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MORPHOMETRIC CHARACTERISTICS, VERTICAL DISTRIBUTION AND DENSITY OF THE LIMPET *PATELLA CAERULEA* L. IN RELATION TO DIFFERENT SUBSTRATA OF THE BAY OF KOPER (GULF OF TRIESTE, NORTHERN ADRIATIC)

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ABSTRACT

The paper presents the results of the study on the populations of Patella caerulea *of the Bay of Koper (Gulf of Trieste, northern Adriatic). The coast in the bay of Koper is composed of different types of substrata—limestone, marl and sandstone—making an ideal opportunity to study the influence of these substrata on the vertical distribution, density and morphological characteristics of this species. The observation revealed that the* Patella *population was distributed on all selected substrata in the midlittoral zone of this region. The density (individuals per 400 cm²) was the highest on sandstone and the lowest on marl. The shells of individuals from the upper midlittoral zone were greater in size than those from the lower midlittoral, in all the investigated substrata. The surface sea temperature, salinity and chlorophyll* a*, that could explain increase of* P. caerulea *populations, have been analyzed.*

Key words: *Patella caerulea*, morphometric characteristics, vertical distribution, density, Gulf of Trieste, northern Adriatic Sea

CARATTERISTICHE MORFOMETRICHE, DISTRIBUZIONE VERTICALE E DENSITÀ DI *PATELLA CAERULEA* L. SU DIVERSI TIPI DI SUBSTRATO DELLA BAIA DI CAPODISTRIA (GOLFO DI TRIESTE, ALTO ADRIATICO)

SINTESI

L'articolo presenta i risultati di uno studio sulle popolazioni di Patella caerulea *della baia di Capodistria (Golfo di Trieste, Alto Adriatico). La costa di quest'area è composta da tre tipi diversi di substrato (calcare, marna ed arenaria), che offrono un'ottima opportunità di studio degli effetti di tali substrati su distribuzione verticale, densità e caratteristiche morfologiche di questa specie. Le osservazioni hanno rilevato che le popolazioni di* P. caerulea *sono distribuite nella zona del mediolitorale dell'area studiata. La densità delle patelle (numero di individui su 400 cm²) è risultata la più alta sull'arenaria e la più bassa sulla marna. La grandezza della conchiglia delle patelle del mediolitorale superiore è maggiore di quella delle patelle del mediolitorale inferiore, su tutti i substrati studiati. Sono state analizzate temperatura, salinità e clorofilla* a *dell'acqua marina come fattori che potrebbero incrementare la densità delle popolazioni di* P. caerulea.

Parole chiave: *Patella caerulea*, caratteristiche morfometriche, distribuzione verticale, densità, Golfo di Trieste, Alto Adriatico

INTRODUCTION

Limpets (Patellidae) occur on different type of shores where there is substratum firm enough for their attachment. They are common on rocky shores from the most exposed to the most sheltered ones and they play a fundamental role in the ecology of rocky midlittoral habitats worldwide, so they are considered the 'keystone' species of the midlittoral zone (Branch, 1981, 1985; Hawkins & Hartnoll, 1983; Menge *et al*., 1994; Menge, 2000). They play an important role within their environment as key herbivores; grazing by limpets is a key process on rocky shores, because not only it determines macroalgal abundance, but it also modifies ecosystem stability and biodiversity and plays a key role in the structure and organization of midlittoral communities (Moreno & Jaramillo, 1983; Chapman, 1995; Coleman *et al*., 2006; Moore *et al*., 2007; Prusina *et al*., 2015). For instance, limpets decrease algal abundance as a direct effect, but also have indirect effects on several organism groups by enhancing the abundance of e.g. barnacles (limiting algal coverage) (Menge, 2000; Arrontes *et al*., 2004). Moreover, limpets are appropriate as *in situ* monitor tools because they are abundant, sedentary or sessile, available all year long and easy to collect (Bat & Öztürk, 1998; Bresler *et al*., 2003, Bat *et al.,* 2000).

In the Adriatic Sea, *Patella* genus is represented by three species, namely *P. caerulea* L., *P. ulyssiponensis* Gmelin (= *Patella aspera* Lam.) and *P. rustica* L. (= *P. lusitanica* Gmelin) (Grubelić, 1992; Šimunović, 1995; Zavodnik *et al*., 2005). They occupy different vertical zones of rocky shores: *P. rustica* occurs in the upper midlittoral and in the supralittoral, *P. caerulea* occurs in the mid to lower midlittoral, and *P. ulyssiponensis* in the low midlittoral and infralittoral fringe (Davies, 1969; Della Santina *et al*., 1993; Šimunović, 1995; Mauro *et al*., 2003).

At each tidal cycle, limpets are out of water, being therefore exposed to high temperature, desiccation and salinity stress (Vermeij, 1973). Limpets are adherent strongly to their permanent place. In many species of limpets, individuals return to the same resting site after feeding, which normally occurs during submersion (Della Santina & Chelazzi, 1991; Aguilera & Navarrete, 2011). Strong adhesion to the substratum reduces water loss, since there is a close fit between the shell and the substratum (Ellem *et al*., 2002). Adhesion to the substratum during inactivity is accomplished by the secretion of pedal mucus with glue-like properties (Smith, 1991, 1992; Smith *et al*., 1999).

Although a number of studies have been carried out on the biology, distribution and ecology of *Patella* species of the Mediterranean Sea (Bacci & Sella, 1970; Bannister, 1975; Guerra & Gaudencio, 1986; Della Santina *et al*., 1993; Navarro *et al*., 2005; Cabral, 2007; Prusina *et al*., 2014a, 2014b; 2015), very little is known about the occurrence of the *Patella* species along the Slovenian coast. Information on this genus has mostly been occasionally collected in the framework of several ecological studies, where some authors mentioned only the species *P. caerulea* for the midlittoral of Slovenian rocky shore (Matjašič & Štirn, 1975; Lipej *et al*., 2004; Pitacco *et al*., 2013). De Min & Vio (1997) reported the presence of *P. caerulea* all along the Slovenian coast as a very common species, and the other two species as very rare: *P. ulyssiponensis* were found only in Strunjan Bay and in Rt Seča, while *P. rustica* was recorded at Rt Madona (Piran) and at Rt Seča.

In early spring 2011, an increase in density of limpets was observed in midlittoral zone all along the Slovenian rocky shore. This phenomenon coincided with the disappearance of *Fucus virsoides* J. Ag. populations, as reported by Battelli (2016).

