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CLADOCERANS SPATIAL AND TEMPORAL DISTRIBUTION IN THE COASTAL SOUTH ADRIATIC WATERS (MONTENEGRO)

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ABSTRACT

Spatial and temporal variability of cladocerans was studied monthly from April to November 2009 at 14 stations divided in three zones in the Montenegrin coast. Six species were determined: *Penilia avirostris*, *Evadne spinifera*, *Evadne tergestina*, *Evadne nordmani*, *Podon intermedius* and *Podon polyphemoides*. Total number of cladocerans, during summer months, overmatches copepods abundances in Boka Kotorska Bay and at Bojana River Mouth during September. The only predominant species at all stations during investigated period was *P. avirostris*. All species were found in Boka Kotorska Bay and Open Sea Coastal Area, while *E. nordmani* and *P. intermedius* were not found near Bojana River Mouth. Influences of environmental factors on cladocerans abundance were discussed. Increased dominance of cladocerans in the pelagic coastal Montenegrin waters could be related with the increased eutrophication in the area, as well as the possible effects of climatic change.

Keywords: species composition, abundance, eutrophication

INTRODUCTION

Cladocerans play a major role in freshwater ecosystems, but they are not successful in colonizing the marine environment (Atienza *et al.* 2008). In contrast to the more then 620 limnetic species of cladocerans (Forro *et al.* 2008), there are only eight cosmopolitan species in the world ocean (Onbé, 1977) distributed in three genera: *Penilia* (comprising only *Penilia avirostris*), *Evadne* and *Podon* (Marazzo & Valentin 2001). Cladocerans include a small fraction of the zooplankton in the open sea. Due to their parthenogenetics reproduction in coastal and estuarine environments they may occur with extent monospecific cladoceran populations that are usually predominant by copepods (Tang *et al.* 1995). Temporal distribution of marine cladocerans is discontinuous: very high abundances are known from early spring to late summer (Gieskes, 1971), followed by rapid decline and absence from the plankton during the winter (Atienza *et al.* 2008). Because of their high abundances and wide distribution in coastal areas, cladocerans are also a common prey of most planktonic carnivorous species and could play an important role in the pelagic food web (Apostolopoluou & Kiortsis 1973, Marazzo *et al.* 2003). In spite of their high densities and important trophodynamic role, the marine cladocerans have been surprisingly little studied, when compared to the large number of works on others planktonic crustaceans (Marazzo & Valentin 2001).

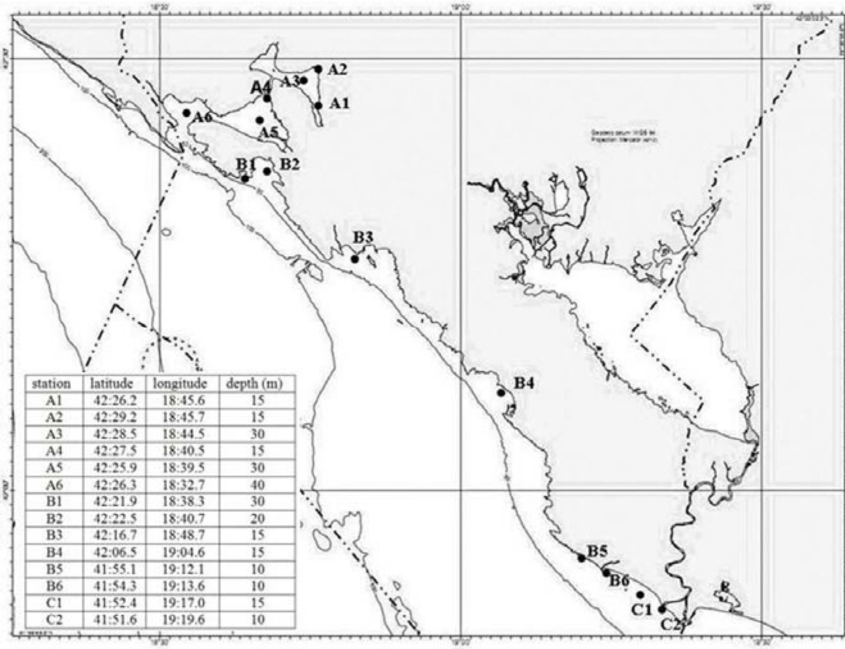
Opposite to detailed studies focused on temporal, spatial distribution and biology of cladocerans in North Adriatic (Malej, 1979, Corni *et al.* 1989, Lipej *et al.* 1997), information on Cladoceran population in Middle and South Adriatic are sporadic (Bender, 1984; Fonda-Umani *et al.*, 1992; Lučić & Kršinić, 1998; Brautović *et al.*, 2000; Vidjak *et al* 2006). Information on the Cladoceran population in the Montenegrin coast is scarce and restricted on

