epithallial cells **(c) (d) (f)** | nd |
| appearance in section | squared, with thin walls | squared | squared | nd | squared **(c) (d) (f)** | rectangular |
| Other pore plate cells in section | rounded with thick walls | squared or rounded | squared | nd | squared **(c) (d)** squared to rounded **(f)** | rectangular |
| Tetrasporangia | | | | | | |
| length | 88-126 µm | 130 µm[b] | nd | nd | 81-135 µm | nd |
| breadth | 49-64 µm | 50 µm[b] | nd | nd | 29-68 µm | nd |

a. one mound-like conceptacle observed; b. based on one measurement.

Table 3. Comparative data for *M. macroblastum*: tetrasporangial features. Sources: **(a)** Foslie, 1897; **(b)** Present study; **(c)** Woelkerling and Harvey, 1993; **(d)** Woelkerling, 1996; **(e)** Cabioch & Mendoza 2003; **(f)** Harvey *et al.*, 2003; **(g)** Harvey *et al.*, 2005; **(h)** Farr *et al.* 2009. nd = no data

| *Locality* / *Characters* | *Gulf of Trieste (Trezza S. Pietro) (b)* | *Tyrrhenian Sea (b)* | *Gulf of Naples (Holotype TRH) (a) (c)* | *France (Port Cros and Corsica) (e)* | *Southern and south-eastern Australia (c) (d)* | *New Zeland (g) (h)* |
|---|---|---|---|---|---|---|
| **Female conceptacles** | | | | | | |
| chamber diameter | 270-480 µm | nd | nd | nd | 175-540 µm (c) (d) | nd |
| chamber height | 190-280 µm | nd | nd | nd | 54-270 µm (c) (d) | nd |
| roof thickness | 120-250 µm | nd | nd | nd | 80-205 µm (c) (d) | nd |
| number of cell layers in roof | 14-34 | nd | nd | nd | 12-30 (c) (d) | nd |
| pore diameter | 55-107 µm | nd | nd | nd | 27-82 µm (c) | nd |
| carpogonial branches | nd | nd | nd | nd | 2-3 celled (c) (d) | nd |
| **Male conceptacles** | | | | | | |
| chamber diameter | nd | nd | nd | nd | 243-310 µm (c) (d) | nd |
| chamber height | nd | nd | nd | nd | 67-81 µm (c) 65-105 µm (d) | nd |
| roof thickness | nd | nd | nd | nd | 62-108 µm (c) (d) | nd |
| number of cell layers in roof | nd | nd | nd | nd | 11-16 (c) (d) | nd |
| pore diameter | nd | nd | nd | nd | 27-46 µm (c) | nd |
| spermatangial filaments | nd | nd | nd | nd | unbranched (c) | unbranched |

electron micrograph of the type (Woelkerling & Harvey, 1993: 623, fig. 17C) but were not recognized by those authors. These variations are not considered taxonomically significant.

**Distribution and habitat**

Published information on the distribution and habitat of *Mesophyllum macroblastum* in the Mediterranean Sea is limited. The species, first described as *Lithothamnion macroblastum* by Foslie (1897) from the Gulf of Naples (Italy), has been reported by Giaccone (1969, as *Lithothamnion*) in Sicily (Aci Trezza and Riserva dei Ciclopi), Ollivier (1929: 141 as *Lithothamnion*) from the Cote d'Azur (France) and Hamel & Lemoine (1953: 95, as *Lithothamnion*) from the Alpes-Maritimes (France). French specimens studied by Cabioch & Mendoza (2003, as *Mesophyllum*) were collected at Port Cros and Corsica and were growing on rocky and coralligenous bottoms at depths of 15-90 m.

Along the Tyrrhenian Sea and the French coasts of the Mediterranean, *M. macroblastum* may represent an important component of coralligenous assemblages (*sensu* Ballesteros, 2006; Volpi & Benvenuti, 2009), while in the eastern sector of the Mediterranean it appears to be a poorly documented species. The record (this study) of *M. macroblastum* on the Trezze at San Pietro in the northern Adriatic confirms the role of this species as a bio-constructor. According to Casellato and Stefanon (2008), the northern Adriatic biogenic outcrops, characterized by rich biocenoses, are comparable to the Mediterranean coralligenous assemblages but differ in having less conspicuous concretions of coralline algae. The Trezze of the Northern Adriatic Sea have been recently proposed as Sites of Community Interest (SCIs) in the context of the Habitats Directive of EU (Natura 2000, Interpretation Manual of European Union Habitats, Eur 25, October 2003, No 1180), and further studies are required for a better understanding of their evolution.

In Australia and New Zealand *M. macroblastum* has been collected in intertidal and subtidal habitats to 27 m deep on rocks, as epiphytes or on molluscs and sponges (Woelkerling & Harvey, 1993; Harvey *et al.*, 2003; Harvey *et al.*, 2005, Farr *et al.* 2009).

Additional substratum and habitat data are provided in Table 1.

**Comparisons with other Mediterranean *Mesophyllum* species**

Cabioch & Mendoza (1998, 2003) presented extensive information on the five species of *Mesophyllum* reported to occur in the Mediterranean, including data on the types of *M. alternans* (1998), *M. expansum* (1998, 2003), and *M. macroblastum* (2003). Additional data on the type of *M. macroblastum* was published by Woelkerling & Harvey (1993). The type of *M. lichenoides* has been studied by Woelkerling & Irvine (1986) (also see Woelkerling & Irvine, 2007), and the type of *M. macedonis* has been studied by Athanasiadis (1999). Cabioch & Mendoza (2003: 266, Table 1) also compared the principle characteristics of the five species, but they did not provide a species key.

Woelkerling & Harvey (1993: 577-580) concluded from an analysis of over 190 populations of species of *Mesophyllum* that characters associated with tetrasporangial conceptacle roof morphology and anatomy provided a reliable basis for delimiting southern Australian species of *Mesophyllum* from one another and from the type species of the genus (*M. lichenoides*). Subsequently,

Chamberlain (2000: 377) confirmed the diagnostic value of these characters, also noting their adoption by subsequent authors, and Cabioch & Mendoza (1998: 219; 2003: 271) reaffirmed this conclusion in relation to Mediterranean species.

Within each species, Woelkerling & Harvey (1993) found that roof morphology and pore canal anatomy were constant in mature tetrasporangial conceptacles. Conceptacle roofs either were volcano-like with a peripheral rim and a sunken pore plate, or roofs were mound-like to flattened without a peripheral rim and sunken pore plate. In one species with volcano-like conceptacles (*M. printzianum*), Woelkerling & Harvey (1993: 595) also found, however, that peripheral rims may not be evident in very young conceptacles, and that in occasional conceptacles in some individuals, the rim was only marginally higher than the pore plate and thus hard to detect in surface view. In sections, by contrast, the rim and sunken pore plate always were evident.

Mature tetrasporangial conceptacles in *M. macroblastum* are volcano-like with rims that are conspicuous in surface view. With one exception (noted above), all Gulf of Trieste and Tyrrhenian Sea tetrasporangial conceptacles examined during the present study were volcano-like.

Woelkerling & Harvey (1993) also found three distinct patterns in relation to cells lining the pore canals:

1) cells lining pore canals are shorter and more squat than adjacent roof cells;
2) cells lining pore canals are narrower and more elongate than adjacent roof cells, especially near the base of the canal;
3) cells lining pore canals are similar in size and shape to other roof cells.

These patterns are illustrated diagrammatically in Fig. 18.

Pore canals in *M. macroblastum* fall into the third category, although some variation in this pattern was found during the present study. In the holotype (Woelkerling & Harvey, 1993: 624, fig. 18B) and southern Australian specimens

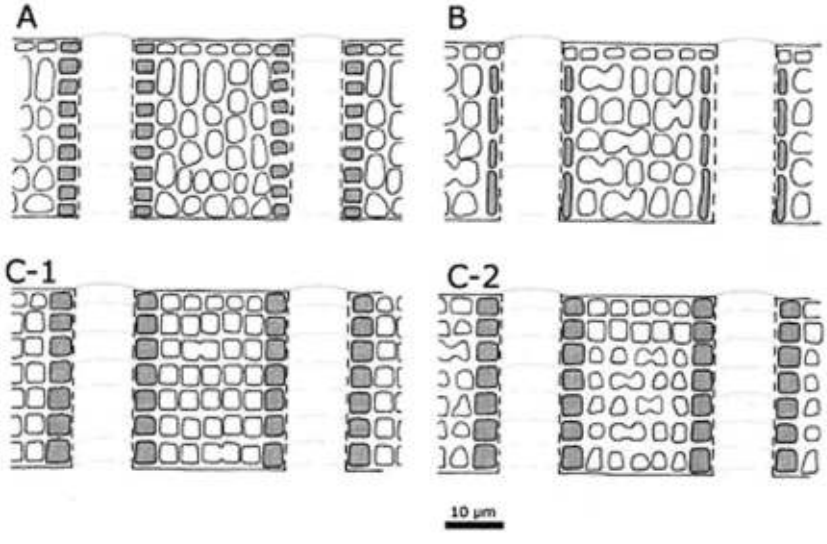



Fig. 18. Diagrams showing patters of pore canal structure: **A.** pore canals bordered by cells that are distinctly shorter and more squat than adjacent roof cells above the chamber; **B.** pore canals bordered by cells that are narrower and more elongate than adjacent roof cells above the chamber; **C1.** pore canals bordered by squared cells that are similar in size and shape to other roof cells of the pore plate; **C2.** pore canals bordered by squared cells as in C-1, but adjacent roof cells in pore plate with thicker cell walls and smaller lumens.

(e.g. Woelkerling & Harvey, 1993: 627, fig. 21 D) cells lining the pore canals as well as other roof cells all are comparatively thin walled and more or less square, as shown in Fig. 18C-1. In the Gulf of Trieste plants, roof cells not lining pore canals tend to be thicker walled and thus have smaller lumens and look slightly more irregular in shape, as shown in Fig. 18C-2. Roof cells away from pore canals in Tyrrhenian Sea specimens are intermediate in terms of wall thickness and lumen shape. Such variation has not been noted before, but appears presently to be of no taxonomic significance.

The five species of *Mesophyllum* known to occur in the Mediterranean can readily be delimited from one another (and specimens can readily be identified) using differences in tetrasporangial conceptacle roof morphology and tetrasporangial conceptacle pore canal anatomy. The dichotomous key below summarizes these differences.

Athanasiadis & Neto (2010: 340) recently reported that the number of cells surrounding pore canals is of diagnostic significance in separating *Mesophyllum expansum* from *M. lichenoides*. Athanasiadis & Neto (2010: 336, figs 12-14; 339, figs 26-29) also noted shape variation in cells lining the pore canals in both species and indicated (on p. 338) that cells lining the pore canals in *M. lichenoides* were generally smaller than neighbouring roof cells. Cells lining the pore canals of *M. expansum* were described (on p. 336) as 'differentiated or not', but no information relative to neighbouring roof cells was provided. In the dichotomous key below, we have incorporated their data on number of cells surrounding pore canals, but we have retained available published information for these two species on size of pore canal cells relative to cells of adjacent roof filaments. For completeness, we also have added data on the number of cells surrounding pore canals in *M. alternans* (sourced from Cabioch & Mendoza, 2003: 266, Table 1) and in *M. macedonis* (sourced from Athanasiadis, 1999: 241).

**Key to species of *Mesophyllum* recorded from the Mediterranean Sea**

1a. Tetrasporangial conceptacles volcano like, with a peripheral rim and a more or less sunken central pore plate ..... 2

1b. Tetrasporangial conceptacles mound-like, with a flattened top that is not differentiated into a peripheral rim and a more or less sunken pore plate..... 3

2a. Cells lining pore canals similar in size to or slightly larger than cells of adjacent conceptacle roof filaments; pore canals surrounded by 8-10 cells ..... *M. macroblastum*

2b. Cells lining pore canals much smaller than cells of adjacent conceptacle roof filaments; pore canals surrounded by 11-12 cells..... *M. alternans*

3a. Pore canals bordered by narrow elongate cells, especially near the base of the pore canal; pore canals surrounded by 4-6 cells..... *M. macedonis*

3b. Pore canals bordered by cells that are not elongate or narrow; pore canals usually surrounded by 7 or more cells..... 4

4a. Cells lining pore canals generally similar in size to cells of adjacent conceptacle roof filaments; pore canals surrounded by (8) 9-11 (12) cells ..... *M. expansum*

4b. Cells lining pore canals generally much smaller than cells of adjacent conceptacle roof filaments; pore canals surrounded by (6) 7-8 (9-10) cells. ..... *M. lichenoides*

## CONCLUSIONS

*M. macroblastum* is one of five distinct species of *Mesophyllum* reported to occur in the Mediterranean Sea and the only species confirmed to occur in the northern Adriatic Sea. It also is one of two species in the Mediterranean known to produce volcano-like tetrasporangial conceptacles with peripheral rims and sunken pore-plates. The other species, *M. alternans*, which was studied in detail by Cabioch & Mendoza (1998), differs in that cells lining pore canals are much smaller in size than cells of adjacent roof filaments. In *M. macroblastum*, cells lining pore canals are similar in size or slightly larger than cells of adjacent filaments.

Four other species of *Mesophyllum* possess volcano-like tetrasporangial conceptacles with peripheral rims and sunken pore-plates: *M. printzianum* Woelkerling *et* Harvey (1993: 593) (also see Woelkerling, 1996: 204) from southern Australia, *M. capense* (Rosanoff) Chamberlain (2000) (also see Rosanoff, 1866:86, as *Lithophyllum*) from South Africa, *M. vancouveriense* (Foslie) Steneck & Paine (1986) (also see Athanasiadis *et al.*, 2004: 132), from the Pacific coasts of Canada and the USA, and *M. nitidum* (Foslie) Adey (1970: 25) (also see Foslie, 1901: 4, as *Lithothamnion*; Printz, 1929: pl. 6, fig. 10, as *Lithothamnion*; Yoshida & Baba, 1998: 599-600, Fig. 3-30, as *Mesophyllum*) from Japan. In *M. printzianum* and *M. capense*, cells lining pore canals in the type specimens are thinner (in sectional view), wider and more elongate than adjacent roof cells. Differences in those two species are summarized by Chamberlain (2000: 277). In *M. vancouvierense*, cells lining the pore canal in a Paine specimen (presumably #47A) from Tatoosh Island, Washington State, USA also were narrower and more elongate than other roof cells, but information on this feature in the lectotype apparently is lacking. Pore canal structure in the type of *M. nitidum* has not been examined in a modern context and thus the situation in this species requires clarification.

Over 140 species and infraspecific taxa have been ascribed to *Mesophyllum* according to Woelkerling (1996: 193), and Athanasiadis *et al.* (2004: 126) estimated that the genus accommodates more than 60 species worldwide. Most species, however, are poorly known. Consequently, broader comparisons of *M. macroblastum* with most other species ascribed to the genus are not possible at present.

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# *Phymatolithon lamii* (Hapalidiaceae, Corallinales, Rhodophyta): a first report for the Mediterranean Sea

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## Abstract

*Phymatolithon lamii* (Hapalidiaceae, Corallinales, Rhodophyta) is reported for the first time in the Mediterranean Sea. A morphological-anatomical account of Gulf of Trieste specimens is presented along with comparisons with *P. lamii* specimens from other regions, comparisons with other Mediterranean species of *Phymatolithon* and a dichotomous key to known Mediterranean species of *Phymatolithon*. Whether *P. lamii* occurs naturally in the Mediterranean Sea but was previously misidentified as *P. lenormandii* or is, alternatively, an alien species, or both, has not been resolved.

**Keywords:** alien species; Corallinales; Mediterranean Sea; *Phymatolithon lamii*; taxonomy.

## Introduction

We give an account of recently discovered specimens of *Phymatolithon lamii* (Lemoine) Y. Chamberlain (Hapalidiaceae, Corallinales, Rhodophyta) in the Gulf of Trieste (Northern Adriatic), a species previously unknown from the Mediterranean Sea. Chamberlain (1991) provided a detailed taxonomic account of *P. lamii*, and concluded from a comparative study of type specimens that *P. rugulosum* Adey (1964: 381) and *Lithophyllum melobesioides* Lemoine in Hamel and Lemoine (1953: 55) were heterotypic synonyms.