The focus of the present study was the limpet *P. caerulea* as one of the most numerically abundant and common midlittoral grazer species distributed along the Slovenian coast. The main objectives of this study were to determine the effects of different type of substrata - limestone, marl and sandstone - on: (a) morphological characteristics (shell length, width and height); (b) vertical distribution-zonation and (c) density of the *P. caerulea* population. In addition, the effects of different position on the shore (above and below the mean water tidal level) of the *P. caerulea* individuals on their shell size (length and height) were also determined for limestone and sandstone. The surface sea temperature, salinity and chlorophyll *a*, which may act on *P. caerulea* density population, have been analyzed. The obtained results contribute to expanding current knowledge on the *P. caerulea* populations in this area.

MATERIAL AND METHODS

Study area and sites

The rocky substratum of the Slovenian coast, situated in the south-eastern part of the Gulf of Trieste, consists mainly of Eocene flysch layers with alternating solid sandstone and soft marl (Ogorelec *et al*., 1997); while in certain areas in Izola the rocky shore is formed of limestone (Pavlovec, 1985). These three types of substrata that occur in close proximity provide a useful occasion to test the influence of the substrata on the distribution and structure of *Patella caerulea* populations.

The study was conducted in the midlittoral zone of six sites located along the coast of the Bay of Koper. They were qualitatively selected on the basis of different types of rocky substrata—limestone, marl and sandstone. All sites will hereafter be indicated after the names of the substrata, as: Sand1 (45°35′12.2″ N, 13°42′34.3″ E) and Sand2 (45°32′30.7″ N, 13°40′28.6″ E) on sandstone, Marl1 (45°35′23.2″ N, 13°42′12.3″ E) and Marl2 (45°31′57.0″ N, 13°38′29.0″ E) on marl, Lim1 (45°32′02.1″ N, 13°38′47.8″ E) and Lim2 (45°32′30.9″

N, 13°39'39.4" E) on limestone. The sites Marl1 and Sand1 were located at Cape Debeli rtič, on the north-western side of the Bay of Koper, while the sites Marl2, Lim1, Lim2 and Sand2 were on the south-western side of the Bay of Koper, near Izola (Fig. 1).

The sites Sand1 and Marl1 consisted of rocky platforms with a horizontal extent of about 200 m; Sand1 was characterized by the presence of boulders of different sizes with slightly rough surface, while Marl1 was formed of large steps with a smooth surface and had a gently sloping rock platform. The sites Lim1 and Lim2 had a horizontal extent of about 250 m. The site Sand2 was located in the small bay of Viližan near Izola and was characterized by the presence of boulders of different sizes with slightly rough surface. The site Marl2 was located on the west side near the site Lim1 with a substratum composed of a gently sloping platform of large steps with a smooth surface. All the sites were exposed to wave action generated by winds blowing from northwest to northeast.

On all the sites, midlittoral zone were characterized by the presence of cyanobacteria (mainly *Scytonematopsis crustacea* (Thuret ex Bornet & Flahault) Kovâlik & Komárek and *Entophysalis deusta* (Meneghini) Drouet & Daily) (Giaccone *et al.*, 2003), barnacles *Chthamalus montagui* Southward and *C. stellatus* (Poli), and the limpet *Patella caerulea*. These organisms were generally present on all sites, although their relative abundance could vary. It is important to note the total absence of the macroalgal vegetation at all the investigated sites (Battelli, 2016). The mean sea level (MW) was 218 cm (Fig. 2) (baseline measurements of the sea level are Mareographic zero at the tide gauge station in Koper; data are available on the website of the Ministry of the Environment and Spatial Planning (MPO), Slovenian Environment Agency (ARSO): www.arso.gov.si/water/sea, 2016).

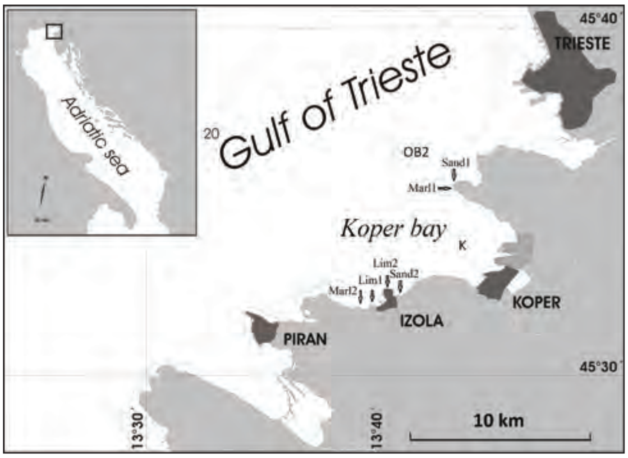

Fig. 1: Map of the study area in the Bay of Koper showing the sampling sites (Marl1, Marl2, Lim1, Lim2, Sand1, Sand2) and sampling stations for sea surface temperature, salinity and chlorophyll* a *(OB2 and K).

Sl. 1: Zemljevid raziskanega območja v Koprskem zalivu z prikazom vzorčevalnih mest (Marl1, Marl2, Lim1, Lim2, Sand1, Sand2) in postaj merjenja temperature, slanosti in klorofila* a *v površinskih vodah (OB2 in K).

Sampling methods

Samplings were carried out during April 2016 along the coast of the Bay of Koper. *Patella caerulea* individuals were analysed from three different types of substrata (limestone, marl and sandstone) in the midlittoral zone during the low water period. Two sampling sites for each type of substratum were randomly chosen (as previously described).

At each site, two transects, 1 m wide and at least 10 m apart, were randomly laid down from the mean lower low water (MLLW) to the mean higher high water tidal level (MHHW) (Fig. 2).

Three replicates 20×20 cm plots (400 cm^2) were randomly allocated to each transect: in total 36 plots were examined. *P. caerulea* individuals were counted in each plot and their abundance expressed as number of individuals per 400 cm^2.

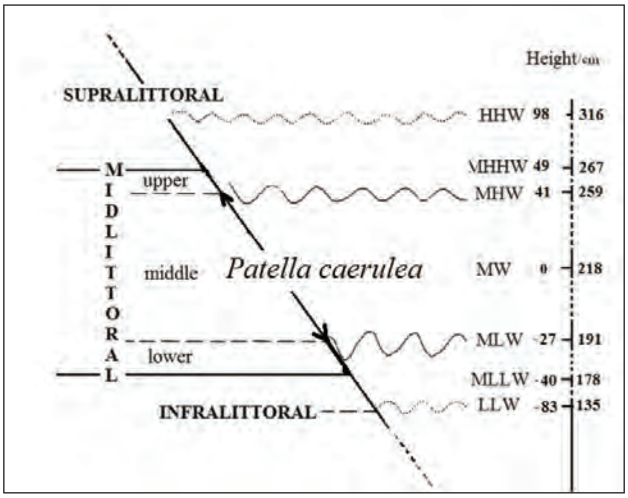

Fig. 2: Schematic representation of the vertical midlittoral zonation pattern of* Patella caerulea *in the Bay of Koper, indicating the mean sea levels for the period 2005-2015. HHW – Higher High water; MHHW – Mean Higher High Water; MHW – Mean High Water; MW – Mean Water; MLW – Mean Low Water; MLLW – Mean Lower Low Water; LLW – Lower Low Water. Source of data: MOP, ARSO, 2016.