Boka Kotorska Bay (Vukanić, 2006). Six species founded in this work were compared with environmental conditions such as temperature, salinity and oxygen saturation. High abundance of *P. avirostris* was recorded in August, causing an abundance maximum for total zooplankton. Values were relative estimated (%) or present as ind. m^{-2}.

Here, we report on the population dynamics of marine cladocerans during the spring and summer period, as a contribution to understanding the main factors that control their temporal and spatial distribution for the overall Montenegrin coastal waters. We hypothesis that hydrographic and productions features considerably influence variability of their population successions and abundance.

Study area

Montenegrin coastal area could be separated into three regions: Boka Kotorska Bay (A zone), open sea coastal area (B zone) and Bojana River mouth (C zone) (Figure 1).



station	latitude	longitude	depth (m)
A1	42:26.2	18:45.6	15
A2	42:29.2	18:45.7	15
A3	42:28.5	18:44.5	30
A4	42:27.5	18:40.5	15
A5	42:25.9	18:39.5	30
A6	42:26.3	18:32.7	40
B1	42:21.9	18:38.3	30
B2	42:22.5	18:40.7	20
B3	42:16.7	18:48.7	15
B4	42:06.5	19:04.6	15
B5	41:55.1	19:12.1	10
B6	41:54.3	19:13.6	10
C1	41:52.4	19:17.0	15
C2	41:51.6	19:19.6	10

Figure 1. Map of sampling area

Boka Kotorska Bay penetrates into the mainland for 28 km and is comprised of four bays that are interconnected: Bay of Herceg-Novi (which directly communicates with the open sea), Bay of Tivat, as well as the inner bay Risan and Kotor Bay. Often referred to as a fjord, owing to its dramatically steep mountain walls, it is, in fact, a submerged river canyon. Owing to the large amount of winter precipitation over its karstic drainage basin, Boka Kotorska Bay is greatly influenced by the large influx of fresh water from streams and submarine springs. Water exchange with the open Adriatic depends primarily on tidal variation, with incoming currents near the bottom and outgoing currents on the surface.

Open coastal area is situated along outer Montenegrin coast (Figure 1). Stations B1 and B2 have a hard substrate bottom, while other stations have sandy bottom. The whole area is under the strong influence of the southern wind and high waves. Also, area is influenced by incoming oligotrophic waters from the Ionian Sea.

Two stations situated near the Bojana River mouth (Figure 1) are high influenced by fresh water, showing average annual flow of 640 m^3/s, especially during late spring month.

MATERIALS AND METHODS

This study was carried out from April to November 2009 at 14 stations divided in three zones (Figure 1). Results were presented as monthly mean values of all positions by zones.

Vertical profiles of temperature and salinity were obtained *in situ* by HQ40d Multi-Parameter Digital Meter at surface, middle, and bottom layer. Dissolved nutrient concentration (phosphate, nitrite and silicate) was determined according to the methods described by Strickland & Parsons (1972). Chlorophyll *a* was analyzed according to Jeffrey *et al.* (1997).

