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CORALLINE ALGAE ON BIOGENIC FORMATIONS IN MARINE WATERS OFF SLOVENIA (NORTHERN ADRIATIC SEA)

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ABSTRACT

*Two major biogenic formations, composed mainly by dead corallites of the Mediterranean stony coral (*Cladocora caespitosa*), have been recently studied in Slovenian marine waters. The paper presents new data about the presence of coralline algae on the biogenic formation situated off Cape Ronek and off Cape Debeli rtič. Coralline algae are very important for the creation, development and maintenance of calcareous bio-concretions that offer new niches for many invertebrates and other algae. They are listed as important builders of the coralligenous biocoenosis in the "Draft Lists of coralligenous/maërl populations and of main species to be considered by the inventory and monitoring" of the RAC-SPA, and should be further deeply studied and appropriately protected.*

Key words: coralline algae**,** biogenic formations**,** circalittoral, northern Adriatic Sea

ALGHE CORALLINE DELLE FORMAZIONI BIOGENICHE IN ACQUE MARINE SLOVENE (ADRIATICO SETTENTRIONALE)

SINTESI

*Due formazioni biogeniche, prevalentemente composte da coralliti morti della madrepora a cuscino (*Cladocora caespitosa*), sono state recentemente studiate nelle acque slovene. Nel presente lavoro vengono riportati nuovi dati relativi alle alghe coralline presenti al largo di Punta Ronco e Punta grossa. Le alghe coralline hanno un ruolo importante nello sviluppo e nel mantenimento delle concrezioni biogeniche, offrendo nicchie per invertebrati e altre alghe. Nel documento "Draft Lists of coralligenous/maërl populations and of main species to be considered by the inventory and monitoring" del RAC-SPA, le alghe coralline sono riportate come importanti organismi biocostruttori della biocenosi coralligena, meritevoli di ulteriori studi e di una appropriata protezione.*

Parole chiave: alghe coralline, formazioni biogeniche, circalitorale, Adriatico settentrionale

INTRODUCTION

The shallow northern Adriatic area is dominated by muddy and sandy bottoms (Lipej *et al.,* 2006) and for a long time it was believed that these are the only bottoms existing in this basin. More than 200 years ago Giuseppe Olivi (1792) was the first to mention that in this part of the Adriatic Sea exist also rocky outcrops. Northern Adriatic fishermen have been familiar with this kind of environments before marine scientists discovered them, since they are rich fishing points, called *tegnùe* along the Venetian coast (Casellato *et al.*, 2006), and *trezze* in the Gulf of Trieste. Around 250 such rocky outcrops, calcareous bio-concretions, have been counted in the Italian part of the Gulf of Trieste, derived from the building action of calcareous organisms on hard substrata of diverse geological origins (Falace *et al*., 2015). Similar formations were recently studied also in Slovenian marine waters (Lipej *et al*., 2016). Currently, two major biogenic formations are known for the Slovenian Sea, which were sampled within the Interreg project TRECORALA. These biogenic formations are located off Cape Ronek and off Cape Debeli rtič. Both have substantially larger dimensions than *trezze* and are linked to the presence of Mediterranean stony coral (*Cladocora caespitosa*), since they are formed entirely by dead corallites of this species.

During a scientific meeting on the coralligenous environment, which took place at the Marine Biology Station in Piran in March 2011, the Italian, Croatian and Slovenian researchers suggested that the northern Adriatic forms of coralligenous environment, such as trezze, tegnùe, the precoralligenous in the infralittoral belt and biogenic formations of Mediterranean stony coral *C. caespitosa* (Linnaeus, 1767), should be recognized as a specific element within the Mediterranean coralligenous biocoenosis. The expression "biogenic formation" refers to any formations that are the result of limestone loading by some marine organisms, known as bioconstructors, during their lifetime. Among

