Zooplankton Community in the Boka Kotorska Bay

B. Pestorić, D. Drakulović, M. Hure, B. Gangai Zovko, I. Onofri, P. Lučić, and D. Lučić

Abstract This study includes a review of recently published results regarding zooplankton in the Boka Kotorska Bay (since 2009), and comparison of these results with earlier investigations. Non-loricate ciliates were the most numerous microzooplankton in spring 2013 (37%). Loricate ciliates (tintinnids) values were low and similar to those recorded in the open Adriatic Sea. However, their diversity was quite high: 20 estuarine–neritic and 26 species typical of the open sea were identified. Copepod nauplii were dominant metazoan microzooplankton component (32%). Seven phylums and 81 mesozooplankton taxa were determined. Copepods were the most dominant group. Among them, *Oncaea*–cyclopoids and *Oithona nana* were the dominant copepod taxa at all stations. Heterotrophic dinoflagellate *Noctiluca scintillans* and cladocera *Penilia avirostris* were often extremely numerous during warm seasons. Changes in the zooplankton community noted during recent investigations can be linked with the observed climate changes identified in the Adriatic and Mediterranean Sea since the 1990s, which are reflected in: (1) zooplankton high densities in the winter period with a lack of spring peak; (2) domination of small-size cyclopoid copepods and decreasing of contribution of neritic calanoid species; (3) prolongation of high *Penilia avirostris* abundance in the

B. Pestorić (✉) and D. Drakulović
Institute of Marine Biology, University of Montenegro, PO Box 69, 85330 Kotor, Montenegro
e-mail: brankap@ac.me; ddragana@t-com.me

M. Hure, B. Gangai Zovko, I. Onofri, and D. Lučić
Institute for Marine and Coastal Research, University of Dubrovnik, Kneza Damjana Jude 12, PO Box 83, 20000 Dubrovnik, Croatia
e-mail: marijana.hure@unidu.hr; barbara.gangai@unidu.hr; ivona.onofri@unidu.hr; davor.lucic@unidu.hr

P. Lučić
Institute of Oceanography and Fisheries, University of Split, I. Meštrovića 63, 21000 Split, Croatia
e-mail: lucic@izor.hr

A. Joksimović et al. (eds.), *The Boka Kotorska Bay Environment*,
Hdb Env Chem (2017) 54: 231–270, DOI 10.1007/698_2016_35,

autumn period; (4) spreading of invasive siphonophorae *Muggiaea atlantica* in the inner part of the Bay; (5) frequent outbreaks of gelatinous zooplankton; and (6) The first registered bloom of the ctenophore *Bolinopsis vitrea* in the Mediterranean in spring 2014, having a major impact on the regular planktonic food web system.

Keywords Boka Kotorska Bay, Mesozooplankton, Microzooplankton, South Adriatic, Spatial and temporal variability

Contents

1 Introduction

Planktonic communities play a vital role in the functioning of ecosystems and biogeochemical cycles [1]. Zooplankton is characterized by a high diversity of different taxonomic categories that occupy different ecological position and importance in the trophic network [2, 3]. Zooplankton is the main source of food for fish larvae; therefore, it has a significant impact on their survival, possibly more than temperature [4]. Information about the space-time variations of zooplankton community structure and succession of species, or group, is of fundamental importance for understanding the functioning of ecosystems in different environments. Many studies have shown that zooplankton can be used as an indicator for monitoring the status of marine ecosystems, as well as climatic changes [5, 6].

The first data on zooplankton pointed to poor fauna of the Boka Kotorska Bay [7, 8]. Among zooplankton species, only copepod *Oithona nana* was found in large numbers. Systematic research started after 1964 with the founding of the Institute of Marine Biology in Kotor. Planktonic copepods remain the main subject of research, and Vukanić [9–11] investigated their annual cycle in the Bay. The author found 70 copepod species and concluded that biodiversity increased from the inner area toward the open sea stations. The subsequent studies used an ecological approach linking hydrographic parameters and abundance of phytoplankton with zooplankton population densities [12–14]. More frequent studies in the Boka Kotorska Bay resulted in a detailed analysis of other mesozooplankton groups: appendicularians [15]; chaetognaths [16]; hydromedusa [17]; cladocerans [18]; and pteropods [19]. Mesozooplankton were collected by vertical tows of plankton nets (250–125 m), and most of the results were shown as percentage contribution or as number of individuals per m^{-2}.

During recent research activities, a more complex approach was used in order to include parameters that explain the processes that are important for understanding the secondary production in the Bay. Comprehensive results, based on more frequent sampling, and which include all animal phyla represented in mesozooplankton community, were presented by Pestorić [20]. Detailed descriptions of planktonic cladocerans, cnidarians, and chaetognaths included their annual abundance variability and influence of abiotic/biotic parameters on it [21–23]. Disturbances within the food web due to the strong grazing influence of ctenophore *Bolinopsis vitrea* were described by Lučić [24].

In difference to the mesozooplankton, microzooplankton (protozoans and metazoans developmental stages) was less investigated. The first data were presented by [8] based on the just one investigation along the Boka Kotorska Bay in November 1937. The author used a Nansen net supplied with a fine silk. Data indicated a qualitative composition and quantitative domination of small copepods. The plankton protozoans, tintinnids, and the radiozoan *Sticholonche zanclea* were numerically important in the inner part of the Bay. More comprehensive investigation was carried by Kršinić and Viličić [25] from December 1981 to December 1982 using a 53 μm mesh-netting net and 5 L Van Dorn sampler. On the basis of monthly interval sampling, they described qualitative and quantitative microzooplankton composition only in the Kotor Bay, and compared their numbers with variations of phytoplankton. Using Niskin 5 L bottle, Lučić [26] studied the microzooplankton horizontal and vertical distributions of the entire area during spring 2013.