Zooplankton were collected by Nansen plankton net (0.55 m diameter, 125 μm mesh size) from bottom to surface. Material was preserved in a buffered 2.5 % formalin-seawater solution and analyzed using Nikon type 104 binocular lenses. Each sample was sub-sampled in laboratory depending on the number of individuals in the total sample. Zooplankton abundance was counted from the representative sample of 1/64 to total catch, and calculated as number of individuals per m^{-3}.

The program Grapher 7.0 (Golden Software) was used for preparation of figures.

A standard Spearman rank order correlation test (Statsoft, version 7.0) was used to compare correlations between cladoceran abundances and environmental parameters. The Mann-Whitney U test (Zar 1974) was used to compare the differences in cladocerans abundance between different zones.

RESULTS

Environmental conditions and chlorophyll *a*

Temperature increased from April to May when a sharp thermocline below 5 m depth was formatted. At the surface of Boka-Kotorska Bay stations, slight temperature variations were noted. At the bottom layers, variations were more pronounced, especially at the deeper station. Maximum temperature values were recorded on surface in July (for B and C zones) and August (A zone), while minimum values were noticed in November (A zone) followed by low salinity at same period (Table 1).

Table 1. Average values and Standard Deviations of temperature and salinity in A, B and C zone by layers (surface, middle, bottom)

		Temp (AVG+SD)	Sal (AVG+SD)	Temp (AVG+SD)	Sal (AVG+SD)	Temp (AVG+SD)	Sal (AVG+SD)
		A		B		C	
APR	surf	16.23+0.36	24.63+9.82	16.26+0.64	34.00+3.59	16.67+0.66	31.10+2.26
	midd	14.88+0.81	37.78+0.45	15.50+0.33	35.43+3.59	16.20+0.57	37.40+0.42
	bott	14.47+0.91	37.98+0.42	15.03+0.72	37.52+0.97	15.69+0.94	37.45+0.35
MAY	surf	24.73+1.01	29.42+2.91	23.25+0.92	31.14+8.28	24.15+0.49	17.62+1.15
	midd	16.38+0.66	36.92+0.54	19.63+2.25	36.80+0.78	19.55+1.34	36.70+0.57
	bott	15.60+0.53	36.85+0.40	17.90+1.58	37.47+0.66	18.50+1.56	37.35+0.35
JUN	surf	23.23+0.74	21.58+10.45	21.48+0.90	30.50+3.90	20.69+0.87	13.61+1.26
	midd	20.27+1.85	36.80+1.09	19.50+1.33	35.00+1.39	21.20+0.99	34.45+0.92
	bott	18.10+1.08	37.02+0.55	18.93+1.73	36.70+0.95	20.45+1.34	36.10+0.85
JUL	surf	22.35+3.87	19.03+10.99	25.23+0.74	36.18+0.64	25.55+0.64	24.14+4.04
	midd	19.05+1.62	39.14+7.24	23.45+1.05	37.75+0.97	24.30+0.71	36.65+0.64
	bott	17.20+0.38	39.03+7.64	21.50+2.97	37.68+0.58	23.05+1.91	37.45+0.21
AUG	surf	25.82+1.39	30.19+9.29	22.93+2.10	36.54+2.64	21.85+1.06	24.33+5.90
	midd	17.33+1.22	37.65+1.54	18.27+0.83	36.71+0.94	18.40+0.85	36.20+0.28
	bott	17.18+0.58	37.54+0.83	17.15+0.97	36.77+0.71	18.20+0.85	35.75+0.78
SEP	surf	25.52+0.81	31.77+6.23	25.24+1.12	34.75+2.53	24.70+0.14	30.30+2.12
	midd	21.15+3.98	36.30+0.38	24.65+0.55	36.55+0.15	25.15+0.49	36.80+0.57
	bott	18.58+1.43	36.00+0.42	23.84+1.94	36.35+0.22	24.70+2.12	36.75+0.21
OCT	surf	18.28+1.96	28.26+4.36	24.68+1.06	37.90+0.48	23.35+0.35	29.30+0.28
	midd	21.32+0.92	33.31+4.14	24.36+0.48	38.38+0.17	23.60+0.28	37.60+1.27
	bott	19.10+1.65	35.73+2.92	24.36+0.56	38.35+0.26	23.70+0.14	38.60+0.28
NOV	surf	14.68+2.54	14.94+16.49	16.95+1.03	34.05+3.28	15.50+0.99	21.79+10.34
	midd	18.30+0.73	38.22+1.35	17.60+0.66	37.28+0.99	17.15+0.07	36.30+1.56
	bott	17.83+0.86	39.45+0.72	17.75+0.48	38.93+1.10	17.25+0.21	36.85+1.06