Sl. 2: Shematski prikaz vertikalne zonacije vrste* Patella caerulea *v Koprskem zalivu. Podane so srednje vrednosti morske gladine za obdobje 2005-2015. HHW – višja visoka voda; MHHW – srednja višja visoka voda; MHW – srednja visoka voda; MW – srednja voda; MLW – srednja nizka voda; MLLW – srednja nižja nizka voda; LLW – nižja nizka voda. Vir podatkov: MOP, ARSO, 2016.

Fig. 3: *Patella caerulea* **shell with annotated shell dimensions: shell width (SW), shell length (SL) and shell height (SH).**
***Sl. 3:* Lupina vrste** *Patella caerulea* **s prikazom meritev: širina (SW), dolžina (SL) in višina (SH).**

Morphometric measurements

To examine the shell size of limpets, as indicated in Figure 3, shell length (SL, greatest distance between the anterior and posterior ends), shell width (SW, greatest distance between margins) and shell height (SH, the greatest vertical distance from the apex to the base of the shell) were measured directly to the nearest 0.1 mm using a caliper. For this purpose, 2 individuals were randomly selected from each plot (72 individuals in total).

To determine differences in shell length (SL), shell height (SH) and shell height/length ratio (SH/SL) between individuals of *P. caerulea* present above and below the mean sea level, 24 individuals were measured *in situ* from 10 to 40 cm above the MW and the same number from 10 to 40 cm below the MW on limestone and sandstone.

Sea surface temperature (SST), salinity (SSS) and chlorophyll *a* (chl *a*) data

Sea surface temperature (°C), salinity and chlorophyll *a* (chl *a*) data, kindly provided by the Environment Agency of the Republic of Slovenia (ARSO) – Ministry of the Environment and Spatial Planning (MOP) were analysed. On the basis of sea temperature (which in general reaches the lowest values during February and the highest during August) monthly means of these data were processed into winter, which includes January, February and March; spring, including April, May and June; summer, including July, August and September), and autumn, including October, November and December, annual means for the period 2005–2015. This was then divided into two main periods, 2005–2010 and 2011–2015, considering abnormal increase in the abundance of limpet *Patella caerulea* observed at the end of 2010.

Data analyses

In order to establish whether there was a relationship among the values of density, morphological measurements of the *P. caerulea* individuals and different types of substrata (limestone, marl and sandstone), the raw data were subject to statistical analysis using non-parametric Kruskal-Wallis test. Comparisons of the means of the variables describing shell size (height, length and shell height/length ratio) at different heights of the shore (above and below the sea mean level) were carried out by means of 2-way Analysis of Variance (IBM SPSS 23.0). The assumption of homoscedasticity of variances was tested using Levene's test. Significance level was set at $P < 0.05$.

RESULTS

Vertical distribution (zonation) of *Patella caerulea*

The vertical midlittoral zonation pattern of the species *Patella caerulea* was determined (Fig. 2). Individuals of *P. caerulea* tend to inhabit the entire midlittoral zone. Our field notes showed that they were present in a variety of locations such as smooth (marl), rough (sandstone, limestone), regular (marl, sandstone) and irregular (limestone) rock surfaces, rocky platforms, vertical boulders, from the most wave-beaten rock surfaces to the most protected ones. They were also present in various kinds of microhabitats like crevices, cracks and rock pools.

It has been observed that the vertical distribution of the *P. caerulea* individuals was restricted within the midlittoral zone. This area ranges vertically about 49 cm below the mean sea level (MW) and about 40 cm above mean sea level with mean amplitude of 89.5 cm, as illustrated in Figure 2. This vertical area extending be-

Tab. 1: Average values of density (number of individuals/400 cm²) and morphological measurements recorded for *Patella caerulea* **on different substrata (limestone, sandstone and marl) in the Bay of Koper. N-number of individuals, SL-Shell length, SW-Shell width and SH-Shell height.**
Tab. 1: Povprečne vrednosti gostote (število osebkov/400 cm²) in morfoloških meritev vrste *Patella caerulea* **na različnih podlagah (apnenec, peščenjak in laporovec) v Koprskem zalivu. N-število osebkov, SL-dolžina lupine, SW--širina lupine in SH-višina lupine.**

Substratum		N / 400 cm²	SL (mm)	SW (mm)	SH (mm)
Limestone	Mean	8.11	23.33	19.54	6.37
	SD	3.34	7.20	6.59	2.30
	Min	4.00	13.50	10.50	3.50
	Max	15.00	39.00	34.20	12.00
Sandstone	Mean	9.33	31.94	26.30	8.12
	SD	3.29	10.74	8.88	3.42
	Min	3.00	16.20	13.80	4.50
	Max	13.00	56.10	46.90	17.50
Marl	Mean	2.08	27.70	23.22	7.63
	SD	0.79	4.14	4.07	1.70
	Min	1.00	18.20	16.20	4.40
	Max	3.00	34.20	29.40	11.20
Total	Mean	7.06	27.65	22.99	7.34
	SD	4.10	8.93	7.60	2.75
	Min	1.00	13.50	10.50	3.50
	Max	15.00	56.10	46.90	17.50

tween the MHHW and MLLW corresponds to the midlittoral zone and is under the direct influence of seawater because of tides and waves.

On the basis of our observations, we found that the lower limit of the presence of *P. caerulea* individuals was the MLLW, which corresponds to the lower horizon of the midlittoral zone. The upper limit was the MHHW, which represents the upper border of midlittoral zone.

Morphometric characteristics

The values of the morphological measurements, given in Table 1, varied among single substratum. The shell length (SL) values recorded at each surveyed substrata showed an average of 27.65 mm, with a minimum size of 13.50 and a maximum of 56.10 mm. The width of shells (SW) was 22.99 mm on average, and varied between 10.50 and 45.90 mm. The average shell height (SH) was 7.34 mm and it varied between 3.50 and 17.50 mm.