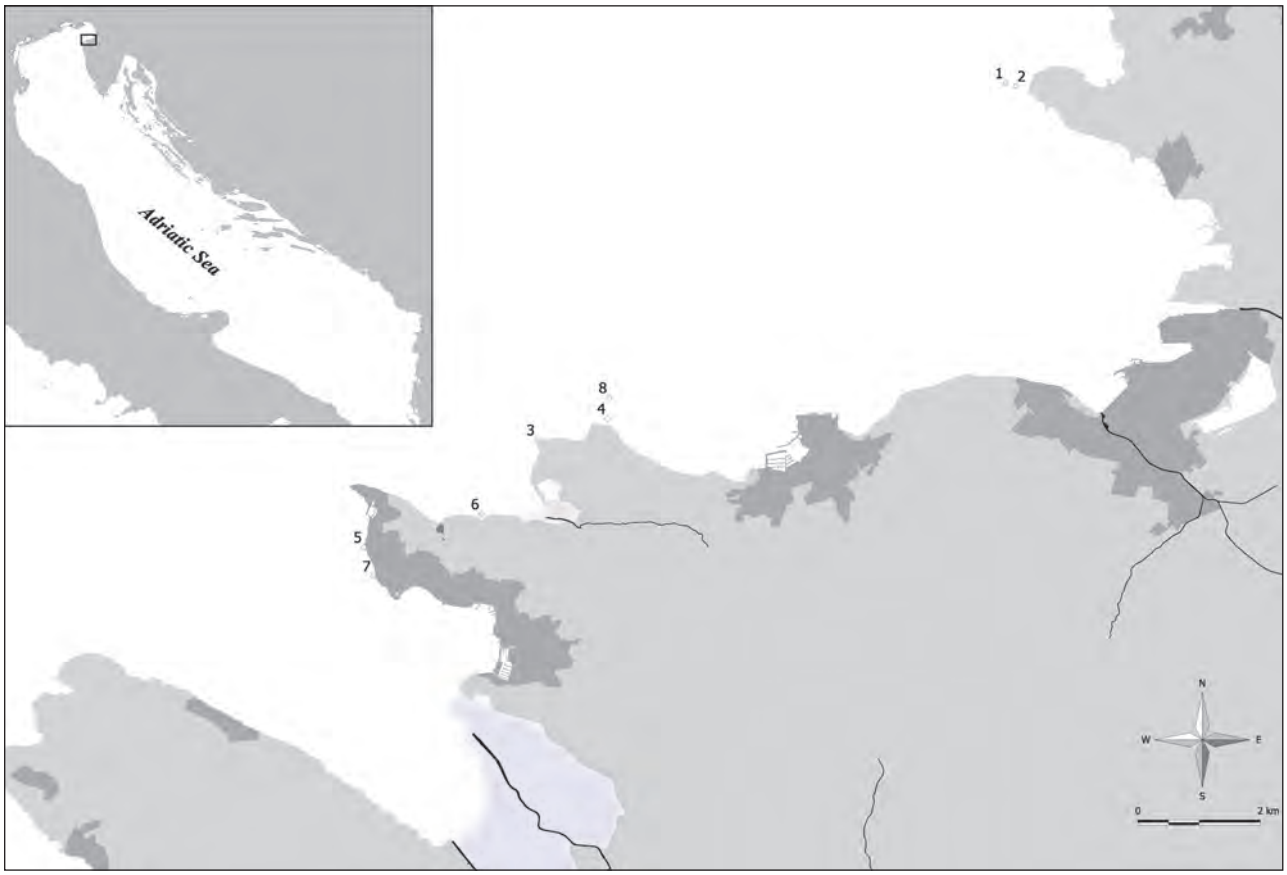

Fig. 1: Locations with Mediterranean stony coral *(Cladocora caespitosa)* ***colonies in the Slovenian coastal sea. Legend: 1 - Biogenic formation at Debeli rtič; 2 - Cape Debeli rtič; 3 - Cape Strunjan; 4 – Cape Ronek; 5 – Piranček; 6 – Pacug; 7 – Bernardin; 8 - Biogenic formation at Ronek.***
Sl. 1: Lokalitete s kolonijami sredozemske kamene korale *(Cladocora caespitosa)* ***v slovenskem morju. Legenda: 1 – Biogena formacija pred Debelim rtičem; 2 - Debeli rtič; 3 - rt Strunjan; 4 – rt Ronek; 5 – Piranček; 6 – Pacug; 7 – Bernardin; 8 – biogena formacija pred rtom Ronek.***