*P. lamii* as delimited by Chamberlain (1991) is known from northern Spain and France, Great Britain, the Republic of Ireland, Norway, Iceland and eastern North America from Newfoundland, Canada to Massachusetts, USA (Chamberlain 1991: 229; also see Adey 1964, as *P. rugulosum*; Adey and Adey 1973, as *P. rugulosum*, and South and Tittley 1986, as *P. rugulosum*). It has also been reported from the Sea of Okhotsk in the western North Pacific Ocean (Zhakova 1985: 53; Perestenko 1994: 58). Adey (1964: 404, figure 10, as *P. rugulosum*) characterised *P. lamii* as a cold water stenothermal species. Hence, the occurrence of *P. lamii* in the Mediterranean Sea may seem incongruous, but the other two species of *Phymatolithon* recorded from the Mediterranean Sea, *P. calcareum* (Pallas) W.H. Adey *et* D. McKibbin and *P. lenormandii* (J.E. Areschoug) W.H. Adey also are known from northern Spain to Arctic Norway (Adey and Adey 1973, Irvine and Chamberlain 1994).

We present morphological/anatomical data for the Gulf of Trieste thalli and comparisons with published data on the species from elsewhere; in addition, we briefly consider the morphological-anatomical characters distinguishing *P. lamii* from *P. calcareum* and *P. lenormandii* and provide a dichotomous key. Possible vectors of introduction are also discussed, along with a brief general consideration of other taxa thought to be introductions into the region.

## Materials and methods

Specimens of *Phymatolithon lamii* were discovered in August 2008 and collected again in April 2009 at the Trezza San Pietro, Gulf of Trieste, Northern Adriatic (Figure 1). The region has recently been proposed as a Site of Community Interest (SCI) in the framework of the EU Habitats Directive Natura 2000. Specimens were preserved in 4% formaldehyde-seawater. For scanning electron microscopy, fragments of material were air dried, mounted on aluminium stubs with acrylic adhesive, sonicated with a Vitec sonicator (Carlsbad, USA) to remove sediments and diatoms, and then coated with gold/palladium (with S150 Sputter Coater, Edwards, Crawley, UK) prior to viewing with a LEICA Steroscan 430i (Cambridge, UK) at 20 kV.

Anatomical terminology follows Woelkerling (1988) and growth-form terminology follows Woelkerling et al. (1993). Herbarium abbreviations are those used in Index Herbarium, formerly in print (Holmgren et al. 1990) and more recently online electronically (Thiers 2012, available at http://sciweb.nybg.org/science2/IndexHerbariorum.asp). Voucher specimens have been lodged at PC [Département Systématique et évolution (bâtiment de Cryptogamie), Muséum national d'histoire naturelle, Paris].

## Results

### *Phymatolithon lamii* (Lemoine) Y.M. Chamberlain 1991: 224

**Basionym** *Lithophyllum lamii* Lemoine 1931: 13.

**Lectotype** *L. lamii*; 1930; dredged from 8 m. PC no. 0719024 (collected under n°26), General Herbarium box collection (non-fossil; filed in non-geniculate coralline type

**Figure 1** *Phymatolithon lamii*: Sampling site: Trezza San Pietro-Gulf of Trieste, Northern Adriatic (45°36.2237′N –13°20.3007′E).

collections cabinet under basionym); lectotype designated by Chamberlain 1991: 219, 220. Additional data: Woelkerling (1998: 315).

**Isolectotypes** PC no. 0719028 (collected under n°21), General Herbarium box collection (non-fossil; filed in non-geniculate coralline type collections cabinet under basionym); PC no. 0719029 (collected under n°11), General Herbarium box collection (non-fossil; filed in non-geniculate coralline type collections cabinet under basionym). Additional data on isolectotypes: Woelkerling (1998: 315).

**Lectotype – locality** Pointe de Cancaval, Rance, France (Chamberlain 1991: 219).

Specimens examined: Gulf of Trieste (Northern Adriatic), Italy: Trezza San Pietro (45°36.2237′N – 13°20.3007′E), leg. D. Poloniato, 15 m depth, August 2008-PC0719004, and April 2009-PC0719005.

**Vegetative features** Gulf of Trieste thalli (Figures 2 and 3, Table 1) were encrusting and flat without protuberances or branches, milky pink in colour with either a matte surface or delicate ridges, attached ventrally to shells of *Chlamys* sp., measuring up to 40 mm across and 0.1–0.35 mm thick, with a thick white margin with or without orbital ridges.

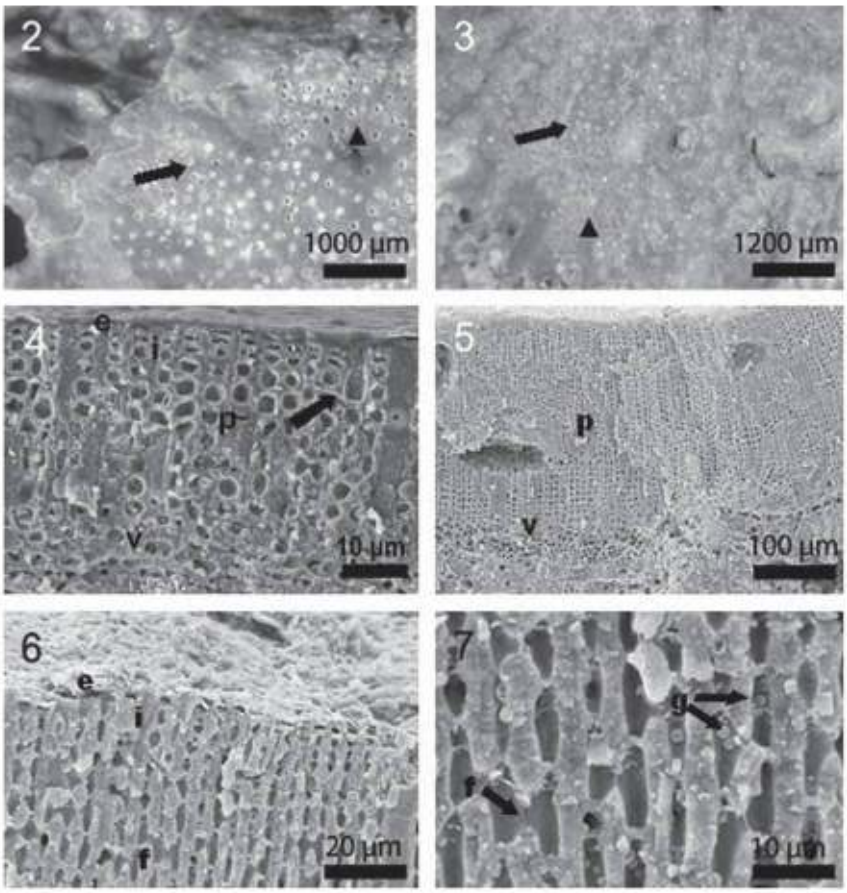
The pseudoparenchymatous thallus has a dorsiventral organisation and monomerous construction (Figures 4 and 5), with a single system of branched filaments forming a thin ventral core region in which filaments run more or less parallel to the thallus surface, and a peripheral region in which core filaments or their derivatives curve upwards towards the thallus surface. In a longitudinal view (Figure 5), core filaments rarely comprise more than 10% of thallus thickness, and the core is generally 30–43 µm thick and composed of up to six layers of filaments. Cells in core region filaments are mostly 6–14 µm long and 4–6 µm in diameter. Portions of filaments in the peripheral region (Figure 4–6) are more or less laterally aligned, up to 30 cells long, and are comprised of cells that are mostly 5–13 µm long and 3–7 µm in diameter and sometimes contain floridean starch grains (Figure 7).

Peripheral region filaments terminate at the thallus surface in one, rarely two, epithallial cells with outermost walls rounded (Figures 4 and 6). Epithallial cells are subtended by initials that are as short as or shorter than their immediate inward derivatives (Figures 4 and 6). Cell elongation occurs mostly in the derivatives after they are cut off from initials. Within the thallus, cells of the same filament are linked by primary pit-connections, whereas cells of adjacent filaments (other than epithallial cells and subepithallial initials), are sometimes linked by cell fusions (Figures 6 and 7). Trichocytes are rare and occur at the thallus surface (Figure 4).

**Conceptacles** Thalli with multiporate or uniporate conceptacles (Figures 8–14, Table 2) occur in the Gulf of Trieste. The thalli collected in August 2008 contained only multiporate conceptacles, whereas material collected in April 2009 contained individuals with either uniporate or multiporate conceptacles.

Developmental stages were not seen, but some conceptacle roofs were still covered by thick pseudoparenchymatous discs (Figure 8) that form during conceptacle development (see Adey 1964 [as *P. rugulosum*] for details). These discs are shed, revealing the underlying uniporate or multiporate roof (Figures 12 and 14) that is, at first, situated below the surrounding thallus surface but eventually becomes more or less flush with the surrounding surface.

Uniporate conceptacles (Figure 12) in thalli from the Gulf of Trieste were densely crowded, and roofs were commonly white due to loss of pigments in roof cells. Gametangial




**Figures 2–7** *Phymatolithon lamii* (Gulf of Trieste: **3, 4**-PC0719004; **2, 5, 6, 7**-PC0719005): **2** Thallus with matte surface, uniporate conceptacles densely crowded. Note mature conceptacle without peripheral rim (arrow) and deep craters left by shedding of old conceptacles (arrowhead). **3** Thallus surface with delicate ridges. Note multiporate conceptacles (arrow) and deep craters (arrowhead). **4** Young thallus with dorisventral organisation and monomerous construction. Note trichochyte (arrow), domed epithallial cells (**e**), initials as long as or shorter of their inward derivates (**i**), cells of peripheral region laterally aligned (**p**), thin ventral region composed of up to 6 filament layers (**v**). **5** Thallus with well-developed peripheral region (**p**) composed of filaments with laterally aligned cells and thin ventral region (**v**) making up <10% of thallus thickness. **6** Adult thalli with domed epithallial cells (**e**), initials as short as or shorter than their immediate inward derivates (**i**), cells of peripheral region joined by cell fusions (**f**). **7** Peripheral cells with starch grains (**g**) and joined by cell fusions (**f**).

conceptacles up to 176 µm in external diameter were observed. Unfortunately, the conceptacles were empty, and thus we cannot be certain whether they were old male or old female/carposporangial conceptacles, although the conceptacle chamber diameter and height (Table 2) makes it more likely that they were male/spermatangial conceptacles.

Multiporate conceptacles (Figure 14) have a white, rimless pore plate and measure up to 346 µm externally. The roof is composed of filaments, each with 4–5 squarish cells, and pore plates that have up to 25 pores. All conceptacles examined were devoid of contents, and thus we are uncertain as to whether they had previously contained tetrasporangia or bisporangia; both are known in the British Isles (Chamberlain 1991, Irvine and Chamberlain 1994).

Roofs of old conceptacles, whether uniportate or multiporate, can break out, leaving crater-like depressions in the thallus surface (Figures 8 and 9), or entire conceptacles can become buried in the thallus (Figures 10 and 11) as a consequence of continued vegetative growth.

## Discussion

### Comparisons with previous studies of *Phymatolithon lamii*

Gulf of Trieste thalli are largely concordant with the type material and British Isles thalli, but are thinner, probably because of continuous abrasion due to the predominantly sedimentary bottom. Like British thalli, Mediterranean thalli are milky-pink with a smooth, matte surface in spring, whereas summer thalli have a patchy pink and white surface with delicate ridges. According to Adey (1964, as *Phymatolithon rugulosum*), thalli from the Gulf of Maine

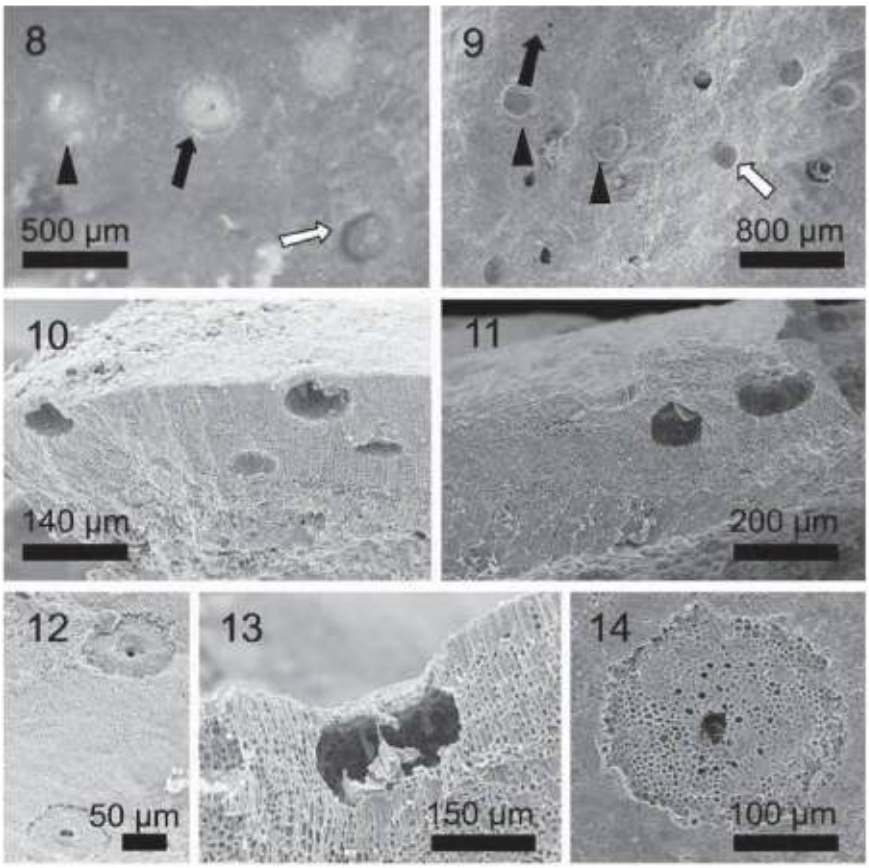
**Table 1** *Phymatolithon lamii*: Vegetative features in various regions.

| Locality and data source / Feature | *P. lamii* (Gulf of Trieste; this study) | *P. lamii* (British Isles; Chamberalin 1991) | *P. lamii* (Gulf of Maine; Adey 1964, as *P. rugulosum*, including type) | *Lithophyllum lamii* (type; Chamberlain 1991) | *Lithophyllum melobesioides* (type; Chamberlain 1991) |
|---|---|---|---|---|---|
| Habitat | | | | | |
| Substratum | shells | rock, shells and algae | rock and shells | rock | porcelain fragments |
| Depth range | 15 m | nd | nd | nd | nd |
| Morphology | | | | | |
| Thallus form | Encrusting | Encrusting | Encrusting | Somewhat warty | Encrusting |
| Thallus diameter | Up to 26–40 mm | Up to 60 mm | nd | 20×15 mm | 50×30 mm |
| Thallus thickness | 330–335 µm | 4 mm | 50 µm–4 mm | 1–2 mm | 200 µm |
| Vegetative anatomy | | | | | |
| Trichocytes | Rare | No | Occur sparingly | nd | nd |
| Cell fusions | Yes | Yes | Yes | Yes | Yes |
| Core region | | | | | |
| No. of filaments | 3–8 | Up to 10 | 2–8 | Up to 8 | 3–4 |
| Thickness | 30–43 µm | Up to 60 µm | 17–50 µm | nd | nd |
| Cell-length | 6–14 µm | (5) 11–40 µm | 8–31 µm | (8) 10–13 (20) µm | 7–8 (12) µm |
| Cell-diameter | 4–6 µm | (2) 3–7 (10) µm | 3–8 µm | 4–8 µm | 2–5 (6) µm |
| Peripheral region | | | | | |
| No. of filaments | Up to 30 | nd | nd | nd | nd |
| Thickness | 106–293 µm | [ca. 600 µm or more] | nd | nd | nd |
| Cell length | 4–13 µm | 2–11 µm | 0.5–13 µm | 6–12 (14) µm | 3–9 µm |
| Cell diameter | 3–7 µm | 2–7 µm | 2.5–8.5 µm | 3–7 (9) µm | 2–4 µm |
| Epithallial region | | | | | |
| Cells in surface view | Roundish | nd | nd | nd | nd |
| Outer walls in section | Domed | Domed | Domed | [Domed or flattened] | Domed |
| Number of cell layers | 1–2 | [1] | 1–2 | nd | nd |
| Cell diameter in surface | 4–6 µm | nd | nd | nd | nd |
| View | | | | | |
| Cell length | 2–3 µm | nd | nd | nd | nd |
| Cell diameter | 3–5 µm | nd | nd | nd | nd |
| Subepithallial initials | | | | | |
| length compared to subtending cells | As long as or shorter | [As long as or shorter] | nd | nd | nd |

Numbers in parentheses are unusually extreme values. Figures in square brackets are derived. nd, no available data.

have dorsal surfaces characterised by white spots and ridges that correspond to rapidly growing areas in which the upper dividing cells are relatively large, vacuolated and lack chromoplasts. Single trichochytes were rarely observed in one individual and occurred sparingly in Gulf of Maine thalli (Adey 1964, as *P. rugulosum*), but they were not observed in British Isles thalli. In the Gulf of Maine thalli (Adey 1964, as *P. rugulosum*), gametangial conceptacles were rare, especially female ones, occurring in <1% of the population. Mature male conceptacles were found in all seasons in the Gulf of Maine, but were more common in autumn and winter. We found only one individual with gametangial (probably spermatangial) conceptacles; it was collected in spring (April).