Minimum salinity values were recorded in June (C zone) on surface as consequence of Bojana river run-off. Bojana river influenced the open coastal area (B zone), indicating lower salinity in this period.

Nutrient concentrations were high variable throughout most of the sampling period (Figure 2). Phosphates concentrations reached maximum mean value of 0.395 µmolL^{-1} in July at B zone. The increase in nitrites and silicates content following the higher influx of freshwater was pronounced at A zone in November and noticed maximum mean values of 0.331 µmol L^{-1} for nitrites and 10.31 µmol L^{-1} for silicates.

Mean values of chlorophyll *a* concentration ranged from 0.109 mgm^{-3} at C zone in November to 1.741 mgm^{-3} in July at same zone (Figure 2)

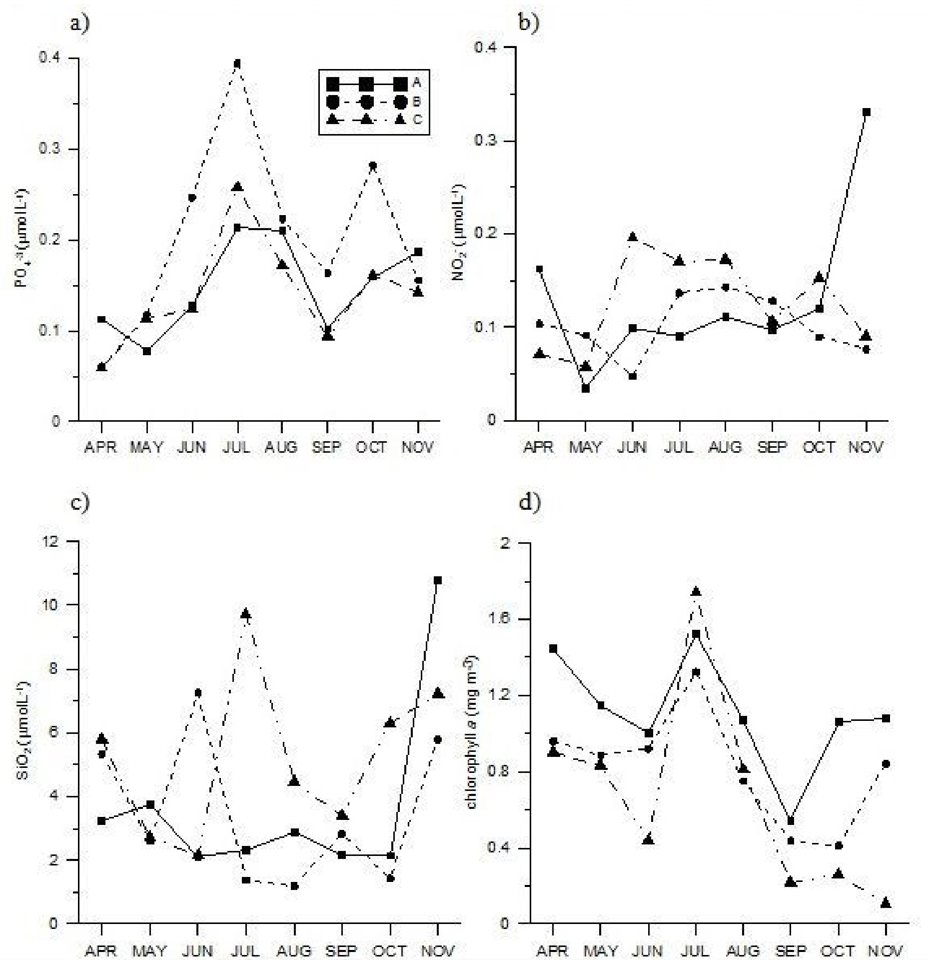


Figure 2. Monthly means of all sampling stations of a) phosphate, b) nitrite, c) silicate and d) chlorophyll a by A, B and C zones.

Cladocerans

We found six of eight known marine cladoceran species: *Penilia avirostris* Dana, *Evadne spinifera* Muller, *Evadne tergestina* Claus, *Evadne nordmani* Lovén, *Podon intermedius* Lilljeborg and *Podon polyphemoides* Leuckart. High total cladocerans numbers during summer months overmatch copepods abundances in zone A, and in zone C during September, only. In contrary, copepods densities pronouncedly dominated in zone B (Figure 3).

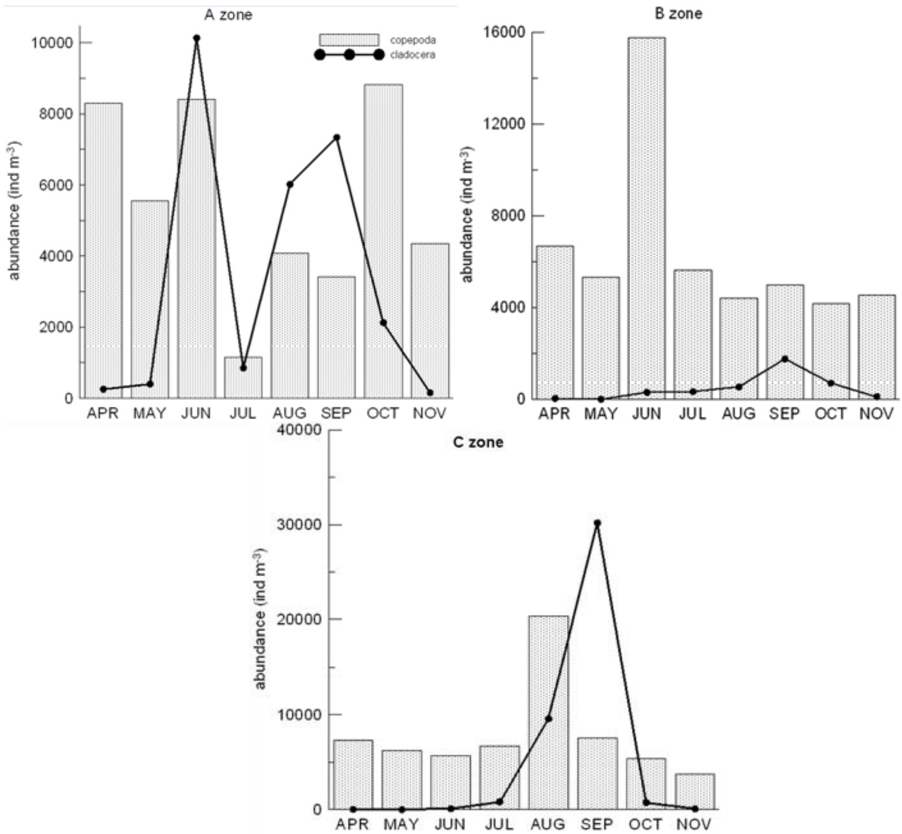


Figure 3. Monthly means of all sampling stations of total copepod and cladoceran abundances in A, B and C zone