invertebrates the most well known bioconstructors are corals (Anthozoa), hydrozoans (Hydrozoa) and marine tube worms (Polychaeta Sedentaria) (Lipej *et al*., 2016). However, the precoralligenous and the coralligenous are primarily built by coralline algae (Laborel, 1961; Sartoretto, 1996). 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).

Coralline algae are very important for the creation, development and maintenance of new niches for many invertebrates and other algae. Their habitat-building capacity is associated with the mechanism of mineralization of the cell wall with calcium and, to a lesser extent, magnesium carbonate. In red algae (Rhodophyta) from the family Corallinaceae, the carbonate is present in the crystalline calcite form mainly, while in red algae from the family Peyssonneliaceae and in green algae (Chlorophyta) from the family Halimedaceae it precipitates as aragonite. The occurrence of calcification helps to balance the carbon dioxide deficit in water, which is due to photosynthesis, and thus contributes to the maintenance of the alkaline potential in sea water (Andreoli *et al*., 2010).

Falace *et al*. (2011) reported on the presence of coralline algae in the Slovenian circalittoral belt, including the biogenic formation off Cape Ronek. The aim of the current paper is to report the first available data about the presence of coralline algal species on the biogenic formation located off cape Debeli rtič, and new data about their occurrence at Cape Ronek.

Tab. 1: Density of Mediterranean stony coral colonies in various areas of the Slovenian Sea (adopted from Lipej et al., 2016).
Tab. 1: Gostota sredozemske kamene korale v različnih predelih slovenskega morja (prirejeno po Lipej in sod., 2016).

Locality	Density of *C. caespitosa* colonies (n/100m^2)
Biogenic formation at Debeli rtič	3 (2-4)
Cape Debeli rtič	83 (70-96)
Cape Strunjan	85 (66-105)
Cape Ronek	108
Piranček	160 (128-192)
Pacug	186
Bernardin	285 (263-306)
Biogenic formation at Ronek	652 (498-806)

MATERIAL AND METHODS

Study area

The biogenic formation at Cape Debeli rtič (Figs. 1 and 2) is more or less of triangular shape with a rounded plateau, which looks like a knob. On the reef there is a relatively steep step where the coastal sandy-rocky bottom sweeps into muddy sediment, which happens very quickly in comparison with the near surroundings. The biogenic formation is mostly covered by a thin layer of mud and, therefore, the accurate assessment of its borders was very difficult. It starts at about 10 m of depth and sweeps down to 17.5 m. This biogenic formation is mainly composed of dead Mediterranean stony coral corallites, with only a few living colonies (Lipej *et al*., 2016).

The biogenic formation at Cape Ronek is located outside in the waters off Strunjan Nature Reserve (Fig. 1). Its shape is elliptical, with the longest axis in the west-east direction, and the shortest in the north-south direction (Fig. 3). The highest point of the biogenic formation is at 12.4 m depth, and it extends down to 21 m, where it shifts into a muddy bottom. It is entirely composed of dead, broken corallites of Mediterranean stony coral. This solitary structure is surrounded on all sides by a muddy bottom, significantly less rich in biodiversity (Lipej *et al*., 2016). This formation is not covered by a surface layer of mud, with the density of living colonies of Mediterranean stony coral considerably higher than in other areas of the Slovenian Sea (see Tab. 1).

Fieldwork and laboratory work

The surveys of coralline algae at biogenic formations were done in July 2013. Algae were randomly manually collected from the sea bottom, scraped when they were found attached, on a transect in a depth range from 10 m to 13 m at Cape Debeli rtič, and from 13 m to 16 m at Cape Ronek (Figs. 2 and 3). Samples were collected in plastic bags and all the material was transported to the laboratory of the Marine Biology Station of the National Institute of Biology. 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.