Mediterranean thalli are thinner than the type of *Phymatolithon lamii* and thalli from the British Isles (Table 1) described by Chamberlain (1991), but in both Mediterranean and British Isles thalli, the peripheral region of the vegetative thallus is well developed and both uniporate and multiporate conceptacles can become buried in the thallus. In contrast, the lectotype specimen of *Lithothamnion melobesioides* (Chamberlain 1991, Figure 4) consists of a thin crust (200 µm) and lacks buried conceptacles. The thickness of the peripheral region depends upon the age of the thallus, and the



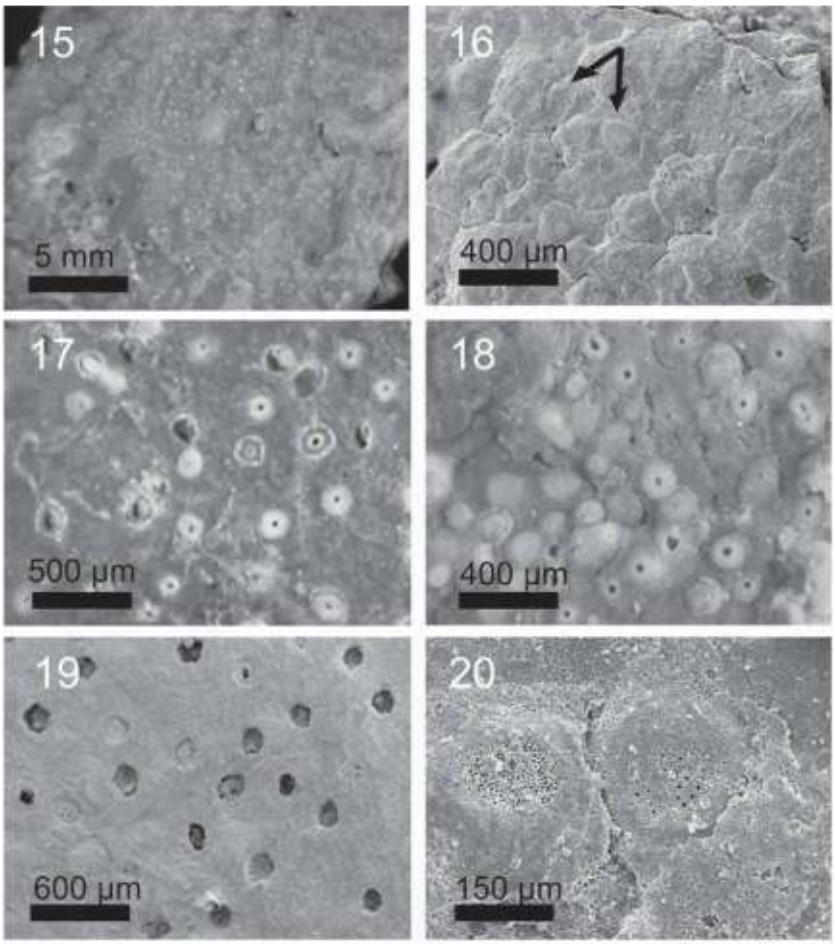

**Figures 8–14** *Phymatolithon lamii* (Gulf of Trieste: **8, 9, 14**-PC0719004; **10, 11, 12, 13**-PC0719005): **8, 9** Thick discs shedding at conceptacle maturity (arrowhead), exposing the conceptacle roofs (black arrow). Old conceptacles with characteristic deep craters after pore plates have broken off (white arrow). **10** Old uniporate conceptacles buried deep in the thallus. **11** Old multiporate conceptacles buried in the thallus. **12** Mature uniporate conceptacles with roof more or less flush with thallus surface. **13, 14** Mature multiporate conceptacle with roof flush with the thallus surface.

absence of buried conceptacles probably indicates a young thallus. Chamberlain (1991) suggests that thinner thalli with more regularly aligned peripheral cells are formed when continually abraded by stones.

In the Gulf of Trieste, we found *Phymatolithon lamii* at the Trezza San Pietro at 15 m depth and as thin crusts growing on shells of *Chlamys* sp. In the Gulf of Maine, it can sometimes overgrow other individuals of the same or different species (Adey 1964, as *P. rugulosum*). In the British Isles *P. lamii* grows on rocks, stones, shells and occasionally on *Laminaria* holdfasts, and can live in low tide pools (Chamberlain 1991), but it is more abundant from 3 to 21 m depth on wave-exposed shores (Adey and Adey 1973, as *P. rugulosum*). On the Rockall Bank east of Rockall (Scotland), it was found at the depth of 90 m (Clokie et al. 1981). In Nova Scotia, Johnson and Mann (1986, as *P. rugulosum*) found that *P. lamii* can inhibit the settlement of fleshy algae by continually shedding epithallial cell layers.

*Phymatolithon lenormandii* and *P. calcareum* are both widely recorded from the Mediterranean Sea, including the Northern Adriatic; species records are summarized by Babbini and Bressan (1997: 288–301) and by Furnari et al. (2003: 181–182), and descriptive accounts appear in Bressan and Babbini (2003: 184–187) and Falace et al. (2012: 136–137). Detailed accounts of the types of *P. lenormandii* and *P. calcareum* have been published by Düwel and Wegeberg (1996: 476–477, Figures 22–28) and Woelkerling and Irvine (1986), respectively.

*Phymatolithon lenormandii*, like *P. lamii*, is an encrusting species without branches or protuberances, and can display a variety of surface patterns (Irvine and Chamberlain 1994), making it easy to confuse with *P. lamii* on cursory examination (Figures 15–20). Based on data in Chamberlain (1991) and in Irvine and Chamberlain (1994), however, the two species differ in several ways. In *P. lamii*, the core region of the vegetative thallus rarely constitutes more than 10% of thallus thickness, whereas in *P. lenormandii*, the core region constitutes up to 50% of the thallus thickness. In *P. lamii*, multiporate conceptacles develop up to 100 µm below the thallus surface and are covered with a thick white disc of old vegetative cells. Discs are eventually shed, uncovering conceptacle roofs sunken in crater-like holes below




**Figures 15–20** Comparisons of Gulf of Trieste specimens of *Phymatolithon lamii* (PC0719004) with *P. lenormandii* (TSB 1147-444). **15** Matte thallus surface of *P. lamii*. **16** Squamulose thallus surface of *P. lenormandii* with multiporate conceptacles (arrows). **17** Mature uniporate conceptacles of *P. lamii* with roofs more or less flush with thallus surface, leaving deep craters after shedding. **18** Mature uniporate conceptacles of *P. lenormandii* more or less raised above surrounding thallus surface. **19** Mature multiporate conceptacles of *P. lamii* with roofs mainly below the thallus surface, leaving a crater-like hole after shedding. **20** Mature multiporate conceptacles of *P. lenormandii* more or less raised above surrounding thallus surface.

the thallus surface. At full maturity, the roofs of both uniporate and multiporate conceptacles commonly become more or less flush with the surrounding thallus surface (Figures 17 and 19). These features are illustrated in Chamberlain (1991: 226: figures 10–13). In *P. lenormandii*, by contrast, multiporate conceptacles form just below the thallus surface and only a thin white "veil" of overlying cells occurs. Conceptacle roofs never lie in deep crater-like holes (Figures 18 and 20), and at maturity the conceptacle roof is flush or more commonly somewhat raised above the surrounding thallus surface (see Irvine and Chamberlain 1994: 226, figure 111D; 227, figure 112; 229, figure 114). In *P. lamii*, senescent conceptacles with intact roofs commonly become buried in the thallus by overgrowth of surrounding vegetative filaments. Sometimes, however, roofs are lost and conceptacles become infilled with new vegetative growth from the bottom of the conceptacle chamber. In *P. lenormandii*, senescent conceptacles with intact roofs never become buried; they always lose roofs and become infilled and indistinguishable in the thallus.

Unlike *Phymatolithon lamii* and *P. lenormandii, P. calcareum* is almost always a branched, fruticose, free-living (unattached) species (see Irvine and Chamberlain 1994: 213, figure 103); most recently it has been recorded from the Gulf of Trieste by Falace et al. (2012). Attached forms were not seen in the Gulf of Trieste, and are rarely recorded in the literature. Cabioch (1966, 1970) described attached basal crusts as having a thin ventral core composed of 5–6 layers of filaments with rectangular cells and a peripheral region composed of filaments with ovoid cells. The crusts give rise to protuberances that become detached when about 1 cm long; these continue to grow and branch in the unattached state. Cabioch (1970) also found tetrasporangial and gametangial conceptacles on attached crustose individuals. The branches of unattached forms have a central core and a peripheral region where core filaments of their derivatives

**Table 2** *Phymatolithon lamii*: Reproductive features in various regions.

| Locality and data source / Characters | *P. lamii* (Gulf of Trieste; this study) | *P. lamii* (British Isles, Chamberlain 1991) | *P. lamii* (Gulf of Maine; Adey 1964, as *P. rugulosum*, including type) | *Lithophyllum lamii* (type; Chamberlain 1991) | *Lithophyllum melobesioides* (type; Chamberlain 1991) |
|---|---|---|---|---|---|
| Spermatangial conceptacle | | | | | – |
| External diameter | 96–176 µm[1] | nd | 120–240 µm | nd | |
| Chamber diameter | 58–152 µm[1] | (70) 99–120 µm | 85–200 µm | 100–150 µm | |
| Chamber height | 64–79 µm[1] | (45) 65–78 µm | 85–140 µm | nd | |
| Roof thickness | 19–38 µm[1] | 27–44 µm | nd | nd | |
| Roof with respect to thallus surface | Flush with[1] | Flush with | Flush with | nd | |
| Carposporangial conceptacle | – | | | | |
| External diameter | | nd | 105–155 µm | nd | nd |
| Chamber diameter | | 190–218 µm | nd | 140–225 µm | 110–140 µm |
| Chamber height | | 117–135 µm | nd | nd | nd |
| Roof thickness | | 44–52 µm | nd | nd | nd |
| Tetrasporangial conceptacle | | | | | |
| External diameter | 171–346 µm[1] | nd | nd | nd | 200 µm |
| Chamber diameter | 156–189 µm[1] | 143–208 µm | 120–240* | 100–150 (200) µm | 200 µm |
| Chamber height | 65–95 µm[1] | 73–104 µm | 33–100* | 70 µm | 70 µm |
| Roof thickness | 15–28 µm[1] | 18–34 µm | nd | nd | 45 µm |
| No. of cell layers in roof | 4–5[1] | 5–9 | nd | nd | nd |
| No. of pores | 13–25[1] | Up to 40 | 12–44 | nd | nd |
| Pore diameter | 6–7 µm[1] | nd | nd | nd | nd |
| No. of bordering pore cells | (5)–6–(7)[1] | nd | nd | nd | nd |
| Pore plate | Flat, rimless[1] | Flat, rimless | Flat, rimless | Flat, rimless | Flat, rimless |
| Roof with respect to thallus surface | Flush with[1] | Flush with | Flush with | Flush with | Flush with |
| Old conceptacles buried | Yes[1] | Yes | nd | Yes | No |
| Bisporangial conceptacle | – | | | – | – |
| External diameter | | 125–156 µm | nd | | |
| Chamber diameter | | 73–99 µm | 120–240* | | |
| Chamber height | | 18–26 µm | 33–100* | | |
| Roof thickness | | nd | nd | | |

In Gulf of Maine thalli, Adey (1964) recorded mainly bisporangial conceptacles without distinguishing measurements (*). Figures in parentheses are unusually extreme values. [1]For convenience of comparison, data on uniporate Gulf of Trieste thalli are placed under spermatangial conceptacles and data on multiporate Gulf of Trieste thalli are placed under tetrasporangial thalli. nd, no available data.

curve outwards towards the thallus surface (see Woelkerling and Irvine 1986: 60, figure 6).

Based on the above data, the three Mediterranean Sea species of *Phymatolithon* can be identified using differences in growth form and in multiporate conceptacles. The dichotomous key below summarizes these differences.

### Key to species of *Phymatolithon* recorded from the Mediterranean Sea

1a. Free-living thalli, with fruticose branches ..... .....*P. calcareum*

1b. Encrusting thalli, without branches..... 2

2a. Core region normally comprising <10% of thallus thickness; immature multiporate conceptacles covered by thick discs, leaving crater-like holes when shed; mature conceptacles mostly flush or below thallus surface; senescent conceptacles commonly becoming buried in thallus .....*P. lamii*

2b. Core region comprising up to 50% of thallus thickness; immature multiporate conceptacles covered by a thin veil, never leaving crater-like holes when shed; mature conceptacles mostly raised above thallus surface; senescent conceptacles never buried in thallus..... *P. lenormandii*

It is possible that *Phymatolithon lamii* originally arrived by natural pathways through the Strait of Gibraltar and is present in other areas of the Mediterranean, but has not yet been reported because it has been confused with the similar and commonly present *P. lenormandii*. Irvine and Chamberlain (1994: 227) note the taxonomic confusion surrounding *P. lenormandii*, as do Cabioch et al. (1992: 133).

It is equally possible, however, that *Phymatolithon lamii* has been introduced into the Mediterranean, at least regionally, as

a consequence of human activity. In the Adriatic Sea, a total of 49 alien macrophytes, of which 35 are well established, have been recorded to date (Zenetos et al. 2010). In particular, the Lagoon of Venice, situated in the western part of the Gulf of Trieste, has the highest number of marine alien taxa and represents a hotspot of introductions (Occhipinti-Ambrogi et al. 2010). It is probable that *Phymatolithon lamii* is also present in the Gulf of Venice, but never reported because many studies do not take calcareous algae into account.

The presence of *Phymatolithon lamii* at the Trezza San Pietro could be due to an introduction of individuals growing on mollusc shells or on macroalgae used as packing material for imported molluscs and then thrown into the sea. Because *P. lamii* commonly grows on rock or shells, introduction via ballast waters seems a less likely mechanism.

*Phymatolithon lamii* most likely prefers cold waters and it seems that the distribution of this species is controlled by maximum summer temperature. In Massachusetts Bay (USA), Adey (1964: 406, as *P. rugulosum*) only found the species in waters where the summer isotherm was below 16°C. The Gulf of Trieste is quite shallow, with a maximum depth <25 m, and has strong annual temperature fluctuations. The lowest temperatures are almost equal at all depths in February (7°C), whereas the highest temperatures at surface occur at the end of July (24°C) and at 20 meters depth in the first half of September (20°C) (Stravisi 1988). The finding of *P. lamii* out of the known temperature range could indicate a major adaptive shift of this species.

The presence of both multiporate (tetrasporangial/bisporangial) thalli and uniporate (gametangial) thalli suggests that the species may have become established in the Gulf of Trieste, but this requires further investigation. Similarly, whether *Phymatolithon lamii* occurs naturally elsewhere in the Mediterranean but has been misidentified as *P. lenormandii* or, alternatively, is alien and introduced regionally, or both, has not been resolved.