Penilia avirostris was predominant species at all stations during investigated period (Figure 4). Maximum value reached in September 29900 ind m^{-3} near mouth of Bojana River (C zone). *Evadne spinifera* had a similar temporal and spatial distribution. However, it was less abundant and less frequent than *P. avirostris*. *E. spinifera* reached highest densities at C zone, with maximum of 458 ind m^{-3} in July. *Evadne tergestina* appeared from July to September and reached maximum in August, 751 ind m^{-3} at C zone. *Evadne nordmani* was less numerous and in zone C was absent. *Podon intermedius* was presented occasionally in zone A, with few species in zone B, and was not found in zone C. *Podon polyphemoides* presented discontinuously through investigated period. It achieved maximum values in April and November in Boka Kotorska Bay, while in July and October was absent at all zones.

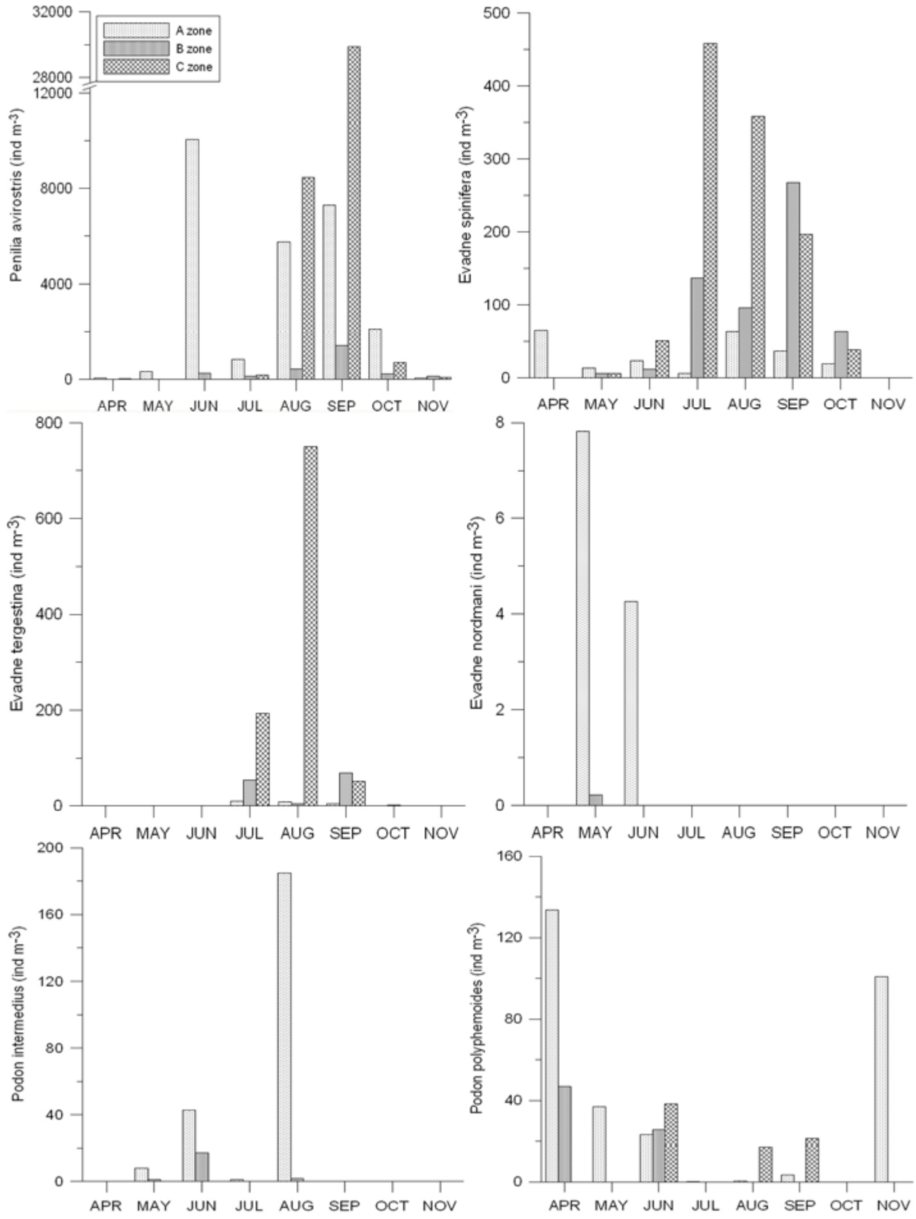


Figure 4. Monthly means of all sampling stations of cladoceran species in A, B and C zone