The comparison of the mean values of the single measurement among each type of substrata is illustrated in Figure 4. The non-parametric Kruskal-Wallis test, calculated for the shell length among each substratum, showed statistically significant differences between limestone and sandstone ($P < 0.001$) and between limestone and marl ($P < 0.05$), while between sandstone and marl the differences were statistically not significant ($P > 0.05$). The same situation was found for values of shell width.

A very different trend resulted from the comparison of shell height: the only statistically significant differ-

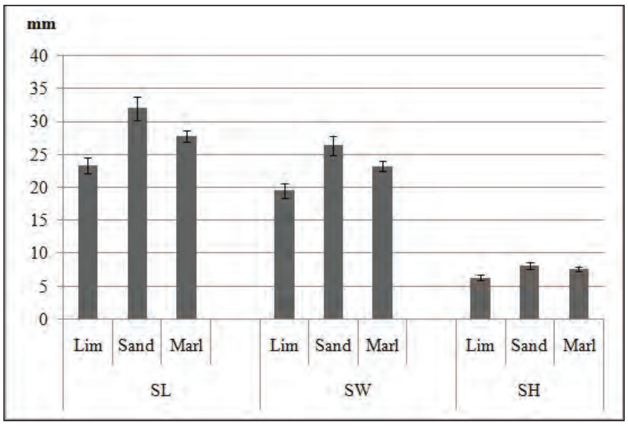

Fig. 4: Graphical representation of the average morphological measurements values recorded for populations of *Patella caerulea* **located on different substrata (limestone-Lim, sandstone-Sand and marl- Marl) along the coast of the Bay of Koper. Legend: SL-Shell length, SW--Shell width and SH-Shell height.**
Sl. 4: Grafični prikaz povprečnih vrednosti morfoloških meritev populacij vrste *Patella caerulea* **na različnih podlagah (apnenec-Lim, peščenjak-Sand in laporovec--Marl) vzdolž obale Koprskega zaliva. Legenda: SL-dolžina lupine, SW-širina lupine in SH-višina lupine.**

Tab. 2: Mean shell length, height and height/length ratio values recorded for** Patella caerulea **for different substrata (limestone and sandstone) and different vertical position (above and below mean sea water tidal level) of the Bay of Koper. SL-Shell length, SH-Shell height and SH/SL-Shell height/length ratio.

Tab. 2: Povprečne vrednosti dolžine, višine in razmerja višina/dolžina lupine vrste** Patella caerulea **na različnih podlagah (apnenec in peščenjak) in različnih višinah (nad in pod srednjim nivojem vode) v Koprskem zalivu. SL--dolžina lupine, SH-višina lupine in SH/SL-razmerje višina/dolžina lupine.

Substratum	Sea level	Above sea mean level			Below sea mean level		
	Variables	SL (mm)	SH (mm)	SH / SL	SL (mm)	SH (mm)	SH / SL
Limestone	Mean	25.74	5.72	0.22	20.03	4.23	0.21
	SD	6.25	2.43	0.05	4.20	1.23	0.04
	Min	17.90	3.20	0.13	13.10	2.80	0.15
	Max	43.20	13.00	0.32	30.70	8.50	0.31
Sandstone	Mean	24.77	5.90	0.24	23.53	4.39	0.19
	SD	6.31	2.22	0.05	3.80	1.10	0.05
	Min	16.40	3.20	0.17	16.30	2.40	0.12
	Max	38.70	13.40	0.35	31.20	6.80	0.30
Total	Mean	25.25	5.81	0.23	21.78	4.31	0.20
	SD	6.23	2.31	0.05	4.34	1.15	0.04
	Min	16.40	3.20	0.13	13.10	2.40	0.12
	Max	43.20	13.40	0.35	31.20	8.50	0.31

ences were found between limestone and sandstone ($P < 0.05$).

In contrast to those living in the lower part of the midlittoral zone (below the mean sea level) the results of the measurements of shell size (shell length, shell height and shell height/length ratio) of the *P. caerulea* individuals living in the upper part of the midlittoral zone (above the mean sea tidal level) showed some significant differentiation (Tab. 2). Statistical analysis supported these results indicating also where significant differences lied. In general, significant differences were found between the upper and lower extents of each single substratum.

Analysis indicated that limpets of different levels on the shore (above the MW and below MW) were of different sizes regarding shell length (SL), shell height (SH) and shell height/length ratio (SH/SL) on both the substrata at all the investigated sites (Tab. 2).

The two-way ANOVA that examined the effect of substrata (limestone and sandstone) and different levels on the shore (above and below the mean water tidal level) on limpet shell length revealed a statistically significant interaction between substrata and shore levels, $F = 4.323$, $P = 0.040$ (Tab. 3). The difference between the mean values of the shore height on sandstone was significantly higher than those on limestone (Tab. 2).

The only statistically significant effect on the shell height, detected in the ANOVA, was the effect of shore height (Tab. 3), where the values of the shells from the shore above the MW level were significantly larger than the values of those from the shore below the MW, on both the investigated substrata (Tab. 2).

The results of the ANOVA, performed for the effect of substrata and shore levels on limpet shell height/length ratio (SH/SL) revealed a statistically significant interaction between substrata and shore levels, $F = 4.941$, $P = 0.029$ (Tab. 3). This was confirmed by a greater difference of the SH/SL ratio values between limpets above the MW level and limpets below the MW level on sandstone in comparison to those on limestone (Tab. 2).

Population density

Average density values recorded for population of *P. caerulea* located on different substrata at selected sites are shown in Table 1. The results showed that the average density at surveyed area was 7.06 individuals /400 cm^2. On sandstone the average density values were 9.33 individuals/400 cm^2, markedly higher and statistically significant ($P < 0.001$) than those recorded on marl, which was 2.08 individuals/400 cm^2. It is also interesting to note that the maximum density values of individuals were found at site Sand1 (13 individuals/400 cm^2) and minimum at site Marl1 with 1 individual/400 cm^2. The highest mean density value of the entire investigated areas was recorded at site Sand1 and corresponded to 10.33 individuals/400 cm^2. Sites on limestone also showed important densities with an average of 8.11 individuals/400 cm^2, which in comparison with the density values on marl (2.08 individuals/400 cm^2) showed statistically significant difference ($P < 0.001$), while versus sandstone (9.33 individuals/400 cm^2) the difference was statistically non-significant ($P > 0.05$).