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# Sublittoral rocky bottoms and coralligenous outcrops in the Northern Adriatic Sea

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## Introduction

The geographical, climatic and biological distinctive features of the Northern Adriatic Sea drive to the existence of particular habitats. The lower infralittoral and circalittoral zones from the Gulfs of Venice to Trieste and off the coasts of Slovenia are dominated by muddy and coastal detritic bottoms (Lipej *et al*. 2006). However, numerous rocky outcrops are scattered at depths between 7 and 25 m and at distances of 0.5-25 nautical miles from the Italian coasts, while *Cladocora caespitosa* reefs are present near the Slovenian shores. The rocky outcrops, locally named as "*tegnùe", "trezze", "grebeni", "bromboli"* and "*presùre*", mainly concentrate between the Po Delta and the Gulf of Trieste, making a sort of arch that follows the shoreline. They are well known by fishermen who knew their existence since the 18$^{th}$ century (Olivi 1792). Stefanon (1967) was the first to describe some of these outcrops off Grado, which were initially interpreted as beachrocks (Braga and Stefanon 1969, Stefanon 1970, Newton and Stefanon 1975). Their genesis is currently related to seeping methane, and cementation and lithification processes (Colantoni *et al*. 1998, Stefanon and Zuppi 2000, Conti *et al*. 2002, Gordini *et al.* 2004, 2012). Most of these rocky outcrops are formed by a base rock (Stefanon and Zuppi 2000) hosting the growth of calcareous bioconcretions.

These rocky outcrops display a wide range of morphologies and dimensions, which, together with environmental factors and human pressures, influence the habitat complexity and thus their biodiversity. Northern Adriatic outcrops have been referred as coralligenous assemblages (Casellato and Stefanon 2008, Curiel *et al*. 2012) although they differ from the typical Mediterranean coralligenous outcrops *sensu stricto* (Ballesteros 2006), showing some distinctive features. Coralligenous formations are endangered throughout the Mediterranean Sea, due to several man-induced disturbances (Ballesteros 2006, RAC/SPA 2008). Increased knowledge about their extent, species composition and structure is essential for a suitable management that guarantees their protection, as specified by EU Directives and international Conventions and Protocols.

The aim of this study is to make an up-to-date contribution to the knowledge of the specific composition of the benthic assemblages and fish fauna from these northern Adriatic sublittoral reefs, based on the revision of literature data.

## Material and methods

### Geomorphological and Oceanographic setting

The Northern Adriatic is the most dynamic basin of the Mediterranean Sea (Russo and Artegiani 1996, Artegiani *et al*. 1997), characterized by strong river run-offs and wide seasonal and interannual temperature and salinity variability. The Adriatic Sea is surrounded by mainland areas, which exhibit sharp contrasts in tectonism, topography, climate and fluvial inputs. The northwestern coasts (venetian littoral up to Grado-Marano) present a long line of coastal lagoons, dominated by fine sediment and featuring important sediment outputs, whereas a number of small embayments can be found in the northeastern part south to Northern Istria which either follow tectonic lines or, as it is frequently the case, have been cut into the more easily eroded Flysch zones (Stefanon 1970, 1971a,b). The water density gradient between the north and the south Adriatic Sea is the most important factor triggering water movements in a main counter clock wise current, down to the Otranto straits and into the Mediterranean Sea, with an average velocity of 10 to 20 cm/sec. This current allows the Adriatic waters to be completely renewed about every 3 years (Zore-Armanda 1969). The highest rivers discharge generally occurs in late spring and autumn. The concentration of inorganic nutrients can be highly variable and is mainly determined by river inputs (Burba *et al*. 1994).

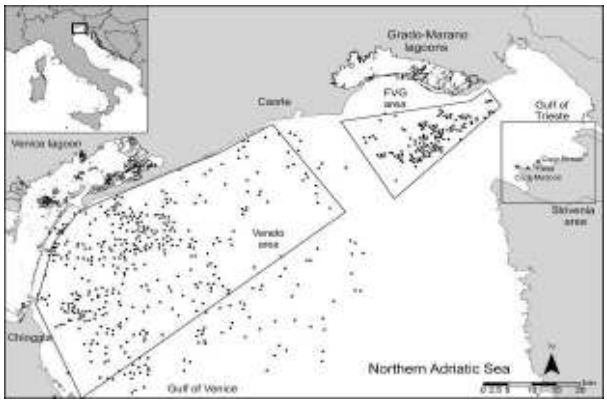


Fig. 1. Location map of the northern Adriatic Sea rocky outcrops (black dots). The Veneto, Friuli Venezia Giulia and Slovenia reefs considered are included into the drawn polygons.

### Datasets and analysis

Macroalgae quantitative data come from studies made over ca. 15 years on 37 rocky outcrops (see Curiel *et al*. 2012 for details). The investigated outcrops are located 0.5-10 nautical miles offshore

the Venice and Grado-Marano lagoons (FVG) at depths ranging from 7 to 25 m (Figure 1). Data related to the Slovenian area come from benthos dredge samplings made in open waters off Cape Madona (Piran), off Fiesa, near Cape Ronek, and in the Bay of Piran (Falace *et al*. 2011) (Figure 1). Qualitative data available in Solazzi and Tolomio (1981), Ponti and Mescalchin (2008) Ponti *et al*. (2011) have also been used.

Benthic invertebrates and fish fauna data are referred to studies reported in Table 1. Composition and abundance of the epibenthic assemblages were investigated in FVG areas using non-destructive methods, based on photographic sampling or video shoots. Voucher specimens were collected for accurate taxonomical identifications. Off the venetian coasts samplings were performed by manual scraping and collecting sessile invertebrates and vagile fauna with a vacuum lift using SCUBA. The number of individuals and the relative abundance of non-colonial taxa were determined, while the coverage was estimated for the colonial ones. Furthermore, the biomass was measured as dry weight. Samplings in Slovenian waters were performed using a benthos dredge. Data referenced by Mizzan (1992), Gabriele *et al.* (1999), Casellato and Stefanon (2008), and Ponti *et al*. (2011) have also been used.

Fish fauna dataset of FVG outcrops comes from visual census samplings and a seasonal study using trammel nets (Tab. 1). Finally, data by Cenci and Mazzoldi (2006) Giovanardi (2010) and Pessa and Molin (2010) using experimental fishing has been considered for the Venetian outcrops.

Table 1. Explored areas and sampling techniques adopted for benthic invertebrates and fish.

| Site | Photographic sampling on benthos | Scraping | Dredging | Visual census on fish | Experimental fishing | References |
|---|---|---|---|---|---|---|
| **N-W outcrops (off venetian littorals)** | X | X | | | | MAG.ACQUE-CORILA-SELC 2006[1] ARPAV-FMCV 2010[1] |
| **N-E outcrops (Gulf of Trieste)** | X | | | X | X | Borme 2010, Borme and Tirelli 2010, Faresi 2010, Odorico *et al*. 2010, Ciriaco *et al*. 2010 |
| **Slovenian sub-littoral bottom** | | | X | | | Orlando-Bonaca *et al*. 2012a,b |

[1] These datasets are cited in the text as Venetian Coast Data (VCD).

## Results and Discussion

### Biodiversity

We have obtained a list of 1001 taxa inhabiting the northern Adriatic sublittoral biogenic reefs (the animal taxa are listed in Annex I, while the macroalgae are reported in Curiel *et al*. (2012). The main groups are molluscs, algae, polychaetes, crustaceans, sponges and fish. Up to 1666 taxa were reported from coralligenous assemblages in the Mediterranean by Ballesteros (2006) (Table 2), the main groups being algae, crustaceans, polychaetes, bryozoans, sponges and fish. Hitherto, protozoans, turbellaria, acari, pycnogonida, brachiopods, pterobranchs, nemertines and crinoids have not been reported from the northern Adriatic biogenic reefs.

Differences in the relative abundance of some groups may be attributed to the presence of specialists working in these environments (i.e. bryozoans or molluscs). To our opinion, both lists will be highly increased as soon as new taxonomic work is performed. This is obvious since in some groups there are more representatives in the Adriatic than in the entire Mediterranean (Table 2).

Table 2. Number of taxa recognized in coralligenous assemblages from throughout the Mediterranean, and in the Northern Adriatic Sea.

| Taxa | Total for Mediterranean | Northern Adriatic |
|---|---|---|
| Algae | 315 | 190 |
| Protozoa | 61 | - |
| Porifera | 142 | 68 |
| Hydrozoa | 55 | 9 |
| Ctenophora | nd | 1 |
| Anthozoa | 43 | 20 |
| Scyphozoa | 1 | - |
| Turbellaria | 3 | - |
| Platyhelmintha | nd | 1 |
| Nemertea | 12 | 1 |
| Nematoda | nd | 1 |
| Polychaeta | 191 | 144 |
| Oligochaeta | nd | 1 |
| Chaetognatha | nd | 1 |
| Sipunculida | 3 | 6 |
| Echiurida | 2 | 1 |
| Chitonida | 7 | 6 |
| Prosobranchia | 61 | 113 |
| Opistobranchia | 33 | 42 |
| Bivalvia | 41 | 90 |

| | | |
|---|---|---|
| Scaphopoda | nd | 2 |
| Cephalopoda | 3 | 3 |
| Acarina | 6 | - |
| Pycnogonida | 15 | 1 |
| Copepoda | 54 | 1 |
| Ostracoda | 10 | 1 |
| Cirripedia | 3 | 7 |
| Phyllocarida | 1 | 1 |
| Mysida | 7 | 1 |
| Cumacea | 3 | 3 |
| Tanaidacea | 2 | 5 |
| Isopoda | 14 | 10 |
| Amphipoda | 100 | 29 |
| Decapoda | 56 | 65 |
| Stomatopoda | nd | 1 |
| Brachiopoda | 8 | - |
| Pterobranchia | 1 | - |
| Bryozoa | 171 | 29 |
| Crinoidea | 2 | - |
| Ophiuroidea | 17 | 7 |
| Echinoidea | 14 | 9 |
| Asteroidea | 8 | 5 |
| Holothurioidea | 9 | 6 |
| Tunicata | 82 | 40 |
| Pisces | 110 | 80 |

Macroalgae

Up to 190 macroalgal taxa have been reported from Veneto and FVG sublittoral rocky outcrops (138 Rhodophyta, 28 Ochrophyta and 24 Chlorophyta) (Curiel *et al*. 2012). The number of macroalgae collected on the Adriatic outcrops is relatively high considering the biogeographical context and the fact that they are dispersed on a sandy bottom (Curiel *et al*. 2012). The studied outcrops are characterized by a rich biodiversity and low coverage, with a high spatial and temporal variability on a small to medium scale. Such observations are in accordance with Ballesteros (2006), Kipson *et al*. (2011) and Gatti *et al*. (2012), who recognized a great heterogeneity within the coralligenous assemblages, due to small scale variation of the environmental factors. Morphological features and geographical locations of the outcrops influence the spatial pattern of the assemblages (Ponti *et al*. 2011, Curiel *et al*. 2012). This variability is more evident on shallower outcrops, where taxa were usually collected in transitional waters (Sfriso and Curiel 2007, Sfriso *et al*. 2009, Falace *et al*. 2009a,b) and on artificial coastal structures (Curiel *et al*. 1999, 2009, Rismondo *et al*. 2008, Falace *et al*. 2009b, Falace *et al*. 2010).

The high variability in the number of species and coverage recorded on the different outcrops is related to distance from the coast, outcrop topography, light availability and depth (Curiel *et al*. 2012). Shallower outcrops fostered the growth of erect algae, even if with low coverage, such as *Ulva laetevirens* Areschoug, *Cryptonemia lomation* (Bertoloni) J.Agardh, *Rhodophyllis divaricata* (Stackhouse) Papenfuss, *Rhodymenia ardissonei* (Kuntze) Feldmann, *Ceramium diaphanum* (Lightfoot) Roth, *Chondria capillaris* (Hudson) M.J.Wynne and *Dictyota dichotoma v. intricata* (C.Agardh) Greville. In contrast, deep water outcrops were characterized by high coverage of encrusting algae such as *Lithophyllum stictaeforme*, *Neogoniolithon mamillosum* and *Mesophyllum alternans*, that are acknowledged as important coralligenous bioconstructors.

Macroinvertebrates

The inventory of taxa collected lists a total of 732 taxa, belonging to 17 phyla (Annex I). The most numerous groups are molluscs (256 taxa), polychaetes (144 taxa), crustaceans (124 taxa), sponges (68 taxa) and tunicates (40 taxa).

Based on VCD data the most frequent taxa (presence >50% of the sampling sites) were the bivalves *Rocellaria dubia*, *Hiatella arctica*, *Modiolus barbatus*, *Striarca lactea*, *Musculus subpictus*, *Mimachlamys varia, Nucula nucleus,* the gastropods *Nassarius incrassatus, Hexaplex* (*Trunculariopsis) trunculus*, the polychaetes *Ceratonereis (Composetia) costae, Sabellaria spinulosa, Eunice vittata, Marphysa sanguinea, Spirobranchus triqueter, Hydroides pseudouncinatus*, the decapods *Pisidia longimana, Alpheus dentipes, Athanas nitescens* and *Pilumnus hirtellus*. Sponges displayed a mean coverage of 11%, with a maximum of 33%. The most abundant and frequent taxa (10-50% of the sampling sites) were *Tedania (Tedania) anhelans, Ircinia variabilis, Cliona viridis, Sarcotragus spinosulus, Chondrilla nucula, Aplysina aerophoba, Chondrosia reniformis* and *Dysidea fragilis*. *Didemnum maculosum, Pyura dura, Microcosmus vulgaris, Styela canopus, Polycitor adriaticus* and *Phallusia fumigata* were the most frequent tunicates (20-60% of the sampling sites), while the most abundant were *P. adriaticus, Aplidium conicum* and *D. maculosum* (mean coverage 1%, max. 8%). The most frequent bryozoans were *Schizobrachiella sanguinea* (50% of the sampling sites), *Amathia lendigera, Caberea boryi, Schizoporella errata* and *Tricellaria inopinata* (10-25% of the sampling sites). *S. sanguinea, S. errata, A. lendigera*, together with *Calpensia nobilis,* displayed also high coverage (mean coverage 2%, max. 42%). Among the echinoderms, the brittlestars *Ophiothrix fragilis* and *Amphipholis squamata* showed the highest frequency (> 90%).

On the Veneto outcrops the greatest values of biomass (VCD data) were measured for the sponges *S. spinosulus, T. anhelans, C. viridis, C. nucula, I. variabilis* (25-35 g dw $m^{-2}$), the tunicates *A.*

*conicum, Ascidia mentula* (1-3 g dw $m^{-2}$), the bryozoan *S. sanguinea* (5 g dw $m^{-2}$), the bivalves *Arca noae, Ostrea edulis, Mimachlamys varia, Chama gryphoides*, *R. dubia* (3-38 g dw $m^{-2}$) and the gastropods *H. trunculus* (16 g dw $m^{-2}$), *Thylacodes arenarius*, *Bolma rugosa* and *Nassarius incrassatus* (1.1-1.5 g dw $m^{-2}$).

Fishes

A total of 80 fish species were observed and/or collected using visual census and experimental fishing (Annex I). Most taxa were benthic (38) or necto-benthic (33), with a very small number of necto-pelagic (4) and pelagic (5) taxa. The most abundant taxa collected (Borme 2010) on the FVG outcrops were *Diplodus annularis*, *Spicara maena*, *Pagellus erythrinus*, *Trisopterus minutus*, *Arnoglossus thori*, *Monochirus hispidus*, *Scorpaena notata*, *S. porcus* and *Symphodus (Crenilabrus) tinca*. The highest species richness was observed in summer, but the maximum number of individuals was recognised in winter, mainly due to *Diplodus annularis* and *Spicara maena*, which use to aggregate in the vicinity of the outcrops when water temperature falls down (Borme 2010). On the Veneto outcrops the most abundant species were *Diplodus annularis*, *Lithognathus mormyrus*, *Trachurus trachurus* and *Diplodus sargus* (Pessa and Molin 2010). Giovanardi (2010) found *Diplodus annularis*, *Pagellus erythrinus*, *Spicara smaris*, *Trisopterus minutus* and *Diplodus vulgaris* as the main species present in fish catches.

**Macroalgal and animal builders**

According to Boldrin (1979), the main builder organisms responsible for the growth of the Adriatic rocky outcrops are coralline algae, bryozoans, molluscs (*Arca noae, Chama gryphoides, Thylacodes arenarius*), anthozoans (*Cladocora cespitosa*) and serpulid polychaetes (*Serpula concharum, Serpula vermicularis, Spirobranchus triqueter, Protula sp*.). Ponti *et al*. (2011) indicate the encrusting calcareous red algae as the dominant reef-forming organisms. However, the epibenthic assemblages of the Northern Adriatic reefs are very heterogeneous in terms of presence and relative abundance of taxa, and thus of the relative importance of the builders activity (Mizzan 1992, Ponti *et al*. 2011; Curiel *et al* 2012).