Although the marked maximum of *P. avirostris* was determined at stations near the Bojana River mouth, significantly higher densities were found in the Boka-Kotorska Bay (Table 2). Significantly higher values in the Boka-Kotorska Bay were noted for *E. nordmani*, *P. intermedius* and *P. polyphemoides*, too. No significant difference was found between *E. spinifera* and *E. tergestina* abundance in different zones.

Table 2. Comparison of A, B and C zone sampling stations with respect to cladocera species abundances (Mann-Whitney test). Species Evadne nordmani and Podon intermedius were not found in zone C.

Species	Probability			Sequence of abundance
Zone	A-B	A-C	B-C	
Penilia avirostris	<0.001	0.02	<0.001	A>B>C
Evadne nordmani	0.001			A>B
Evadne spinifera	n.s.	n.s.	n.s.	A=B=C
Evadne tergestina	n.s	n.s	n.s	A=B=C
Podon intermedius	>0.05			A>B
Podon polyphemoides	0.01	n.s	n.s	A>B=C

Cladocerans abundance and relationship with environmental parameters

According Spearman rank order correlation test (Table 3), species *P. avirostris, E. spinifera* and *E. tergestina* showed significant positive correlation with temperature in all zones. Other species almost always negatively correlate with temperature. Most of the species did not have significant correlation with chlorophyll *a*, or correlations were negative. Pronounced positive correlations with phosphates were noted for *P. avirostris* and *E. spinifera* in zone B only.

Significantly negative correlations between numerous cladoceran species and silicate were noted in zone A. Results of other correlation didn't show regularity and they are abstruse (Table 3).

Table 3. Spearman rank order correlation between cladoceran species and environmental parameters. Significant correlations are marked with asterisk ($p < 0.05$).

Species	Zone	Sal	PO_4^{-3}	NO_2^-	SiO_2
P. avirostris	A	0.122	-0.201	**-0.346***	**-0.450***
E. spinifera		0.118	0.019	-0.206	**-0.425***
E. tergestina		0.059	0.069	**-0.253***	**-0.347***
E. nordmani		**-0.354***	-0.029	-0.086	**0.282***
P. intermedius		-0.128	0.013	-0.230	0.030
P. polyphemoides		**-0.390***	0.100	**0.371***	0.221
P. avirostris	B	0.025	**0.581***	0.185	-0.253
E. spinifera		0.004	**0.449***	**0.383***	**-0.460***
E. tergestina		-0.128	0.245	0.213	-0.181
E. nordmani		-0.288	-0.005	0.150	0.058
P. intermedius		-0.259	0.117	-0.081	0.057
P. polyphemoides		-0.040	-0.240	-0.180	**0.345***
P. avirostris	C	0.122	-0.086	0.160	-0.089
E. spinifera		-0.245	-0.049	0.142	-0.160
E. tergestina		-0.177	-0.050	0.386	0.064
P. polyphemoides		-0.107	0.242	0.239	-0.195

DISCUSSION

The present work reports spatial and temporal distribution of marine cladocerans populations for the overall coastal waters of Montenegro. Previous research was included only stations in Boka-Kotor bay, and these results are not comparable to ours, because they were counted as relative abundance of cladoceran species (%), or as number of individuals per m^{-2} (Vukanić, 2006).