Tab. 3: ANOVA of the effect of substrata (limestone, sandstone) and different position on the shore (above and below the mean water tidal level) on *Patella caerulea* ***shell length, height and height/length ratio, in the Bay of Koper.***
Tab. 3: ANOVA vpliva podlage (apnenec, peščenjak) in navpične lege (nad in pod srednjim nivojem vode) na dolžino, višino in razmerje višina/dolžina latvice *Patella caerulea* ***v Koprskem zalivu.***

Dependent Variable: length				
Source	df	MS	F	P
Shore height	1	289.468	10.435	0.002
Substrate	1	38.633	1.393	0.241
Shore height X Substrate	1	119.930	4.323	0.040
Error	92	27.739		
Total	95			
Dependent Variable: height				
Source	df	MS	F	P
Shore height	1	53.700	15.855	0.000
Substrate	1	0.700	0.207	0.650
Shore height X Substrate	1	0.004	0.001	0.974
Error	92	3.387		
Total	95			
Dependent Variable: height/length ratio				
Source	df	MS	F	P
Shore height	1	0.019	8.038	0.006
Substrate	1	4.972E-5	0.022	0.884
Shore height X Substrate	1	0.011	4.941	0.029
Error	92	0.002		
Total	95			

On the basis of the comparison of sea surface temperature (SST), salinity (SSS) and chlorophyll *a* (SSChl *a*) for the Bay of Koper (MOP, ARSO, 2015), shown in Figure 5, it was evident that the differences in mean values between the period before 2010 (before the increasing in abundance of *P. caerulea* populations) and after 2010 are not so remarkable. The Kruskal-Wallis test revealed that differences were no statistically significant, although slightly higher values were in general observed during the period 2011–2015, with some exceptions.

Monthly mean SST showed a consistent annual pattern with evident very similar seasonality in both periods. A slightly higher mean seasonal temperature was characteristic for the period 2011–2015 in winter, summer and autumn, while in spring it was slightly lower in this period. The highest temperature values were observed during summer and spring. The main differences were registered between winter and summer period, minimum between spring and autumn.

The SSS data also showed strong annual seasonality: a decrease in warmer seasons (spring and summer) and increase during winter and autumn were evident. The SSS values were slightly higher during the period 2011–2015 in all the seasons except in summer (Fig. 5).

The seasonal trend of the SSChl *a* revealed a slight decrease of values from winter to summer and a greater increase in autumn for both investigated periods. It is clearly evident that during the period 2005-2010 the mean values of the Chl *a* were slightly higher than those of the period 2011-2015 in all seasons (Fig. 5).

DISCUSSION

Our study provides a general perspective on the relationship between three types of substrata (limestone, marl and sandstone) and the morphological characteristics (shell size), vertical distribution and abundance of the *P. caerulea* samples. They were found on all types of substrata: on smooth (marl, sandstone) and rough surfaces (limestone), and also in crevices, cracks, gullies, overhangs, rock pools, pebbles and boulders.

Morphological characteristics

Statistical analysis clearly showed significant differences in shell size (shell length and height) between the limpets present above the mean water tidal level (MW) and those present below the MW. It was found that the

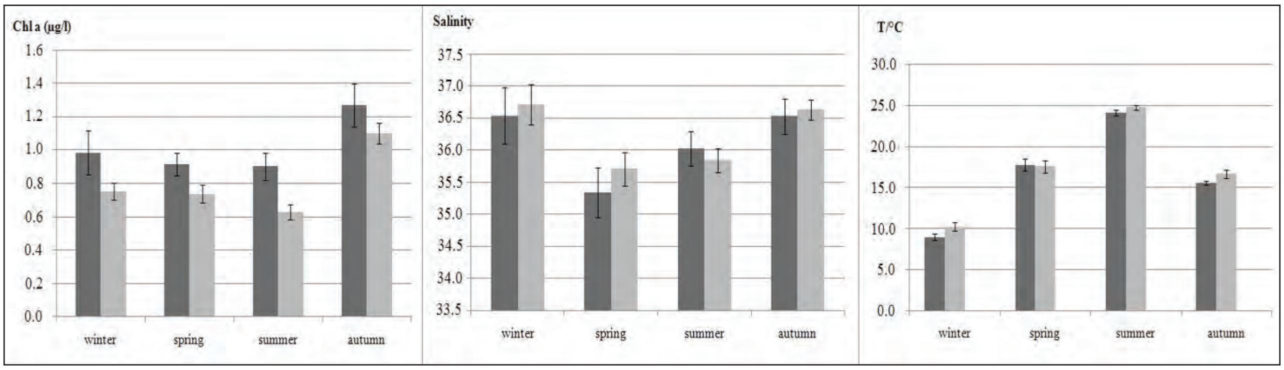

Fig. 5: Seasonal values (mean ± SE) of sea surface temperature, salinity and chlorophyll *a* ***during the period 2005–2010 (black columns) and 2011–2015 (grey columns) in the Bay of Koper (Source of data: MOP, ARSO, 2016 - http://www.arso.gov.si/en/).***

Sl. 5: Sezonske vrednosti (povprečje ± SE) temperature, slanosti in klorofila *a* ***površinskih voda v obdobju 2005–2010 (črni stolpci) in 2011–2015 (sivi stolpci) v Koprskem zalivu (vir podatkov: MOP, ARSO, 2016 - http://www.arso.gov.si/en/).***

values of the shell length and the shell height of *P. caerulea* individuals that live above the MW were significantly higher than those living below MW at all investigated sites. Our findings are similar to the results of the study conducted by several authors as Davies (1969), Öztürk & Ergen (1999) and Davenport & Davenport (2005). According to Öztürk & Ergen (1999) in animals living in drier zones, longer and higher shell are adaptive characteristic against dehydration. The differences in the shell size of the limpets from the upper midlittoral zone compared to those from the lower zone are most likely due to different periods of emersion. The upper part of the shore could therefore be considered as having harsher conditions leading to greater problems of desiccation (Lowell, 1984; Miller *et al*., 2009). So we can consider, in consistence with certain authors as Davies (1969, 1966), Sella (1976), Nolan (1991), that the shell size (length and height) of the *P. caerulea* individuals is heavily influenced by environmental conditions, in particular with respect to the gradients of tidal height (vertical position on the shore) and, at the same time, the type of substrata as an irrelevant factor.