Up to 22 Corallinales and 5 Peyssonneliaceae have been reported (Curiel *et al*. 2012). The most common species were *Lithophyllum pustulatum* and *Lithothamnion philippii*, while the genus *Peyssonnelia* showed the highest coverage. In Table 3 the main builder algae are reported. Free-living, unattached nodules of coralline algae were observed in the seabed surrounding the FVG outcrops. *Lithophyllum racemus* (Lamarck) Foslie was predominant on sandy bottoms, while maërl facies with *Lithothamnion corallioides* (P.L.Crouan & H.M.Crouan) P.L.Crouan & H.M.Crouan and *Phymatolithon calcareum* (Pallas) W.H.Adey & D.L.McKibbin, along with *Lithothamnion*

*minervae* Basso and *L. racemus*, were present on pelitic-sandy bottoms. *Mesophyllum macroblastum*, a rair species in the Adriatic, was also collected in the FVG region (Kaleb *et al*. 2011) along with *Phymatolithon lamii* (M.Lemoine) Y.M.Chamberlain reported for the first time in the Mediterranean Sea (Kaleb *et al*. 2012).

On the Slovenian bottoms 11 coralline algae were collected (Falace *et al*. 2011). The most frequent were: *L. philippii*, *Lithothamnion sonderi, L. minervae* and *Pneophyllum confervicola* (Kützing) Y.M.Chamberlain, followed by *L. pustulatum* and *Neogoniolithon brassica-florida*. In some sites sub-fossil rhodoliths were also abundant.

Table 3. Main northern Adriatic builder macroalgae (*first report for the studied area)

| **Taxa** | **Outcrops** | **Slovenian Circalittoral belt** |
|---|---|---|
| *Lithophyllum incrustans* Philippi | + | |
| *Lithophyllum pustulatum* (Lamouroux) Foslie | + | + |
| *Lithophyllum stictaeforme* (Areschoug) Hauck | + | |
| *Lithothamnion minervae* Basso | + | +* |
| *Lithothamnion philippii* Foslie | + | +* |
| *Lithothamnion sonderi* Hauck | + | +* |
| *Mesophyllum alternans* (Foslie) Cabioch and Mendoza | + | |
| *Mesophyllum macroblastum* (Foslie) Adey | +* | |
| *Neogoniolithon brassica-florida* (Harvey) Setchell and Mason | + | +* |
| *Neogoniolithon mamillosum* (Hauck) Setchell and Mason | + | + |
| *Peyssonnelia harveyana* Crouan and Crouan ex J.Agardh | + | |
| *Peyssonnelia polymorpha* (Zanardini) F.Schmitz | + | |
| *Peyssonnelia rosa-marina* Boudouresque and Denizot | + | |
| *Peyssonnelia rubra* (Greville) J.Agardh | + | |
| *Peyssonnelia squamaria* (Gmelin) Decaisne | + | |
| *Phymatolithon lenormandii* (Areschoug).Adey | + | + |

Among the "large animal builders" (*sensu* Hong 1980, Ballesteros 2006) we report the bryozoans *Myriapora truncata* (Orlando-Bonaca *et al*. 2012a,b), the serpulids *Serpula vermicularis* (Casellato *et al*. 2007, Faresi 2010, Ponti *et al*. 2011, VCD), *S. concharum* (Gabriele *et al*. 1999, Casellato and

Stefanon 2008, Ponti *et al*. 2011, VCD) and *Spirobranchus polytrema* (Gabriele *et al*. 1999), the molluscs *Vermetus triquetrus* (Orlando-Bonaca *et al*. 2012a,b, VCD), *Thylacodes arenarius* (Mizzan 1992, Casellato and Stefanon 2008, Faresi 2010, Ponti *et al*. 2011, VCD) and the scleractinians *Leptopsammia pruvoti* (Casellato and Stefanon 2008, Ponti *et al*. 2011), *Caryophyllia inornata* (Mizzan 1992, Casellato and Stefanon 2008), *C. smithii* (Mizzan 1992, Faresi 2010, Ponti *et al*. 2011). The most common and widespread on the Veneto outcrops are *S. vermicularis, S. concharum* and *V. triquetrus* (Gabriele *et al*. 1999, Casellato and Stefanon 2008, Ponti *et al*. 2011, VCD). *C. caespitosa* resulted to be rare on the Italian outcrops, while it proved to be an important builder in Slovenia.

The most common animals with a "reduced builder activity" (*sensu* Hong 1980) are the serpulids *Hydroides* spp. (Gabriele *et al*. 1999, Ponti *et al*. 2011, VCD) and the barnacle *Verruca strömia* (Gabriele *et al*. 1999, Casellato and Stefanon 2008, VCD). Finally, the "agglomerative builders" (*sensu* Hong 1980) are the bryozoans *Beania* sp. (VCD) and the alcyonarian *Epizoanthus arenaceus* (Gabriele *et al*. 1999, Casellato and Stefanon 2008, VCD). *Geodia cydonium* is frequent and abundant on the Veneto and FVG outcrops and was also found in Slovenia (Casellato and Stefanon 2008, Faresi 2010, Ponti *et al*. 2011, Orlando-Bonaca *et al*. 2012a,b).

It is worth to mention that according to Ballesteros (2006) bryozoans largely contribute as builders of the coralligenous framework, while during our studies only two species were found.

The role of the bioeroders on the biogenic reefs of the Northern Adriatic has not yet been exhaustively explored. On the rocky outcrops of the Northern Adriatic a total of 14 bioeroders were found, of which 4 Porifera, 2 Sipunculida, 4 Bivalvia, 3 Polychaeta and 1 Echinodermata (Annex I). On the Veneto outcrops *Cliona viridis* and *C. celata* are abundant and frequent taxa (Gabriele *et al*. 1999, Casellato and Stefanon 2008, Ponti *et al*. 2011, VTD) while *C. rhodensis* and *C. thoosina* were found only by Ponti *et al*. (2011). *Echinus melo* was restricted to the FVG outcrops even if its bioerosional role could be considered very limited, because of the exiguous number of individuals observed on the rocky surfaces.

The microborers (i.e. green algae, fungi, cyanobacteria) have not been taken into consideration, while among the macroborers the most frequent were the Mollusca *H. arctica* (66% of the Veneto sampling sites, with mean biomass of 0,2 g dw $m^{-2}$) and *R. dubia* (83% of the Veneto sites; mean biomass 3 g dw $m^{-2}$) that are widespread on the FVG and Veneto rocky outcrops and on Slovenian bottoms (Mizzan 1992, Gabriele *et al*. 1999, Casellato and Stefanon 2008, Faresi 2010, Ponti *et al*. 2011, Orlando-Bonaca *et al*. 2012a,b, VTD). *Lithophaga lithophaga* (17% of the Veneto sites; mean biomass 1,5 g dw $m^{-2}$) and *Petricola lithophaga* (13% of the Veneto sites; mean biomass 0,1 g dw $m^{-2}$) were reported by Casellato and Stefanon (2008) and VCD.

**Geographical gradients**

The macroalgal assemblages of the Veneto and FVG outcrops were similar in the number of taxa, but differed in coverage (Fig. 2), the abundance of macroalgae being larger in FVG (Curiel *et al*. 2012). Both the number of algae and their coverage showed a great variability in relation to the morphology of the outcrops, distance from the coast, depth and geographical location (Curiel *et al*. 2012). On the inshore outcrops situated near the fluvial inflows and the Venice lagoons, the algal coverage was very low and the substrate was largely covered by sediment. On the contrary, the rocky outcrops situated in deeper water offshore the Venice Lagoon (mean distance 10 km) along with the sites off the Grado-Marano Lagoons, were characterized by the highest total algal coverage. In particular, the FVG outcrops, distinguished by lower turbidity and sedimentation, displayed a higher number of taxa and total coverage of encrusting algae such as *Lithophyllum incrustans*, *L. minervae*, *L. philippii*, *Peyssonnelia polymorpha* and *P. rosa-marina*. Some erect algae, such as *Arthrocladia villosa* (Hudson) Duby, *Cryptonemia lomation, Dictyota dichotoma* (Hudson) J.V. Lamouroux v. *dichotoma, Halymenia elongata* C. Agardh, *H. floresii* (Clemente) C. Agardh, *Nithophyllum punctatum* (Stackhouse) Greville, *R. ardissonei, Scinaia complanata* (F.S. Collins) A.D. Cotton and *Taonia atomaria* (Woodward) J. Agardh, were also abundant. Although the turf-forming and filamentous algae numerically succeeded both on the Veneto and FVG outcrops, they showed low coverage, with the exception of *Pseudochlorodesmis furcellata* (Zanardini) Børgesen.

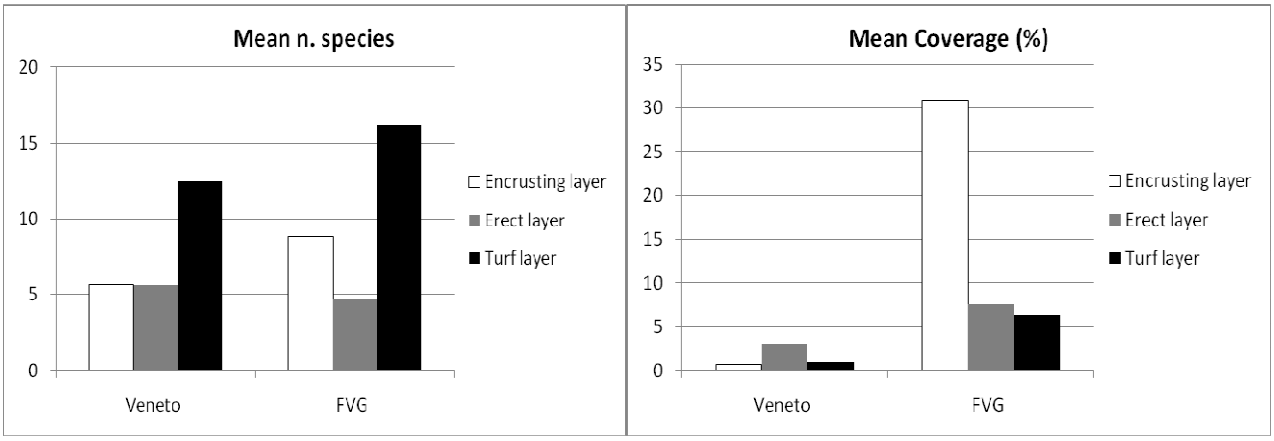


Fig. 2 Mean number of species and coverage of main algal morphological groups.

The Veneto outcrops show a great number of zoobenthic taxa in comparison to the FVG ones and the Slovenian circalittoral bottoms. In particular, the main differences were observed for crustaceans, molluscs, polychaetes, sponges and tunicates (Fig. 3). Noticeably, this difference

should be mostly due to the great number of rocky outcrops investigated and published studies along the Venetian coasts and to the different sampling methods. Nevertheless, since in terms of trophic guilds the majority of these epibenthic invertebrates are filter feeders, the greater incidence of organic suspended matter that characterize the western sector of the Northern Adriatic (Bianchi *et al*. 2004, Solidoro *et al*. 2009) could also contribute to explain the observed differences.

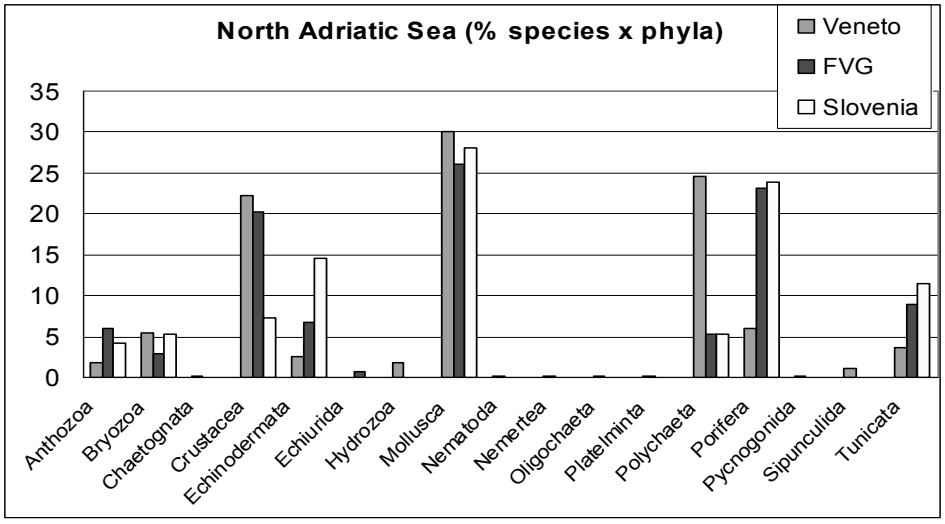


Fig. 3 Zoobenthic taxa percentage in the different study areas.

The sublittoral belt off Slovenia is characterized by a bionomic element formerly defined as "precoralligenous" stage (Pérès and Gamulin Brida 1973), composed mostly by *Corallina officinalis* Linnaeus, *Flabellia petiolata* (Turra) Nizamuddin, *Halimeda tuna* (J.Ellis & Solander) J.V.Lamouroux, *Lithothamnion* spp. and *Peyssonnelia squamaria* (Orlando-Bonaca and Lipej 2005). In Slovenia this assemblage is distributed from 3 m to 14 m, within the area between Cape Ronek and Cape Madona Nature Monument in Piran. It comes clear that the extension of this habitat is currently unknown, as a complete mapping is not yet available. These assemblages increase the habitat heterogeneity by offering many ecological niches for many benthic invertebrates. At the very same time this habitat type hosts outstanding fish diversity (Lipej *et al*. 2003, Orlando-Bonaca and Lipej 2007). The circalittoral belt hosts a different habitat represented by smaller biogenic formations colonized mainly by coralline algae (Falace *et al*. 2011) and benthic filter-feeders. Moreover, in waters off Cape Ronek, the only biogenic reef till now described for the Slovenian area is a solitary reef created by the stony coral *C. caespitosa.* The species is also present, in a much smaller extention, in the Cape Madona Nature Monument in Piran. At those localities dense agglomerations of the stony coral form a peculiar facies, despite the fact that the largest colonies do not even reach 50 cm in diameter. The main ecological parameters which seem to play a major role accounting for the distribution of those agglomerations are light availability, substrate

heterogeneity and hydrodinamic features. *C. caespitosa* is mainly threatened by pollution, as well as by siltation, anchoring and trawling (Lipej *et al*. 2006). It seems that it is also sensitive to the temperature increase due to the global climatic changes, and, on a general overview, it is undergoing a rapid decrease in both size and spatial distribution in the Mediterranean Sea (Morri *et al*. 2001). In the venetian outcrops, *C. caespitosa* is a rare species, but the discovery of fossils testifies the relevant role that this bioconstructor had in the past (Ponti and Mescalchin 2008). In the Northern Adriatic recent work reported banks of *Cladocora* along the Prvić and Pag Islands (Croatia) (Kružić and Benković 2008).

**Comparisons with typical Mediterranean coralligenous habitat**

The origin of the Northern Adriatic rocky outcrops is mainly related to the cementation process due to methane seepings and not only to bioconstruction activity (Gordini *et al*. 2012). This habitat due to the turbidity that characterizes the Northern Adriatic develops at shallower depths when compared to typical Mediterranean coralligenous outcrops that are described at depths from 20 to 120 meters (Ballesteros 2006).

17 taxa considered characteristic of the coralligenous habitat (Ballesteros 2006) are reported on the Adriatic rocky outcrops, of which 7 Crustacea (*Alpheus dentipes*, *Athanas nitescens*, *Cestopagurus timidus*, *Eualus cranchii*, *Galathea bolivari*, *Pilumnus hirtellus*, *Porcellana platycheles*), 5 Polychaeta (*Eunice torquata*, *Haplosyllis spongicola*, *Lumbrineris coccinea*, *Pholoe minuta*, *Platynereis coccinea*), 4 Porifera (*Acanthella acuta*, *Agelas oroides*, *Axinella damicornis*, *Haliclona* (*Reniera*) *mediterranea*) and 1 Tunicata (*Cystodytes dellechiajei*). On the contrary, the large anthozoans, like *Paramuricea clavata* (Risso 1826), *Leptogorgia sarmentosa* (Esper 1789) and *Eunicella* species, are lacking. Even if on the Adriatic rocky outcrops 29 species of Bryozoa have been reported (Annex I), the large bryozoans, such as *Margaretta cereoides* (Ellis & Solander 1786), *Cellaria salicornioides* Lamouroux, 1816, *Pentapora fascialis* (Pallas 1766) and *Reteporella grimaldii* (Jullien 1903) are missing, except for *Myriapora truncata* that was found in Slovenia.