Cladocerans react to environmental changes with growth dynamics so they are good representative group of zooplankton. It will be possible to consider these species as a fine ecological indicators to environment assessment, when the characteristics of their biological cycles and their environmental exigencies area well known (Brautović *et al.,* 2000).

Investigations of the cladocerans variability in the Montenegrin coastal area indicated that these typically neritic organisms have not been equally distributed. The establishment and maintenance of their populations in the plankton community dependent on certain environmental factors (Onbe, 1977; Ramirez & Perez Seijas, 1985; Marazzo & Valentin, 2001), and adequate food concentrations (Lipej *et al.*, 1997; Katechakis & Stibor, 2004). In general, the highest values for the Adriatic Sea were found during summer in high productive areas, (Malej *et al.* 1979; Lučić and Kršinić, 1998), but sometimes they were found also in oligotrophic coastal area, generally in short-term (Brautović *et al*., 2000). The cladocerans abundance is a generally high in disturbed areas in which perturbations of zooplankton causes domination of small number of species (Siokou-Frangou & Papathanassiou, 1991). Our results are consistent with this knowledge and constant high densities were found in eutrophicated Boka-.Kotorska Bay. Moreover, high abundance of cladocera *Penila avirostris* exceeds densities of all total copepods populations in this area.

Penilia avirostris dominated in the period related to higher water temperatures, that confirms its thermophilic nature (Onbè, 1977; Ramirez & Perez Seijas, 1985; Marazzo & Valentin, 2001). It is known that this species has an optimum temperature around 25^0C (Kim and Onbé 1995). *P. avirostris* may not be related only to temperature: it was more abundant in A and C zone, and as typical neritic species showed that the highest densities were associated with lower salinities. Moreover, *P. avirostris* was found when the concentrations of nutrients and chlorophyll above the pycnocline layer were rather low (Turk, 1992). These conditions can survive only species which are capable to filtering organic matter and pico- and nanoplanktonic autotrophs which are abundant throughout the water column in that period (Turk, 1992).

Evadne spinifera is considered stenotermal and stenohaline species with preference for higher temperature and higher salinity waters (Gieskes, 1971; Onbé, 1999), which was confirmed in this study.

Information on the ecology of *Evadne tergestina* is scarse. Distribution of *E. tergestina* was closely related to lower temperatures and fresh water influence (Pillai & Pillai, 1975), which coincided with conditions in C zone. These results are in concordance with ours and previous data for Boka Kotorska Bay (Vukanić, 2006).

Podon intermedius is a typical species of subtropical water (Gomes, 2000). It was a very rare species in our samples that is in concordance with previous findings by for Boka-Kotorska bay, only (Vukanić, 2006).

Podon polyphemoides mostly occurred in A zone is an estuarine species, living between 5 to 30‰ salinity and its presence in open waters may be regarded as an indicator of originally estuarine waters (Gieskes, 1971). *P. polyphemoides* reached maximum in April then declined rapidly in summer when the water temperature exceeded and population reestablished as the water cooled in November. The same situation was recorded in Chesapeake Bay (Bosh & Taylor, 1973).

A comparison between the average nutrients and chlorophyll concentrations per water column with cladocerans abundance are not brought with distinctly results. We believe that the main reason for this is unequal vertical distribution of certain cladocerans species and in the water column they format large aggregations in certain layers (Lučić and Kršinić, 1998; Brautović, 2000). Nevertheless, our results are consistent with the results by Brucet *et al.* (2009): they concluded that cladocerans richness increased with increasing total phosphorous, but not influenced by total nitrogen or chlorophyll-*a*. Theirs results imply that the indirect effects of climate warming, such as changes in salinity and hydrology, will have a larger impact on brackish lagoon ecosystems.

Increased dominance of cladocerans in the pelagic coastal Montenegrin waters could be related with the increased eutrophication in the area, as well as the possible effects of climatic change. It will be necessary to investigate their functional responses and to examine in more detail the importance of their abundance, spatial and temporal distribution, and their role in marine pelagic food webs.

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