Vertical (zonation) distribution

The present investigation attempts to illustrate the vertical (zonation) distribution of the species *P. caerulea,* which is widely distributed on the coast of Slovenia. *P. caerulea* individuals were found in an area with a vertical extension of about 89 cm, which corresponds to the midlittoral zone (between the Mean Lower Low Water - MLLW and Mean Higher High Water - MHHW). This is in accordance with observations of several authors from the Gulf of Trieste (Matjašič & Štirn, 1975; Vio & De Min, 1996; De Min & Vio, 1997; Lipej *et al*., 2004) and from others areas of the Adriatic (Grubelić, 1992; Zavodnik *et al*. 2005). Della Santina & Chelazzi (1991) monitored the activity of two species of limpets (*P. caerulea* and *P. rustica*) on the Tyrrhenian coast and have established that *P. caerulea* inhabits the lower and the upper midlittoral zone, while *P. rustica* inhabits the upper midlittoral and supralittoral fringe, but moves up to the supralittoral zone during foraging. Both species have a strict homing behaviour, returning to the same location after foraging. The authors pointed out also the difference of the foraging strategies of the two species: *P. caerulea* performs short, mainly regular foraging trips, while *P. rustica* carries out longer and irregularly excursions. On the basis of our field observations we noted that *P. caerulea* performs both, short regular and longer and irregular foraging excursions that reach the supralittoral zone. Our opinion is that this phenomenon could be explained with the absence of the species *P. rustica* along Slovenian coast.

Some others authors, as Evans (1947) and Davenport & Davenport (2005), for example, observed that limpets are largely restricted to the area between the tide marks and, according to this, they considered the necessity for some amount of emersion as the prime factor deciding the vertical distribution of limpets.

Density

One of the main outcomes of our investigation on the population of *P. caerulea* was high mean density found at investigated sites, especially on limestone and sandstone. Within a single substratum it has been observed that significant differences occurred between limestone and marl and between sandstone and marl. We observed that individuals of this species were generally absent from marl where fine sediment covered this substratum. Analyses have shown that the maximum number of limpets occurred on limestone and the minimum on marl. This is in accordance with many authors (e.g. Airoldi & Virgilio, 1998; Airoldi, 2003; Schiel *et al*., 2006) that pointed out that herbivorous organisms, including limpets, are often scarce in areas with high sediment loading, even if the critical levels of perturbation by sediment are not known. Marl is a very friable sedimentary *rock* made of clay and limestone and at all investigated sites this substratum was covered by very fine sediment. This effect of sediment on limpets is particularly important because grazing is a key process controlling algal vegetation on rocky shores (Southward, 1964; Lubchenco & Gaines, 1981; Hawkins & Hartnoll, 1983; Benedetti-Cecchi *et al.*, 2001). In the observed areas *P. caerulea* forms high-density populations on rocky midlittoral shores along the coast of the Bay of Koper and should be with the utmost attention, as highlighted by many authors, regarding the impact of climate change on Mediterranean midlittoral communities (Sarà *et al*., 2014).

We also wanted to know if there were any significant differences in the sea surface temperature (SST), salinity (SSS) and chlorophyll a (SSChl *a*) between the period before 2010 (before the increasing in abundance of *P. caerulea* populations) and after 2010, and if these differences could be related with the increase in the density of limpets. No significant differences in mean values of these parameters were obtained between the period before 2010 and after 2010. It was very interesting to note that the mean seasonal values of the chlorophyll *a* of the period before the increase in abundance of *P. caerulea* populations were higher than those of the period after the increase of *P. caerulea* populations, in all seasons. Probably the determination of the abundance of the epilithic microbial film by measuring the concentration of chlorophyll *a* on the rock surface could better explain the variations in density of the *P. caerulea* population, as observed by a number of authors (e.g. Jenkins *et al.*, 2001; Espinosa *et al.*, 2006). Espinosa *et al*., 2006 observed that food supply decreased significantly with increases in limpet densities, as observed in the present study, with the difference that in our study we measured the concentration of planktonic chlorophyll *a*.

CONCLUSIONS

Patella caerulea individuals are present in all examined locations and substrata (limestone, marl and sandstone), extending, vertically, from MLW to MHW.

Maximum population density of this species occurred on limestone (15 individuals per 400 cm^2) and minimum on marl where the presence of fine sediment represents an important source of stress for *P. caerulea*.

P. caerulea is an important macroalgae grazer, controlling the abundance and distribution of macroalgae of the midlittoral zone of the Bay of Koper.

The shell size of *P. caerulea* individuals is in relation with their position (above and below the MW) on the shore: significantly higher above the MW.

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MORFOMETRIČNE ZNAČILNOSTI, VERTIKALNA RAZŠIRJENOST IN GOSTOTA LATVICE *PATELLA CAERULEA* L. GLEDE NA RAZLIČNE TIPE PODLAG V KOPRSKEM ZALIVU (TRŽAŠKI ZALIV, SEVERNI JADRAN)

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POVZETEK

V prispevku avtor poroča o rezultatih raziskave populacije latvic vrste Patella caerulea *v Koprskem zalivu (Tržaški zaliv, severni Jadran). Obalo Koprskega zaliva sestavljajo različni tipi podlage kot so apnenec, laporovec in peščenjak, ki nudijo idealne možnosti za študij vpliva teh podlag na vertikalno razširjenost, gostoto in morfološke značilnosti te vrstec. Opazovanja so pokazala, da se populacija vrste* P. caerulea *pojavlja na vseh obravnavanih podlagah v mediolitoralnem pasu tega geografskega območja. Najvišje vrednosti gostote (števila osebkov na 400 cm^2) se pojavljajo na peščenjaku, najnižje pa na laporovcu. Lupine latvic zgornjega mediolitorala so na vseh raziskanih podlagah večje od tistih iz spodnjega mediolitorala. Avtor obravnava tudi temperaturo, slanost in koncentracijo klorofila* a *kot parametre, s katerimi bi lahko razložili porast populacije latvic.*

Ključne besede*:* *Patella caerulea*, morfometrične značilnosti, vertikalna razširjenost, gostota, Tržaški zaliv, severni Jadran

REFERENCES

Airoldi, L. (2003): The effects of sedimentation on rocky coast assemblages. Oceanogr. Mar. Biol., 41, 161–236.

Airoldi, L. & M. Virgilio (1998): Responses of turf-forming algae to spatial variations in the deposition of sediments. Mar. Ecol. Prog. Ser., 165, 271–282.

Aguilera, M.A. & S.A. Navarrete (2011): Distribution and activity patterns in an intertidal grazer assemblage: influence of temporal and spatial organization on interspecific associations. Mar. Ecol. Prog. Ser., 431, 119–136.

Arrontes, J., F. Arenas, C. Fernández, J.M. Rico, J. Oliveros, M. Martínez, R.M. Viejo & D. Alvarez (2004): Effect of grazing by limpets on mid-shore species assemblages in northern Spain. Mar. Ecol. Prog. Ser., 277, 117–133.