The absence of these species is probably related to the scarce elevation of the outcrops, an increased sediment resuspension, a reduced surface of colonization and a high water turbidity.

None of the reported fish species (Annex I) could be considered typical of the coralligenous habitat (Ballesteros 2006), although most of them are characteristic of hard bottoms or gravel substrata. In particular *Diplodus puntazzo*, *Scorpaena scrofa*, *Serranus cabrilla*, *Spicara smaris*, *Spondyliosoma cantharus* are considered abundant species, and *Chromis chromis*, *Conger conger*, *Coris julis*, *Dentex dentex*, *Diplodus vulgaris*, *Labrus merula*, *Sciaena umbra*, *Scorpaena notata*, *Zeus faber*,

*Symphodus mediterraneus* and *S. tinca* are considered common species in coralligenous habitats from the North Western Mediterranean (Sartoretto *et al*. 1997, Ballesteros 2006).

## Conclusions

The rocky outcrops of the Northern Adriatic Sea represent an important hot spot for species diversity since they represent the only hard bottoms in the lower infralittoral and upper circalittoral zones. These biogenic reefs probably represent a unique type of outcrops related to coralligenous reefs, similar to those described from the Apulian coasts (Sarà 1969), and they seem to withstand high salinity and temperature variations. They are characterized by a high number of suspension feeders and by a low complexity at structural and functional levels. Due to their rarity, their biogenic origin and the fact that they concentrate a large number of hard bottom animals and algae, which are extremely rare in the Northern Adriatic, these formations need to be protected at the same level of that already established for coralligenous assemblages under the Barcelona Convention and the Habitats Directive.

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**Annex I**

**Porifera**

*Acanthella acuta* Schmidt, 1862
*Agelas oroides* (Schmidt, 1864)
*Antho (Antho) inconstans* (Topsent, 1925)
*Aplysilla sulfurea* Schulze, 1878
*Aplysina aerophoba* Nardo, 1833
*Axinella cannabina* (Esper, 1794)
*Aplysina cavernicola* (Vacelet, 1959)
*Axinella damicornis* (Esper, 1794)
*Axinella polypoides* Schmidt, 1862
*Axinella verrucosa* (Esper, 1794)
*Bubaris vermiculata* (Bowerbank, 1866)
*Chondrilla nucula* Schmidt, 1862
*Chondrosia reniformis* Nardo, 1847
*Clathria (Clathria) compressa* Schmidt, 1862
*Clathria (Clathria) coralloides* (Olivi, 1792)
*Cliona celata* Grant, 1826
*Cliona rhodensis* Rützler and Bromley, 1981
*Cliona thoosina* Topsent, 1888
*Cliona viridis* (Schmidt, 1862)
*Cliothosa hancocki* (Topsent, 1888)
*Crambe crambe* (Schmidt, 1862)
*Dercitus (Stoeba) plicatus* (Schmidt, 1868)
*Dictyonella incisa* (Schmidt, 1880)
*Dysidea avara* (Schmidt, 1862)
*Dysidea fragilis* (Montagu, 1818)
*Dysidea tupha* (Martens, 1824)
*Geodia cydonium* (Jameson, 1811)
*Halichondria (Halichondria) panicea* (Pallas, 1766)
*Halichondria (Halichondria) semitubulosa* Lieberkühn, 1859
*Haliclona (Haliclona) simulans* (Johnston, 1842)
*Haliclona (Reniera) cratera* (Schmidt, 1862)
*Haliclona (Reniera) mediterranea* Griessinger, 1971
*Haliclona (Soestella) mamillata* (Griessinger, 1971)
*Hemimycale columella* (Bowerbank, 1874)
*Hexadella racovitzai* Topsent, 1896
*Hippospongia communis* (Lamarck, 1814)
*Hymeniacidon perlevis* (Montagu, 1818)
*Ircinia dendroides* (Schmidt, 1862)
*Ircinia variabilis* (Schmidt, 1862)
*Leucandra aspera* (Schmidt, 1862)
*Lissodendoryx (Lissodendoryx) isodictyalis* (Carter, 1882)
*Mycale (Mycale) massa* (Schmidt, 1862)
*Mycale tunicata* (Schmidt, 1862)
*Myxilla (Myxilla) rosacea* (Lieberkühn, 1859)
*Oscarella lobularis* (Schmidt, 1862)
*Petrosia (Petrosia) ficiformis* (Poiret, 1789)
*Phorbas fictitius* (Bowerbank, 1866)
*Phorbas tenacior* (Topsent, 1925)
*Pione vastifica* (Hancock, 1849)
*Pleraplysilla minchini* Topsent, 1905
*Pleraplysilla spinifera* (Schulze, 1879)
*Polymastia mamillaris* (Müller, 1806)
*Pseudosuberites sulphureus* (Bowerbank, 1866)
*Raspailia (Raspailia) viminalis* Schmidt, 1862
*Sarcotragus fasciculatus* (Pallas, 1766)
*Sarcotragus spinosulus* Schmidt, 1862
*Scalarispongia scalaris* (Schmidt, 1862)
*Spongia (Spongia) officinalis* Linnaeus, 1759
*Suberites carnosus* (Johnston, 1842)
*Suberites domuncula* (Olivi, 1792)
*Suberites massa* Nardo, 1847
*Sycon raphanus* Schmidt, 1862
*Tedania (Tedania) anhelans* (Lieberkühn, 1859)
*Terpios fugax* Duchassaing and Michelotti, 1864
*Tethya aurantium* (Pallas, 1766)
*Tethya citrina* Sarà and Melone, 1965

*Ulosa stuposa* (Esper, 1794)

*Ute glabra* Schmidt, 1864

**Hydrozoa**

*Aglaophenia* sp.

*Campanularia hincksii* Alder, 1856

*Clytia gracilis* (Sars, 1850)

*Ectopleura crocea* (Agassiz, 1862)

*Eudendrium racemosum* (Cavolini, 1785)

*Gonothyraea loveni* (Allman, 1859)

*Obelia dichotoma* (Linnaeus, 1758)

*Sertularella mediterranea* Hartlaub, 1901

*Zanclea costata* Gegenbaur, 1857

**Ctenophora**

*Beroe ovata* Bosc, 1802

**Anthozoa**

*Adamsia carciniopados* (Otto, 1823)

*Adamsia palliata* (Fabricius, 1779)

*Aiptasia mutabilis* (Gravenhorst, 1831)

*Astroides calycularis* (Pallas, 1766)

*Balanophyllia (Balanophyllia) europaea* (Risso, 1826)

*Calliactis parasitica* (Couch, 1842)

*Caryophyllia (Caryophyllia) inornata* (Duncan, 1878)

*Caryophyllia (Caryophyllia) smithii* Stokes and Broderip, 1828

*Cereus pedunculatus* (Pennant, 1777)

*Cerianthus membranaceus* (Spallanzani, 1784)

*Cladocora caespitosa* (Linnaeus, 1767)

*Condylactis aurantiaca* (Delle Chiaje, 1825)

*Cornularia cornucopiae* (Pallas, 1766)

*Epizoanthus arenaceus* delle Chiaje, 1823

*Leptopsammia pruvoti* Lacaze-Duthiers, 1897

*Maasella edwardsi* (de Lacaze-Duthiers, 1888)

*Paralcyonium spinulosum* Delle Chiaje, 1822

*Parazoanthus axinellae* (Schmidt, 1862)

*Sagartia elegans* (Dalyell, 1848)

*Sarcodictyon roseum* (Philippi, 1842)

**Platyhelminthes** n.d.

**Nemertea** n.d.

**Nematoda** n.d.

**Echiura**

*Bonellia viridis* Rolando, 1821

**Sipunculida**

*Aspidosiphon (Aspidosiphon) muelleri* Diesing, 1851

*Golfingia (Golfingia) elongata* (Keferstein, 1862)

*Golfingia (Golfingia) vulgaris vulgaris* (De Blainville, 1827)

*Phascolion (Phascolion) strombus strombus* (Montagu, 1804)

*Phascolosoma (Phascolosoma) granulatum* Leuckart, 1828

*Sipunculus (Sipunculus) nudus* Linnaeus, 1766

**Polyplacophora**

*Callochiton septemvalvis* (Montagu, 1803)

*Chiton (Rhyssoplax) corallinus* (Risso, 1826)

*Chiton (Rhyssoplax) olivaceus* Spengler, 1797

*Ischnochiton (Ischnochiton) rissoi* (Payraudeau, 1826)

*Leptochiton scabridus* (Jeffreys, 1880)

*Parachiton africanus* (Nierstrasz, 1906)

**Gastropoda**

*Aclis attenuans* Jeffreys, 1883

*Acteon tornatilis* (Linnaeus, 1758)

*Akera bullata* Müller O.F., 1776

*Alvania beanii* (Hanley in Thorpe, 1844)

*Alvania cancellata* (da Costa, 1778)

*Alvania cimex* (Linnaeus, 1758)

*Alvania discors* (Allan, 1818)

*Alvania geryonia* (Nardo, 1847)

*Alvania lactea* (Michaud, 1832)

*Alvania punctura* (Montagu, 1803)

*Alvania subsoluta* (Aradas, 1847)

*Alvania testae* (Aradas and Maggiore, 1844)

*Ammonicera rota* (Forbes and Hanley, 1850)

*Ulosa stuposa* (Esper, 1794)

*Ute glabra* Schmidt, 1864

**Hydrozoa**

*Aglaophenia* sp.

*Campanularia hincksii* Alder, 1856

*Clytia gracilis* (Sars, 1850)

*Ectopleura crocea* (Agassiz, 1862)

*Eudendrium racemosum* (Cavolini, 1785)

*Gonothyraea loveni* (Allman, 1859)

*Obelia dichotoma* (Linnaeus, 1758)

*Sertularella mediterranea* Hartlaub, 1901

*Zanclea costata* Gegenbaur, 1857

**Ctenophora**

*Beroe ovata* Bosc, 1802

**Anthozoa**

*Adamsia carciniopados* (Otto, 1823)

*Adamsia palliata* (Fabricius, 1779)

*Aiptasia mutabilis* (Gravenhorst, 1831)

*Astroides calycularis* (Pallas, 1766)

*Balanophyllia (Balanophyllia) europaea* (Risso, 1826)

*Calliactis parasitica* (Couch, 1842)

*Caryophyllia (Caryophyllia) inornata* (Duncan, 1878)

*Caryophyllia (Caryophyllia) smithii* Stokes and Broderip, 1828

*Cereus pedunculatus* (Pennant, 1777)

*Cerianthus membranaceus* (Spallanzani, 1784)

*Cladocora caespitosa* (Linnaeus, 1767)

*Condylactis aurantiaca* (Delle Chiaje, 1825)

*Cornularia cornucopiae* (Pallas, 1766)

*Epizoanthus arenaceus* delle Chiaje, 1823

*Leptopsammia pruvoti* Lacaze-Duthiers, 1897

*Maasella edwardsi* (de Lacaze-Duthiers, 1888)

*Paralcyonium spinulosum* Delle Chiaje, 1822

*Parazoanthus axinellae* (Schmidt, 1862)

*Segartia elegans* (Dalyell, 1848)

*Sarcodictyon roseum* (Philippi, 1842)

**Platyhelminthes** n.d.

**Nemertea** n.d.

**Nematoda** n.d.

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*Alvania subsoluta* (Aradas, 1847)

*Alvania testae* (Aradas and Maggiore, 1844)

*Ammonicera rota* (Forbes and Hanley, 1850)

*Aplysia* sp.
*Aporrhais pespelecani* (Linnaeus, 1758)
*Barleeia rubra* (J. Adams, 1797)
*Bela nebula* (Montagu, 1803)
*Bela taprurensis* (Pallary, 1904)
*Berthella ocellata* (delle Chiaje, 1830)
*Bittium incile* Watson, 1897
*Bittium latreillii* (Payraudeau, 1826)
*Bittium reticulatum* (da Costa, 1778)
*Bolinus brandaris* (Linnaeus, 1758)
*Bolma rugosa* (Linnaeus, 1767)
*Caecum clarkii* Carpenter, 1859
*Caecum trachea* (Montagu, 1803)
*Caecum subannulatum* De Folin, 1870
*Calliostoma conulus* (Linnaeus, 1758)
*Calliostoma virescens* Coen, 1933
*Calliostoma zizyphinum* (Linnaeus, 1758)
*Calyptraea chinensis* (Linnaeus, 1758)
*Capulus ungaricus* (Linnaeus, 1758)
*Cerithiopsis tubercularis* (Montagu, 1803)
*Cerithium vulgatum* Bruguière, 1792
*Chauvetia brunnea* (Donovan, 1804)
*Chrysallida excavata* (Philippi, 1836)
*Chrysallida incerta* (Milaschewitsch, 1916)
*Chrysallida indistincta* (Montagu, 1808)
*Chrysallida monozona* (Brusina, 1869)
*Clanculus corallinus* (Gmelin, 1791)
*Clanculus cruciatus* (Linnaeus, 1758)
*Clathrella clathrata* (Philippi, 1844)
*Cratena peregrina* (Gmelin, 1791)
*Crepidula cataldi* (Parenzan, 1970)
*Crepidula gibbosa* Defrance, 1818
*Crepidula unguiformis* Lamarck, 1822
*Crisilla semistriata* (Montagu, 1808)
*Cylichnina umbilicata* (Montagu, 1803)
*Dendrodoris grandiflora* (Rapp, 1827)
*Dendrodoris limbata* (Cuvier, 1804)
*Diodora gibberula* (Lamarck, 1822)
*Diodora graeca* (Linnaeus, 1758)
*Diodora italica* (Defrance, 1820)
*Doris pseudoargus* Rapp, 1827
*Ebala pointeli* (de Folin, 1868)
*Emarginula huzardii* (Payraudeau, 1826)
*Emarginula rosea* Bell, 1824
*Epitonium clathrus* (Linnaeus, 1758)
*Eulima bilineata* Alder, 1848
*Eulima glabra* (da Costa, 1778)
*Eulimella acicula* (Philippi, 1836)
*Eulimella scillae* (Scacchi, 1835)
*Euspira guilleminii* (Payraudeau, 1826)
*Euthria cornea* (Linnaeus, 1758)
*Felimare villafranca* (Risso, 1818)
*Fissurella nubecula* (Linnaeus, 1758)
*Flabellina affinis* (Gmelin, 1791)
*Flabellina pedata* (Montagu, 1815)
*Fossarus ambiguus* (Linnaeus, 1758)
*Fusceulima minuta* (Jeffreys, 1884)
*Fusinus pulchellus* (Philippi, 1844)
*Fusinus rostratus* (Olivi, 1792)
*Fusinus rudis* (Philippi, 1844)
*Galeodea echinophora* (Linnaeus, 1758)
*Gibberula miliaria* (Linnaeus, 1758)
*Gibberula philippii* (Monterosato, 1878)
*Gibbula albida* (Gmelin, 1791)
*Gibbula guttadauri* (Philippi, 1836)
*Gibbula magus* (Linnaeus, 1758)
*Hadriania craticulata* Bucquoy, Dautzenberg and Dollfus, 1882
*Haliotis tuberculata* Linnaeus, 1758
*Haminoea hydatis* (Linnaeus, 1758)
*Hexaplex (Trunculariopsis) trunculus* (Linnaeus, 1758)
*Hyala vitrea* (Montagu, 1803)
*Jujubinus exasperatus* (Pennant, 1777)
*Jujubinus montagui* (Wood, 1828)
*Jujubinus striatus striatus* (Linnaeus, 1758)