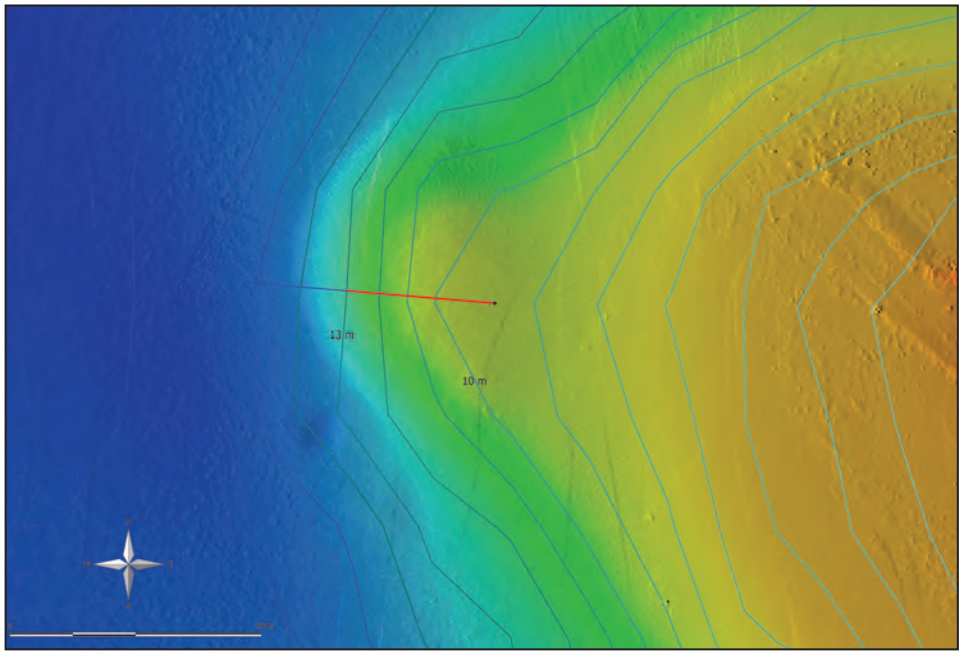

Fig. 2: Image of biogenic formation at Cape Debeli rtič generated from multi-beam ecosounder data (photo: E. Gordini). Coralline algae were collected along the red transect.
Sl. 2: Slika biogene formacije pred Debelim rtičem, narejena na podlagi podatkov iz ehosonderja (avtor E. Gordini). Koraligene alge so bile nabrane vzdolž transekta, označenega z rdečo črto.

RESULTS AND DISCUSSION

Over the surveys performed in 2013, six species of coralline algae were found at the biogenic formation of Cape Debeli rtič, while seven were found at Cape Ronek (Table 2). In samples collected in 2010 by Falace *et al.* (2011) at the biogenic formation of Cape Ronek, *Neogoniolithon brassica-florida* (Harvey) Setchell & L.R. Mason and *Titanoderma pustulatum* (J.V. Lamouroux) Nägeli were missing. However, in those samples they recorded *Lithothamnion philippii* Foslie, *Pneophyllum confervicola* (Kützing) Y.M. Chamberlain and *Pneophyllum fragile* Kützing that were not found at Cape Ronek in 2013.

During the present study, encrusting thalli of *Lithothamnion sonderi* Hauck, *N. brassica-florida* and *Phymatolithon lenormandii* (Areschoug) W.H.Adey were collected at both biogenic formations. *P. fragile* was found as an epiphyte on dead Mediterranean stony coral corallites only at Cape Debeli rtič, where also few encrusting thalli of *P. confervicola* were collected. Conversely, *Lithophyllum racemus* (Lamarck) Foslie, *Lithothamnion minervae* Basso and *T. pustulatum* were found only at the biogenic formation of Cape Ronek; the first only as non living sub-globular thalli (rhodoliths), the second both as encrusting form and live rhodoliths, and the third only as encrusting thalli. The term "rhodolith" includes all biogenic excrescences where calcareous red algae represent at least 50% of the nodule, which consists of the coralline alga together with the substrate/core (Bressan & Babbini, 2003). The fact that thalli of *L. minervae* were found alive on all sides of the rhodolith proves that the structure is occasionally rolled by marine currents, representatives of the vagile fauna and/or anthropogenic activities such as fisheries, diving and anchorage.