ARSO (2016): Ministry of the Environment and Spatial Planning (MPO), Slovenian Environment Agency (ARSO): www.arso.gov.si/water/sea. 25/08/2016.

Ayas, D. (2010): Distribution and morphometric characteristics of *Patella* species (Archaeogastropoda) in Mersin-Viranşehir region of the Northeastern Mediterranean sea. J. Fisheries Sciences, 4(2), 171–176.

Bacci, G. & G. Sella (1970): Correlations between characters and environmental conditions in *Patella* of the *coerulea* group. Pubbl. Staz. Zool. Napoli, 38, 1–24.

Bannister, V. (1975): Shell Parameters in Relation to Zonation in Mediterranean Limpets. Mar. Biol., 31(1), 63–67.

Bat, L. & M. Öztürk (1998): *Patella caerulea* as a Biomonitor of Coastal Metal Pollution. Faculty of Arts and Sciences, Dept. of Biology, Celal Bayar Univ., ISSN 1301–2428, 142–146.

Bat, L., G. Gönlügür, M. Andaç, M. Öztürk & M. Öztürk (2000): Heavy Metal Concentrations in the Sea Snail *Rapana venosa* (Valenciennes, 1846) from Sinop Coasts of the Black Sea. Turk. J. Mar. Sci., 6, 227–240.

Battelli, C. (2016): Disappearance of *Fucus virsoides* J. Agardh from Slovenian coast (Gulf of Trieste, northern Adriatic). Annales, Ser. Hist. Nat., Koper, 26(1), 1–12.

Benedetti-Cecchi, L., F. Bulleri, S. Acunto & F. Cinelli (2001): Scales of variation in the effects of limpets on rocky shores in the northwest Mediterranean. Mar. Ecol. Prog. Ser., 209, 131–141.

Branch, G.M. (1981): The biology of limpets: physical factors, energy flow and ecological interactions. Oceanogr. Mar. Biol. Ann. Rev., 19, 235–380.

Branch, G.M. (1985): Limpets: their role in littoral and sublittoral community dynamics. In P.G. Moore & R. Seed (eds). The ecology of rocky coast, New York. Columbia University Press, 97–116.

Bresler, V., Y.O. Mokad, L. Fishelson, T. Feldstein & A. Abelson (2003): Marine Molluscs in Environmental Monitoring. II. Experimental Exposure to Selected Pollutants. Helgol. Mar. Res., 57, 206.

Cabral, J. (2007): Shape and growth in European Atlantic *Patella limpets* (Gastropoda, Mollusca). Ecological implications for survival. Web. Ecol., 7, 11–21.

Coleman, R.A., A.J. Underwood, L. Benedetti-Cecchi, P. Åberg, F. Arenas, J. Arrontes, J. Castro, R.G. Hartnoll, S.R. Jenkins, J. Paula, P. Della Santina & S.J. Hawkins (2006): A continental scale evaluation of the role of limpet grazing on rocky shores. Oecologia, 147, 556–564.

Davenport, J. & J.L. Davenport (2005): Effects of shore height, wave exposure and geographical distance on thermal niche width of intertidal fauna. Mar. Ecol. Prog. Ser., 292, 41–50.

Davies, P.S. (1966): Physiological ecology of *Patella*. I. The effect of body size and temperature on metabolic rate. J. Mar. Biol. Ass. U.K., 49, 291–304.

Davies, P.S. (1969): Effect of environment on metabolic activity and morphology of Mediterranean and British species of *Patella*. Pubbl. Stn. Zool. Napoli, 37, 641– 656.

Della Santina, P. & G. Chelazzi (1991): Temporal organization of foraging in two Mediterranean limpets, *Patella rustica* (L.) and *Patella caerulea* (L.). J. Exp. Mar. Biol. Ecol., 153, 75–85.

Della Santina, P., C. Sonni, G. Sartoni & G. Chelazzi (1993): Food availability and diet composition of three coexisting Mediterranean limpets (*Patella* spp.). Mar. Biol., 116, 87–95.

De Min, R. & E. Vio (1997): Molluschi conchiferi del litorale sloveno. Ser. Hist. Nat., 11, 241–258.

Ellem, G.K., J.E. Furst & K.D. Zimmerman (2002): Shell clamping behaviour in the limpet *Cellana tramoserica*. – J. Exp. Biol., 205, 539–547.

Espinosa, F., J.M. Guerra-García, D. Fa & J.C. García-Gómez (2006): Effects of competition on an endangered limpet *Patella ferruginea* (Gastropoda: Patellidae): Implications for conservation. J. Exp. Biol., 330, 482– 492.

Evans, R.G. (1947): Studies on the Biology of British Limpets. Proc. zool. Soc. Lond., 117, 411–423.

Giaccone G., G. Alongi, C. Battelli, M. Catra, L.A. Ghirardelli, A. Pezzino & S. Stefani (2003): Guida alla determinazione delle alghe del Mediterraneo. Parte I: alghe azzurre (Cyanophyta o Cyanobacteria) (in ambiente naturale e biodeteriogeni su manumenti lapidei). Università di Catania, 92 p.

Grubelić, I. (1992): Comparative studies of littoral biocoenoses of the Kornati Islands. Acta Adriat., 33, 1/2,127–161.

Guerra, M.T. & M.J. Gaudencio (1986): Aspects of the ecology of *Patella* spp. on the Portuguese coast. Hidrobiología, 142, 57–69.

Hawkins, S.J. & R.G. Hartnoll (1983): Grazing of intertidal algae by marine invertebrates. Oceanogr. Mar. Biol., 21, 195–282.

Jenkins, S.R., F. Arenas, J. Arrontes, J. Bussell, J. Castro, R.A. Coleman, S.J. Hawkins, S. Kay, B. Martínez, J. Oliveros, M.F. Roberts, S. Sousa, R.C. Thompson & R.G. Hartnoll (2001): European-scale analysis of seasonal variability in limpet grazing activity and microalgal abundance. Mar. Ecol. Prog. Ser., 211, 193–203.

Jenkins, S.R., R.A. Coleman, P. Della Santina, S.J. Hawkins, M.T. Burrows & R.G. Hartnoll (2005): Regional scale differences in the determinism of grazing effects in the rocky intertidal. Mar. Ecol. Prog. Ser., 287, 77–86.

Lipej, L., M. Orlando-Bonaca & T. Makovec (2004): Raziskovanje biodiverzitete v slovenskem morju. Morska biološka postaja, Nacionalni inštitut za biologijo. Piran, 136 p.