*Kleinella (Euparthenia) bulinea* (Lowe, 1841)
*Kleinella (Euparthenia) humboldti* (Risso, 1826)
*Littorina saxatilis* (Olivi, 1792)
*Lunatia fusca* (Blainville, 1825)
*Mangelia attenuata* (Montagu, 1803)
*Mangelia costulata* Risso, 1826
*Mangelia stosiciana* Brusina, 1869
*Mangelia unifasciata* (Deshayes, 1835)
*Marshallora adversa* (Montagu, 1803)
*Melanella polita* (Linnaeus, 1758)
*Metaxia metaxa* (delle Chiaje, 1828)
*Mitra zonata* Marryat, 1818
*Mitrella scripta* (Linnaeus, 1758)
*Monophorus perversus* (Linnaeus, 1758)
*Muricopsis (Muricopsis) cristata* (Brocchi, 1814)
*Nassarius cuvierii* (Payraudeau, 1826)
*Nassarius incrassatus* (Strøm, 1768)
*Nassarius lima* (Dillwyn, 1817)
*Nassarius nitidus* (Jeffreys, 1867)
*Nassarius pygmaeus* (Lamarck, 1822)
*Nassarius reticulatus* (Linnaeus, 1758)
*Natica hebraea* (Martyn, 1786)
*Natica stercusmuscarum* (Gmelin, 1791)
*Noemiamea dolioliformis* (Jeffreys, 1848)
*Obtusella intersecta* (Wood S., 1857)
*Ocenebra erinaceus* (Linnaeus, 1758)
*Ocinebrina edwardsii* (Payraudeau, 1826)
*Ocinebrina ingloria* (Crosse, 1865)
*Odostomella doliolum* (Philippi, 1844)
*Odostomia acuta* Jeffreys, 1848
*Odostomia nitens* Jeffreys, 1870
*Odostomia plicata* (Montagu, 1803)
*Odostomia turrita* Hanley, 1844
*Ondina divisa* (J. Adams, 1797)
*Ondina vitrea* (Brusina, 1866)
*Philbertia papillosa* Pallary, 1904
*Philine* sp.
*Pollia dorbignyi* (Payraudeau, 1826)
*Pollia scabra* Locard, 1892
*Pseudoacteon pusillus* Forbes, 1844
*Puncturella noachina* (Linnaeus, 1771)
*Pusillina sarsii* (Lovén, 1846)
*Raphitoma* sp.
*Retusa truncatula* (Bruguière, 1792)
*Rissoa auriscalpium* (Linnaeus, 1758)
*Rissoa lia* (Monterosato, 1884)
*Rissoa violacea* Desmarest, 1814
*Rissoina bruguieri* (Payraudeau, 1826)
*Scaphander lignarius* (Linnaeus, 1758)
*Scissurella costata* d'Orbigny, 1824
*Semicassis saburon* (Bruguière, 1792)
*Thylacodes arenarius* (Linnaeus, 1767)
*Setia globulinus* Monterosato, 1884
*Tectura virginea* (O.F. Müller, 1776)
*Tethys fimbria* Linnaeus 1767
*Thuridilla hopei* (Vérany, 1853)
*Tjaernoeia exquisita* (Jeffreys, 1883)
*Tricolia pullus* (Linnaeus, 1758)
*Tricolia pullus pullus* (Linnaeus, 1758)
*Turbonilla jeffreysii* (Jeffreys, 1848)
*Turbonilla lactea* (Linnaeus, 1758)
*Turritella communis* Risso, 1826
*Vermetus triquetrus* Bivona Ant., 1832
*Vexillum (Pusiolina) savignyi* (Payraudeau, 1826)
*Vexillum (Pusiolina) tricolor* (Gmelin, 1791)
*Vitreolina curva* (Monterosato, 1874)
*Vitreolina perminima* (Jeffreys, 1883)
*Weinkauffia turgidula* (Forbes, 1844)

**Scaphopoda**

*Antalis inaequicostata* (Dautzenberg, 1891)
*Dentalium* sp.

**Bivalvia**

*Abra alba* (W. Wood, 1802)
*Abra prismatica* (Montagu, 1808)
*Abra segmentum* (Récluz, 1843)
*Acanthocardia aculeata* (Linnaeus, 1758)

*Acanthocardia aculeata* (Linnaeus, 1758)
*Aequipecten opercularis* (Linnaeus, 1758)
*Anadara transversa* (Say, 1822)
*Anodontia (Loripinus) fragilis* (Philippi, 1836)
*Anomia ephippium* Linnaeus, 1758
*Arca noae* Linnaeus, 1758
*Arcuatula senhousia* (Benson in Cantor, 1842)
*Atrina pectinata* (Linnaeus, 1767)
*Azorinus chamasolen* (da Costa, 1778)
*Barbatia barbata* (Linnaeus, 1758)
*Callista chione* (Linnaeus, 1758)
*Chama gryphoides* Linnaeus, 1758
*Chamelea gallina* (Linnaeus, 1758)
*Corbula gibba* (Olivi, 1792)
*Crassostrea gigas* (Thunberg, 1793)
*Ensis minor* (Chenu, 1843)
*Flexopecten glaber* (Linnaeus, 1758)
*Flexopecten glaber glaber* (Linnaeus, 1758)
*Flexopecten glaber proteus* (Dillwyn, 1817)
*Galeomma turtoni* Turton, 1825
*Gari fervensis* (Gmelin, 1791)
*Gari tellinella* (Lamarck, 1818)
*Gastrana fragilis* (Linnaeus, 1758)
*Glycymeris glycymeris* (Linnaeus, 1758)
*Glycymeris pilosa* (Linnaeus, 1767)
*Gouldia minima* (Montagu, 1803)
*Gregariella petagnae* (Scacchi, 1832)
*Hemilepton nitidum* (Turton, 1822)
*Heteranomia squamula* (Linnaeus, 1758)
*Hiatella arctica* (Linnaeus, 1767)
*Hiatella rugosa* (Linnaeus, 1767)
*Hinnites* sp.
*Irus irus* (Linnaeus, 1758)
*Kellia suborbicularis* (Montagu, 1803)
*Kurtiella bidentata* (Montagu, 1803)
*Laevicardium oblongum* (Gmelin, 1791)
*Lasaea adansoni* (Gmelin, 1791)
*Limaria hians* (Gmelin, 1791)
*Limaria loscombi* (G.B. Sowerby I, 1823)
*Limaria tuberculata* (Olivi, 1792)
*Limatula gwyni* (Sykes, 1903)
*Lithophaga lithophaga* (Linnaeus, 1758)
*Loripes lucinalis* (Lamarck, 1818)
*Lucinella divaricata* (Linnaeus, 1758)
*Mactra stultorum* (Linnaeus, 1758)
*Mimachlamys varia* (Linnaeus, 1758)
*Modiolula phaseolina* (Philippi, 1844)
*Modiolus barbatus* (Linnaeus, 1758)
*Moerella donacina* (Linnaeus, 1758)
*Monia patelliformis* (Linnaeus, 1767)
*Musculus costulatus* (Risso, 1826)
*Musculus discors* (Linnaeus, 1767)
*Musculus subpictus* (Cantraine, 1835)
*Mysia undata* (Pennant, 1777)
*Mytilaster minimus* (Poli, 1795)
*Mytilus galloprovincialis* Lamarck, 1819
*Nucula nucleus* (Linnaeus, 1758)
*Nucula nucleus* (Linnaeus, 1758)
*Nuculana pella* (Linnaeus, 1767)
*Ostrea edulis* Linnaeus, 1758
*Paphia* sp.
*Parvicardium exiguum* (Gmelin, 1791)
*Parvicardium minimum* (Philippi, 1836)
*Parvicardium pinnulatum* (Conrad, 1831)
*Pecten jacobaeus* (Linnaeus, 1758)
*Petricola lithophaga* (Retzius, 1788)
*Phaxas adriaticus* (Coen, 1933)
*Pinna nobilis* Linnaeus, 1758
*Pitar rudis* (Poli, 1795)
*Plagiocardium papillosum* (Poli, 1795)
*Polititapes aureus* (Gmelin, 1791)
*Polititapes virgineus* (Linnaeus, 1767)
*Rocellaria dubia* (Pennant, 1777)
*Saxicavella jeffreysi* Winckworth, 1930
*Solecurtus strigilatus* (Linnaeus, 1758)
*Striarca lactea* (Linnaeus, 1758)

*Talochlamys multistriata* (Poli, 1795)
*Tellimya ferruginosa* (Montagu, 1808)
*Tellina balaustina* Linné, 1758
*Tellina distorta* Poli, 1791
*Tellina nitida* Poli, 1791
*Thracia papyracea* (Poli, 1791)
*Timoclea ovata* (Pennant, 1777)
*Venerupis decussata* (Linnaeus, 1758)
*Venerupis philippinarum* (A. Adams and Reeve, 1850)
*Venus verrucosa* Linnaeus, 1758

**Cephalopoda**

*Eledone moschata* (Lamarck, 1798)
*Loligo vulgaris* Lamarck, 1798
*Sepia officinalis* Linnaeus, 1758

**Polychaeta**

*Ampharete grubei* Malmgren, 1865
*Amphiglena mediterranea* (Leydig, 1851)
*Amphitritides gracilis* (Grube, 1860)
*Aphrodita aculeata* Linnaeus, 1758
*Aponuphis bilineata* (Baird, 1870)
*Arabella geniculata* (Claparède, 1868)
*Arabella iricolor (*Montagu, 1804)
*Asclerocheilus intermedius* (Saint-Joseph, 1894)
*Autolytus* sp.
*Bispira* sp.
*Boccardiella ligerica* (Ferronnière, 1898)
*Callizona* sp.
*Caulleriella killariensis* (Southern, 1914)
*Ceratonereis (Composetia) costae* (Grube, 1840)
*Ceratonereis (Composetia) hircinicola* (Eisig, 1870)
*Chaetopterus variopedatus* Cuvier, 1827
*Chrysopetalum debile* (Grube, 1855)
*Cirratulus cirratus* (O. F. Müller, 1776)
*Cirriformia* sp.
*Dasybranchus* sp.
*Diopatra neapolitana* Delle Chiaje, 1841
*Dipolydora giardi* (Mesnil, 1896)
*Dodecaceria concharum* Örsted, 1843
*Dysponetus* sp.
*Eteone flava* (Fabricius, 1780)
*Euclymene lombricoides* (Quatrefages, 1866)
*Euclymene oerstedi* (Claparède, 1863)
*Eulalia bilineata* (Johnston, 1840)
*Eunice aphroditois* (Pallas, 1788)
*Eunice floridana* (Pourtale` s, 1867)
*Eunice harassii* Audouin and Milne Edwards, 1834
*Eunice oerstedii* Stimpson, 1853
*Eunice pennata* (O.F. Müller, 1776)
*Eunice schizobranchia* Claparède, 1870
*Eunice torquata* Quatrefages, 1866
*Eunice vittata* (Delle Chiaje, 1828)
*Eupolymnia nebulosa* (Montagu, 1818)
*Euratella salmacidis* (Claparède, 1869)
*Exogone (Exogone) naidina* Örsted, 1845
*Filograna* sp.
*Fimbriosthenelais minor* (Pruvot and Racovitza, 1895)
*Galathowenia oculata* (Zachs, 1923)
*Glycera convoluta* Keferstein, 1862
*Glycera lapidum* Quatrefages, 1866
*Haplosyllis spongicola* (Grube, 1855)
*Harmothoe areolata* (Grube, 1860)
*Harmothoe imbricata* (Linnaeus, 1767)
*Hediste diversicolor* (O.F. Müller, 1776)
*Hydroides dianthus* (Verrill, 1873)
*Hydroides pseudouncinatus* Zibrowius, 1968
*Hydroides pseudouncinatus pseudouncinatus* Zibrowius, 1971
*Hydroides uncinata* (Phillipi, 1844)
*Jasmineria* sp.
*Lagis koreni* Malmgren, 1866
*Laonome kroyeri* Malmgren, 1866
*Lepidonotus clava* (Montagu, 1808)

*Lumbrineriopsis paradoxa* (Saint-Joseph, 1888)
*Lumbrineris adriatica* Fauvel, 1940
*Lumbrineris coccinea* (Renier, 1804)
*Lumbrineris fragilis* (O.F. Müller, 1766)
*Lumbrineris gracilis* Ehlers, 1868
*Lumbrineris impatiens* Claparède, 1868
*Lumbrineris latreilli* Audouin and Milne Edwards, 1834
*Lysidice ninetta* Audouin and Milne-Edwards, 1833
*Malmgreniella ljungmani* (Malmgren, 1867)
*Marphysa bellii* (Audouin and Milne-Edwards, 1833)
*Marphysa fallax* Marion and Bobretzky, 1875
*Marphysa kinbergi* Mc Intosh, 1910
*Marphysa sanguinea* (Montagu, 1815)
*Micromaldane ornithochaeta* Mesnil, 1897
*Micronereis* sp.
*Myrianida brachycephala* (Marenzeller, 1874)
*Myrianida prolifera* (O.F. Müller, 1788)
*Myriochele heeri* Malmgren, 1867
*Mysta picta* (Quatrefagues, 1865)
*Mystides borealis* Theel, 1879
*Myxicola infundibulum* (Montagu, 1808)
*Neanthes fucata* (Savigny in Lamarck, 1818)
*Nematonereis hebes* Verrill, 1900
*Nematonereis unicornis* (Grube, 1840)
*Nephtys* sp.
*Nereiphylla paretti* Blainville, 1828
*Nereiphylla rubiginosa* (Saint-Joseph, 1888)
*Neanthes irrorata* (Malmgren, 1867)
*Nereis rava* Ehlers, 1864
*Notomastus* sp.
*Oenone fulgida* (Savigny in Lamarck, 1818)
*Palola siciliensis* (Grube, 1840)
*Paramarphysa* sp.
*Pherusa eruca* (Claparède, 1869)
*Pholoe minuta* (Fabricius, 1780)
*Pholoides dorsipapillatus* (Marenzeller, 1893)
*Phyllodoce lineata* (Clapare` de, 1870)
*Phyllodoce maculata* (Linnaeus, 1767)
*Phyllodoce mucosa* Örsted, 1843
*Phyllodoce pusilla* (Claparède, 1870)
*Phyllodoce* sp.
*Piromis eruca* (Claparède, 1870)
*Platynereis coccinea* (delle Chiaje, 1822)
*Platynereis dumerilii* (Audouin and Milne Edwards, 1834)
*Dipolydora armata* (Langerhans, 1880)
*Polydora ciliata* (Johnston, 1838)
*Pontogenia chrysocoma* (Baird, 1865)
*Potamilla torelli* (Malmgren, 1866)
*Prionospio caspersi* Laubier, 1962
*Protula tubularia* (Montagu, 1803)
*Pseudomystides limbata* (Saint-Joseph, 1888)
*Pseudopotamilla reniformis* (Müller, 1771)
*Pterosyllis* sp.
*Raphidrilus nemasoma* Monticelli, 1910
*Sabella lamyi* Gravier, 1906
*Sabella pavonina* Savigny, 1822
*Sabella spallanzanii* (Gmelin, 1791)
*Sabellaria alveolata* (Linnaeus, 1767)
*Sabellaria spinulosa* Leuckart, 1849
*Sabellonga disjuncta* Hartman, 1969
*Scoletoma impatiens* (Claparède, 1868)
*Serpula concharum* Langerhans, 1880
*Serpula lobiancoi* Rioja, 1917
*Serpula vermicularis* Linnaeus, 1767
*Sigalion* sp.
*Sphaerosyllis bulbosa* Southern, 1914
*Sphaerosyllis ovigera* Langerhans, 1879
*Spirobranchus lamarcki* (Quatrefages, 1866)
*Spirobranchus triqueter* (Linnaeus, 1758)
*Sthenelais* sp.
*Stygocapitella* sp.
*Stylarioides* sp.