So far 31 species of coralline algae were reported for the Slovenian sea (Falace *et al.,* 2011). Among the 10 species collected in 2013 (Table 2), four were found for the first time in this coastal area in 2010: *Lithothamnion minervae* Basso, *L. philippii*, *Lithothamnion sonderi* and *N. brassica-florida* (Falace *et al.,* 2011). However, all of them were previously recorded in the Italian part of the Gulf of Trieste. Several species of coralline algae found in Slovenian marine waters are listed as important builders of the coralligenous biocoenosis 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). In the Mediterranean Sea, the coralligenous biocoenosis comprises at least 315 algal species (Boudouresque, 1973; Ballesteros, 2006). Among them, some species are bioconstructors (coralline algae), others bore holes into hard structures (particularly certain green algae

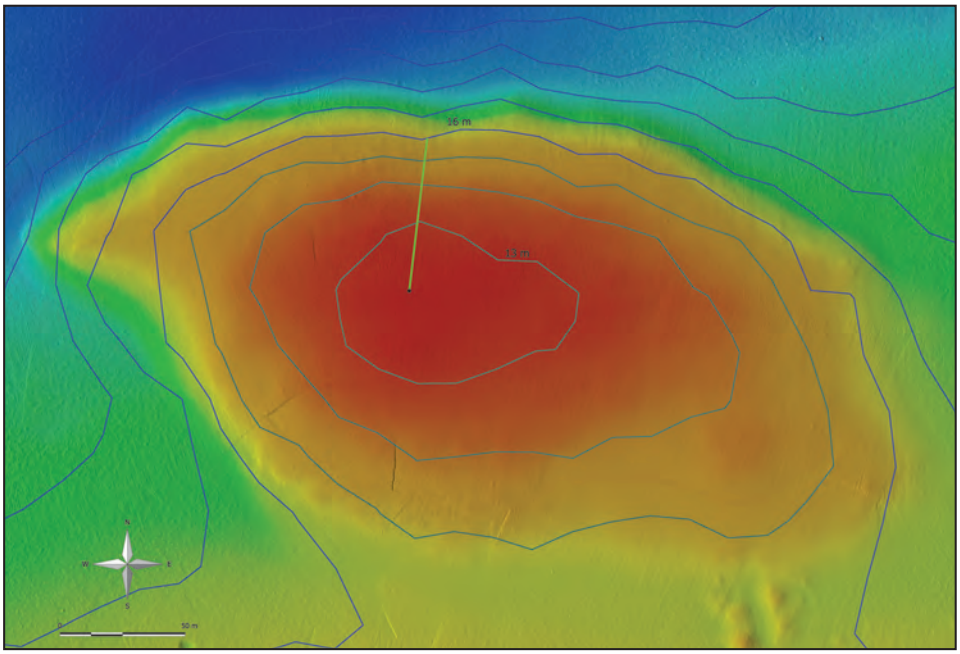

Fig. 3: Image of biogenic formation at Cape Ronek generated from multi-beam ecosounder data (photo: E. Gordini). Coralline algae were collected along the green transect.
Sl. 3: Slika biogene formacije pred rtom Ronek, narejena na podlagi podatkov iz ehosonderja (avtor E. Gordini). Koraligene alge so bile nabrane vzdolž transekta, označenega z zeleno črto.