Lowell, R.B. (1984): Desiccation of intertidal limpets: effects of shell size, fit to substratum and shape. J. Exp. Mar. Biol. Ecol., 77, 197–207.

Lubchenco, J. & S.D. Gaines (1981): A unified approach to marine plant–herbivore interactions. I. Populations and communities. Annu. Rev. Ecol. Syst., 12, 405–437.

Mauro, A., M. Arculeo & N. Parrinello (2003): Morphological and molecular tools in identifying the Mediterranean limpets *Patella caerulea*, *Patella aspera* and *Patella rustica*. J. Exp. Mar. Biol. Ecol., 295, 131–143.

Matjašič, J. & J. Štirn (1975): Flora in favna severnega Jadrana. Ljubljana, Prisp. 1., Slovenska Akademija Znanosti in Umetnosti, Razprave, 4, 19–23.

Menge, B.A., E.L. Berlow, C.A. Blanchette, S.A. Navarrete & S.B. Yamada (1994): The keystone species concept: variation in interaction strength in a rocky intertidal habitat. Ecol. Monogr., 64, 249–286.

Menge, B.A. (2000): Top-down and bottom-up community regulation in marine rocky intertidal habitats. J. Exp. Mar. Biol. Ecol., 250, 257–289.

Miller, L.P., C.D.G. Harley & M.W. Denny (2009): The role of temperature and desiccation stress in limiting the local-scale distribution of the owl limpet, *Lottia gigantea*. Funct. Ecol., 23, 756–767.

Moore, P., R.C. Thompson & S.J. Hawkins (2007): Effects of grazer identity on the probability of escapes by a canopy-forming macroalga. J. Exp. Mar. Biol. Ecol., 344, 170–180.

Navarro, P.G., R. Ramirez, F. Tuya1, C. Fernandez-Gil, P. Sanchez-Jerez & R.J. Haroun (2005): Hierarchical analysis of spatial distribution patterns of patellid limpets in the Canary Islands. J. Moll. Stud., 71, 67–73.

Nolan, C.P. (1991): Size, shape, and shell morphology in the antarctic limpet *Nacella concinna* at Signy Island, south Orkney Islands. J. Moll. Stud., 57, 225–238.

Ogorelec, B., J. Faganeli, M. Mišič & B. Čermelj (1997): Reconstruction of paleoenvironment in the bay of Koper (Gulf of Trieste, Northern Adriatic). Annales, Ser. Hist. Nat., 11, 187–200.

Öztürk, B. & Z. Ergen (1999): *Patella* species (Archaeogastropoda) distributed in Saros Bay (northeast Aegean Sea). Tr. J. Zool., 23, 513–520.

Pavlovec, R. (1985): Numulitine iz apnencev pri Izoli (SW Slovenija). Razprave 4. razred Slovenska Akademija Znanosti in Umetnosti, 26, 219–230.

Pitacco, V., B. Mavrič, M. Orlando-Bonaca & L. Lipej (2013): Rocky macrozoobenthos mediolittoral community in the Gulf of Trieste (North Adriatic) along a gradient of hydromorphological modifications. Acta Adriat., 54(1), 67–86.

Prusina, I., D. Ezgeta-Balić, S. Ljubimir, T. Dobroslavić & B. Glamuzina (2014a): On the reproduction of the Mediterranean keystone limpet *Patella rustica*: histological overview. J.M.B.A. U.K., 1–10.

Prusina, I., G. Sarà, M. De Pirro, J.W. Dong, G.D. Han, B. Glamuzina & G.A. Williams (2014b): Variations in physiological responses to thermal stress in congeneric limpets in the Mediterranean Sea. J. Exp. Mar. Biol. Ecol., 456, 34–40.

Prusina, I., M. Peharda, D. Ezgeta-Balić, S. Puljas, B. Glamuzina & S. Golubić (2015): Life-history trait of the Mediterranean keystone species *Patella rustica*: growth and microbial bioerosion. *Medit. Mar. Sci., 16/2, 393–401.*

Sarà, G., M. Milanese, I. Prusina, I. Sarà, A. Angel, D.L. Glamuzina, B. Tali, B. Nitzan, S. Freeman, A. Rinaldi, V. Palmeri, V. Montalto, M. Lo Martire, P. Gianguzza, V. Arizza, S. Lo Brutto, M. De Pirro, B. Helmuth, J. Murray, S. De Cantis & G.A. Williams (2014): The impact of climate change on Mediterranean intertidal communities: losses in coastal ecosystem integrity and services. Regional Environmental Change, 14(14), 5–17.

Schiel, D.R., S.A. Wood, R.A. Dunmore & D.I. Taylor (2006): Sediment on rocky intertidal reefs: effects on early post-settlement stages of habitat-forming seaweeds. J. Exp. Mar. Biol. Ecol., 331, 158–172.

Sella, G. (1976): Biometrical relationships between mesolittoral and infralittoral *Patella* populations in the Mediterranean. Publ. Staz. 2001. Napoli, 40, 123–132.

Smith, A. M. (1991): The role of suction in the adhesion of limpets. J. Exp. Biol., 161,151–169.

Smith, A. M. (1992): Alternation between attachment mechanisms by limpets in the field. J. Exp. Mar. Biol. Ecol., 160, 205–220.

Smith, A.M., T.J. Quick & R.L. St. Peter (1999): Differences in the composition of adhesive and non-adhesive mucus from the limpet *Lottia limatula*. Biol. Bull., 196, 34–44.

Southward, A.J. (1964): Limpet grazing and the control of vegetation on rocky shores. In: Crisp DJ (ed) Grazing in terrestrial and marine environments. Blackwell Scientific Publications, Oxford, p. 265–273.

Šimunović, A. (1995): Ecological study of Prosobranchiata (Gastropoda) in the eastern part of the Adriatic Sea and their relationship to benthic biocenoses. Acta Adriat., 36, 3–162.

Vermeij, G.J. (1973): Morphological patterns in high-intertidal gastropods: adaptive strategies and their limitations. Mar. Biol., 20, 319–346.

Vio, E. & R. De Min (1996): Contributo alla conoscenza dei molluschi marini del Golfo di Trieste. Atti Mus. Civ. Nat. Trieste, 47, 173–233.

Zavodnik, D., A Pallaoro, A. Jaklin, M. Kovačić & M. Arko Pijevac (2005): A benthos survey of the Senj Archipelago (North Adriatic Sea, Croatia). Acta Adriat., 46(2), 3–68.