*Subadyte pellucida* (Ehlers, 1864)
*Syllis amica* Quatrefages, 1866
*Syllis gracilis* Grube, 1840
*Syllis hyalina* Grube, 1863
*Syllis nigricirris* Grube, 1863
*Syllis prolifera* Krohn, 1852
*Syllis variegata* Grube, 1860
*Syllis vivipara* Krohn, 1869
*Terebella lapidaria* Linnaeus, 1767
*Tharyx multibranchiis* (Grube, 1863)
*Trypanosyllis (Trypanosyllis) coeliaca* Claparède, 1868
*Trypanosyllis zebra* (Grube, 1840)
*Vermiliopsis infundibulum* (Philippi, 1844)
*Vermiliopsis labiata* (O. G. Costa, 1861)
*Vermiliopsis striaticeps* (Grube, 1862)
*Websterinereis glauca* (Claparède, 1870)
**Oligochaeta** n.d.
**Copepoda**
*Stenhelia* sp.
**Ostracoda**
*Skogsbergia costai* Kornicker, 1974
**Cirripedia**
*Acasta spongites* (Poli, 1795)
*Amphibalanus amphitrite* (Darwin, 1854)
*Balanus trigonus* Darwin, 1854
*Elminius modestus* Darwin, 1854
*Lepas anatifera* Linnaeus, 1758
*Sacculina carcini* Thompson, 1836
*Verruca stroemia* O.F. Müller, 1776
**Leptostraca**
*Nebalia* sp.
**Stomatopoda**
*Squilla mantis* (Linnaeus, 1758)
**Decapoda**
*Alpheus dentipes* Guérin, 1832
*Alpheus glaber* (Olivi, 1792)
*Alpheus macrocheles* (Hailstone, 1835)
*Anapagurus laevis* (Bell, 1846)
*Atelecyclus rotundatus* (Olivi, 1792)
*Athanas nitescens* (Leach, 1813 [in Leach, 1813-1814])
*Brachynotus sexdentatus* (Risso, 1827)
*Carcinus aestuarii* Nardo, 1847
*Cestopagurus timidus* (Roux, 1830)
*Clibanarius erythropus* (Latreille, 1818)
*Corystes cassivelaunus* (Pennant, 1777)
*Derilambrus angulifrons* (Latreille, 1825)
*Diogenes pugilator* (Roux, 1829)
*Dromia personata* (Linnaeus, 1758)
*Dyspanopeus sayi* (Smith, 1869)
*Ebalia edwardsii* Costa, 1838
*Ethusa mascarone* (Herbst, 1785)
*Eualus cranchii* (Leach, 1817 [in Leach, 1815-1875])
*Eualus occultus* (Lebour, 1936)
*Eualus pusiolus* (Krøyer, 1841)
*Eurynome aspera* (Pennant, 1777)
*Galathea bolivari* Zariquiey Álvarez, 1950
*Galathea intermedia* Liljeborg, 1851
*Galathea squamifera* Leach, 1814
*Galathea strigosa* (Linnaeus, 1761)
*Homarus gammarus* (Linnaeus, 1758)
*Ilia nucleus* (Linnaeus, 1758)
*Inachus communissimus* Rizza, 1839
*Inachus dorsettensis* (Pennant, 1777)
*Inachus thoracicus* Roux, 1830
*Liocarcinus maculatus* (Risso, 1827)
*Lysmata seticaudata* (Risso, 1816)
*Macropodia czernjawskii* (Brandt, 1880)
*Macropodia linaresi* Forest and Zariquiey Alvarez, 1964
*Macropodia longirostris* (Fabricius, 1775)
*Macropodia rostrata* (Linnaeus, 1761)
*Macropodia tenuirostris* (Leach, 1814)
*Maja crispata* Risso, 1827

*Maja squinado* (Herbst, 1788)
*Melicertus kerathurus* (Forskål, 1775)
*Nepinnotheres pinnotheres* (Linnaeus, 1758)
*Paguristes eremita* (Linnaeus, 1767)
*Pagurus alatus* Fabricius, 1775
*Pagurus anachoretus* Risso, 1827
*Pagurus cuanensis* Bell, 1846
*Pagurus excavatus* (Herbst, 1791)
*Pagurus prideaux* Leach, 1815
*Palaemon serratus* (Pennant, 1777)
*Parthenope massena* (Roux, 1830)
*Pestarella tyrrhena* (Petagna, 1792)
*Pilumnus hirtellus* (Linnaeus, 1761)
*Pilumnus spinifer* H. Milne Edwards, 1834
*Pilumnus villosissimus* (Rafinesque, 1814)
*Pinnotheres pisum* (Linnaeus, 1767)
*Pisa armata* (Latreille, 1803)
*Pisidia longimana* (Risso, 1816)
*Porcellana platycheles* (Pennant, 1777)
*Processa edulis edulis* (Risso, 1816)
*Rhithropanopeus harrisii* (Gould, 1841)
*Sirpus zariquieyi* Gordon, 1953
*Synalpheus gambarelloides* (Nardo, 1847)
*Typton spongicola* O.G. Costa, 1844
*Upogebia deltaura* (Leach, 1815)
*Xantho pilipes* A. Milne-Edwards, 1867
*Xantho poressa* (Olivi, 1792)

**Mysida**

*Anchialina agilis* (G.O. Sars, 1877)

**Cumacea**

*Diastylis rugosa* Sars, 1865
*Iphinoe serrata* Norman, 1867
*Leucon (Leucon) mediterraneus* Sars, 1878

**Tanaidacea**

*Apseudes talpa* (Montagu, 1808)
*Apseudopsis latreillii* (Milne-Edwards, 1828)
*Heterotanais oerstedii* (Kroyer, 1842)
*Leptochelia savignyi* (Krøyer, 1842)
*Tanais dulongii* (Audouin, 1826)

**Isopoda**

*Cirolana* sp.
*Cyathura carinata* (Krøyer, 1847)
*Cymodoce truncata* Leach, 1814
*Gnathia phallonajopsis* Monod, 1925
*Idotea* sp.
*Jaera (Jaera) nordmanni* (Rathke, 1837)
*Joeropsis brevicornis brevicornis* Koehler, 1885
*Lekanesphaera hookeri* (Leach, 1814)
*Paracerceis sculpta* (Holmes, 1904)
*Sphaeroma serratum* (Fabricius, 1787)

**Amphipoda**

*Ampelisca sarsi* Chevreux, 1888
*Apocorophium acutum* (Chevreux, 1908)
*Atylus vedlomensis* (Bate and Westwood, 1862)
*Colomastix pusilla* Grube, 1861
*Dexamine spinosa* (Montagu, 1813)
*Elasmopus* sp.
*Eusiroides dellavallei* Chevreux, 1899
*Gammarella fucicola* (Leach, 1814)
*Gammaropsis maculata* (Johnston, 1828)
*Jassa marmorata* Holmes, 1905
*Laetmatophilus ledoyeri* Ruffo, 1986
*Leucothoe spinicarpa* (Abildgaard, 1789)
*Leucothoe venetiarum* Giordani- Soika, 1950
*Liljeborgia dellavallei* Stebbing, 1906
*Lysianassa costae* (Milne-Edwards, 1830)
*Maera grossimana* (Montagu, 1808)
*Maera inaequipes* (Costa, 1857)
*Maera schmidti* Stephensen, 1915
*Maera sodalis* Karaman and Ruffo, 1971
*Medicorophium runcicorne* (Della Valle, 1893)
*Microdeutopus sporadhi* Myers, 1969
*Monocorophium acherusicum* (Costa, 1853)
*Monocorophium insidiosum* (Crawford, 1937)
*Monocorophium sextonae* (Crawford, 1937)
*Phtisica marina* Slabber, 1769

Podocerus variegatus Leach, 1814
*Pseudoprotella phasma* Montagu, 1804
*Scopelocheirus hopei* (Costa, 1851)
*Synchelidium longidigitatum* Ruffo, 1947

**Pycnogonida**

Pantopoda n.d.

**Bryozoa**

*Aetea truncata* (Landsborough, 1852)
*Amathia lendigera* (Linnaeus, 1758)
*Beania* sp.
*Bowerbankia gracilis* Leidy, 1855
*Bugula fulva* Ryland, 1960
*Bugula neritina* (Linnaeus, 1758)
*Bugula stolonifera* Ryland, 1960
*Caberea boryi* (Audouin, 1826)
*Calpensia nobilis* (Esper, 1796)
*Cellepora pumicosa* (Pallas, 1766)
*Chartella papyrea* (Pallas, 1766)
*Colletosia* sp.
*Crisia fistulosa* (Heller, 1867)
*Cryptosula pallasiana* (Moll, 1803)
*Disporella hispida* (Fleming, 1828)
*Fenestrulina malusii* (Audouin, 1826)
*Membranipora membranacea* (Linnaeus, 1767)
*Micropora coriacea* (Johnston, 1847)
*Myriapora truncata* (Pallas, 1766)
*Plagioecia patina* (Lamarck, 1816)
*Puellina radiata* (Moll, 1803)
*Rhynchozoon neapolitanum* Gautier, 1962
*Savignyella lafontii* (Audouin, 1826)
*Schizobrachiella sanguinea* (Norman, 1868)
*Schizoporella errata* (Waters, 1878)
*Schizoporella unicornis* (Johnston in Wood, 1844)
*Scrupocellaria bertholleti* (Audouin, 1826)
*Scrupocellaria scruposa* (Linnaeus, 1758)
*Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985

**Chaetognatha**

*Parasagitta setosa* (Müller, 1847)

**Echinodermata**

*Amphipholis squamata* (Delle Chiaje, 1828)
*Amphiura chiajei* Forbes, 1843
*Anseropoda placenta* (Pennant, 1777)
*Arbacia lixula* (Linnaeus, 1758)
*Astropecten irregularis* (Pennant, 1777)
*Astropecten spinulosus* (Philippi, 1837)
*Brissus unicolor* (Leske, 1778)
*Cucumaria* sp.
*Echinaster sepositus* (Retzius, 1783)
*Echinocyamus pusillus* (O.F. Müller, 1776)
*Echinus melo* Lamarck, 1816
*Gracilechinus acutus* (Lamarck, 1816)
*Holothuria (Holothuria) tubulosa* Gmelin, 1791
*Holothuria (Roweothuria) poli* Delle Chiaje, 1824
*Leptopentacta elongata* (Düben and Koren, 1846)
*Marthasterias glacialis* (Linnaeus, 1758)
*Ocnus planci* (Brandt, 1835)
*Ocnus syracusanus* (Grube, 1840) Panning, 1949
*Ophiacantha setosa* (Bruzelius, 1805)
*Ophioderma longicauda* (Bruzelius, 1805)
*Ophiopsila aranea* Forbes, 1843
*Ophiothrix fragilis* (Abildgaard, in O.F. Müller, 1789)
*Ophiothrix quinquemaculata* (Delle Chiaje, 1828)
*Ova canaliferus* (Lamarck, 1816)
*Paracentrotus lividus* (Lamarck, 1816)
*Psammechinus microtuberculatus* (Blainville, 1825)
*Sphaerechinus granularis* (Lamarck, 1816)

**Tunicata**

*Aplidium conicum* (Olivi, 1792)
*Aplidium coniferum* Kott, 1963
*Aplidium densum* (Giard, 1872)
*Aplidium elegans* (Giard, 1872)
*Aplidium proliferum* (Milne-Edwards, 1841)
*Aplidium tabarquensis* Ramos-Espla, 1991

*Ascidia mentula* Müller, 1776
*Ascidia virginea* Müller, 1776
*Ascidiella aspersa* (Müller, 1776)
*Botrylloides leachii* (Savigny, 1816)
*Botryllus schlosseri* (Pallas, 1766)
*Ciona intestinalis* (Linnaeus, 1767)
*Clavelina lepadiformis* (Müller, 1776)
*Clavelina sabbadini* Brunetti, 1987
*Cystodytes dellechiajei* (Della Valle, 1877)
*Didemnum coriaceum* (Drasche, 1883)
*Didemnum lahillei* Hartmeyer, 1909
*Didemnum maculosum* (Milne-Edwards, 1841)
*Diplosoma listerianum* (Milne-Edwards, 1841)
*Distaplia* sp.
*Distomus variolosus* Gaertner, 1774
*Eudistoma mucosum* (Drasche, 1883)
*Lissoclinum perforatum* (Giard, 1872)
*Metandrocarpa* sp.
*Microcosmus polymorphus* Heller, 1877
*Microcosmus sabatieri* Roule, 1885
*Microcosmus vulgaris* Heller, 1877
*Molgula appendiculata* Heller, 1877
*Molgula manhattensis* (De Kay, 1843)
*Perophora* sp.
*Phallusia fumigata* (Grube, 1864)
*Phallusia mammillata* (Cuvier, 1815)
*Polycarpa* sp.
*Polycitor adriaticus* (Drasche, 1883)
*Pycnoclavella taureanensis* Brunetti, 1991
*Pyura dura* (Heller, 1877)
*Pyura microcosmus* (Savigny, 1816)
*Pyura squamulosa* (Alder, 1863)
*Styela canopus* (Savigny, 1816)
*Styela plicata* (Lesueur, 1823)

**Pisces**

*Mustelus mustelus* (Linnaeus, 1758)
*Mustelus punctulatus* Risso, 1827
*Myliobatis aquila* (Linnaeus, 1758)
*Conger conger* (Linnaeus, 1758)
*Alosa fallax* (Lacepède, 1803)
*Sardina pilchardus* (Walbaum, 1792)
*Engraulis encrasicolus* (Linnaeus, 1758)
*Merlangius merlangus* (Linnaeus, 1758)
*Trisopterus minutus* (Linnaeus, 1758)
*Gaidropsarus* sp. Rafinesque, 1810
*Ophidion barbatum* Linnaeus, 1758
*Atherina boyeri* Risso, 1810
*Zeus faber* Linnaeus, 1758
*Hippocampus guttulatus* Cuvier, 1829
*Scorpaena notata* Rafinesque, 1810
*Scorpaena porcus* Linnaeus, 1758
*Scorpaena scrofa* Linnaeus, 1758
*Chelidonichthys lucerna* (Linnaeus, 1758)
*Trigla lyra* Linnaeus, 1758
*Trigloporus lastoviza* (Bonnaterre, 1788)
*Dicentrarchus labrax* (Linnaeus, 1758)
*Serranus cabrilla* (Linnaeus, 1758)
*Serranus hepatus* (Linnaeus, 1758)
*Serranus scriba* (Linnaeus, 1758)
*Seriola dumerili* (Risso, 1810)
*Trachurus trachurus* (Linnaeus, 1758)
*Boops boops* (Linnaeus, 1758)
*Dentex dentex* (Linnaeus, 1758)
*Diplodus annularis* (Linnaeus, 1758)
*Diplodus puntazzo* (Walbaum, 1792)
*Diplodus sargus sargus* (Linnaeus, 1758)
*Diplodus vulgaris* (Geoffroy Saint-Hilaire, 1817)
*Lithognathus mormyrus* (Linnaeus, 1758)
*Oblada melanura* (Linnaeus, 1758)
*Pagellus acarne* (Risso, 1827)
*Pagellus bogaraveo* (Brünnich, 1768)
*Pagellus erythrinus* (Linnaeus, 1758)
*Sarpa salpa* (Linnaeus, 1758)
*Sparus aurata* Linnaeus, 1758
*Spondyliosoma cantharus* (Linnaeus, 1758)
*Spicara maena* (Linnaeus, 1758)

*Spicara smaris* (Linnaeus, 1758)
*Sciaena umbra* Linnaeus, 1758
*Umbrina cirrosa* (Linnaeus, 1758)
*Mullus barbatus* Linnaeus, 1758
*Mullus surmuletus* Linnaeus, 1758
*Chromis chromis* (Linnaeus, 1758)
*Coris julis* (Linnaeus, 1758)
*Labrus merula* Linnaeus, 1758
*Symphodus cinereus* (Bonnaterre, 1788)
*Symphodus mediterraneus* (Linnaeus, 1758)
*Symphodus ocellatus* Forsskål, 1775
*Symphodus rostratus* (Bloch, 1791)
*Symphodus tinca* (Linnaeus, 1758)
*Trachinus draco* Linnaeus, 1758
*Tripterygion delaisi* Cadenat and Blache, 1970
*Tripterygion tripteronotus* (Risso, 1810)
*Microlipophrys adriaticus* (Steindachner and Kolombatović, 1883)
*Microlipophrys dalmatinus* (Steindachner and Kolombatović, 1883)
*Parablennius gattorugine* (Linnaeus, 1758)
*Parablennius rouxi* (Cocco, 1833)
*Parablennius tentacularis* (Brünnich, 1768)
*Parablennius zvonimiri* (Kolombatović, 1892)
*Deltentosteus quadrimaculatus* (Valenciennes, 1837)
*Gobius bucchichi* Steindachner, 1870
*Gobius cruentatus* Gmelin, 1789
*Gobius niger* Linnaeus, 1758
*Odondebuenia balearica* (Pellegrin and Fage, 1907)
*Scomber scombrus* Linnaeus, 1758
*Arnoglossus laterna* (Walbaum, 1792)
*Arnoglossus thori* Kyle, 1913
*Platichthys flesus* (Linnaeus, 1758)
*Scophthalmus rhombus* (Linnaeus, 1758)
*Zeugopterus regius* (Bonnaterre, 1788)
*Buglossidium luteum* (Risso, 1810)
*Monochirus hispidus* Rafinesque, 1814
*Pegusa impar* (Bennett, 1831)
*Pegusa lascaris* (Risso, 1810)
*Solea solea* (Linnaeus, 1758)
*Synapturichthys kleinii* (Risso, 1827)
n.d. = not determined

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