and blue-green algae (Cyanobacteria)), and some are accompanying species, which include a number of exotic and invasive taxa (Andreoli *et al.*, 2010). The genus *Lithophyllum* is known to be the most species-diverse genus of coralline algae in the Mediterranean Sea and plays a key role in the formation of several widespread bioconstructions (Falace *et al.*, 2016). These taxa contribute with their growth to the construction of organogenic formations also in shallow northern Adriatic Sea (Bressan & Babbini, 2003; Bressan *et al.*, 2009; Giaccone *et al.*, 2009; Falace *et al.*, 2016). Among the 25 species of coralline algae reported for the northern Adriatic calcareous bio-concretions, *Lithophyllum incrustans* Philippi is one of the most important bioconstructors, in particular at the outcrops located at a depth of 23–25 m and at a distance ≥10 km from the coast (Falace *et al.*, 2015). Even though *L. incrustans* has been reported for the Slovenian area (Falace *et al.*, 2011) it was not observed at the biogenic formations near Cape Debeli rtič and Cape Ronek. Therefore, on the basis of the recent findings of coralline algae on biogenic formations in Slovenian waters, it is reasonable to expect that future researches in the area will reveal new species among algae and benthic invertebrates, as well.

In the light of the current (limited) knowledge about coralline algae, biogenic formations, and other infralittoral and circalittoral coralligenous environments in the Slovenian Sea, some recommendations can be made, according to Ballesteros (2003), for their conservation: a) prohibition of trawling in areas with coralligenous forms and their vicinity, to avoid both the physical damage of trawling and also the indirect effects due to increased turbidity and sedimentation rates; b) prohibition of other anthropogenic activities that lead to increased water turbidity and/or sediment removal (*e.g.* coastline modifications) in the vicinity of coralligenous forms; c) no waste water discharge in these areas; d) implementation of the management of traditional and recreational fisheries in order to prevent stock depletion of target species; e) controlled recreational diving pressures; f) urgent need for a protection law of coralligenous environments; g) further scientific research to increase the knowledge about biology and ecology of taxa inhabiting the coralligenous biocoenosis, to give a more accurate estimation of the coralligenous biodiversity.

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Tab. 2: Coralline algae found at biogenic formations at Cape Debeli rtič and Cape Ronek (* alive thalli, ** dead thalli). Data from 2010 were published in Falace** et al. **(2011).
Tab. 2: Koraligene alge, najdene na biogenih formacijah pred Debelim rtičem in rtom Ronek (* žive steljke, ** mrtve steljke). Podatki iz leta 2010 so bili objavljeni v delu Falace in sod. (2011).

Location	Biogenic formation Cape Debeli rtič	Biogenic formation Cape Ronek	Biogenic formation Cape Ronek
Taxa/ Year	**2013**	**2013**	**2010**
Lithophyllum racemus		**	**
Lithothamnion minervae		*	*
Lithothamnion sonderi	*	*	*
Lithothamnion sp.	*	*	
Lithothamnion philippii			*
Neogoniolithon brassica-florida	*	*	
Phymatolithon lenormandii	*	*	*
Pneophyllum confervicola	*		*
Pneophyllum fragile	*		*
Titanoderma pustulatum		*	

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KORALIGENE ALGE NA BIOGENIH FORMACIJAH V SLOVENSKIH MORSKIH VODAH (SEVERNI JADRAN)

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POVZETEK

*Pred kratkim so raziskovalci v slovenskem morju pričeli z raziskavami dveh velikih biogenih formacij, ki jih sestavljajo mrtvi koraliti sredozemske kamene korale (*Cladocora caespitosa*). Avtorji poročajo o novih podatkih o navzočnosti koraligenih alg na biogeni formaciji pri Ronku in biogeni formaciji pred Debelim rtičem. Koraligene alge so zelo pomembne pri ustvarjanju, razvoju in ohranjanju apnenčastih tvorb in nudijo življenjske niše za mnoge nevretenčarje in druge alge. So pomembni gradniki koraligene biocenoze, navedene tudi v seznamu populacij koraligenih/maërl alg, ki jih je potrebno popisati in redno spremljati na podlagi priporočil RAC-SPA, zato bi jih bilo potrebno natančno raziskati in primerno zavarovati.*

Ključne besede: koraligene alge**,** biogene formacije**,** cirkalitoral, severni Jadran

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