The objective of this chapter is to review the main results of all previous studies of zooplankton in the Boka Kotorska Bay with particular emphasis on results of more recent research activities providing a more detailed overview of relations with hydrographic parameters, primary production, and food web in general. In addition, we intend to present some unpublished results related to changes in the zooplankton composition and abundance that have been recorded in the past few years in the Bay, and which could correlate with global warming phenomena.

2 Material and Methods

Microzooplankton samples were collected at three stations (A1, B1, and C1) from March to May 2013 (Fig. 1 and Table 1). Plankton was sampled at 0, 5, 10, 20, and 30 m depth and above the sea-bottom, using 5-L Niskin bottles. The samples were preserved in 2.5% formaldehyde–seawater solution, previously buffered with $CaCO_3$. The methodology of samples sedimentation and decanting used was described in detail by Kršinić [27]. Counting and identification of the species were performed with "Olympus" inverted microscopes IMT_2 and CK40 at 100× and 400× magnification. The abundance was expressed as number of cells per liter (cells L^{-1}).

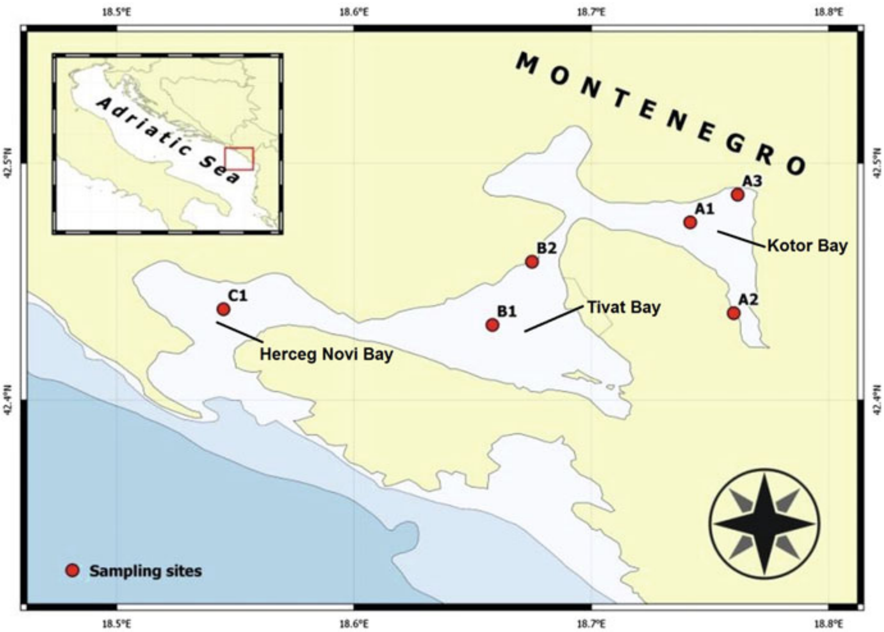

Fig. 1 Map of sampling sites in the Boka Kotorska Bay. Microzooplankton (A1, B1, and C1) and mesozooplankton (A1, A2, A3, B1, B2, and C1)

Table 1 Longitude and latitude of sampling stations

Station	Latitude	Longitude	Working depth (m)
A1	42°28.5′N	18°44.5′E	A 30
A2	42°26.2′N	18°45.6′E	A 15
A3	42°29.2′N	18°45.7′E	A 15
B1	42°25.9′N	18°39.5′E	B 30
B2	42°27.5′N	18°40.5′E	B 15
C1	42°26.3′N	18°32.7′E	C 40

Mesozooplankton samples were collected at three stations in the Kotor Bay (A1, A2, A3), two stations in the Tivat Bay (B1, B2) and one station in the Herceg Novi Bay (C1) from March 2009 to June 2010 (Fig. 1 and Table 1). One station in the Kotor Bay (A2) was sampled weekly. The remaining stations in the Kotor Bay and the Tivat Bay were sampled twice a month while one station in the Herceg Novi Bay was sampled monthly.

Zooplankton samples were taken by vertical hauls from bottom to surface with a Nansen plankton net, 0.55 m diameter and 125 μm mesh size. The collected zooplankton material was preserved in 2.5% formaldehyde seawater solution and analyzed using a Nikon SMZ800 stereomicroscope.

Detailed methodology of sampling and counting of mesozooplankton samples are described by [28–32].

3 Microzooplankton

Microzooplankton are a group of heterotrophic and mixotrophic organisms 20–200 mm in size, which include many protists, as well as small metazoans, such as copepod nauplii and some copepodites, and some meroplanktonic larvae. Traditionally, microzooplankton has been relegated to the ranks of secondary contributors when describing the dynamics of marine ecosystems, especially those of productive waters [3]. They occupy a key position in marine food webs as major consumers of primary production [33], as intermediaries between primary producers and copepods [34], and as key components of the microbial loop [35]. On average, their consumption is 60–75% of particulate primary production and about half of the phytoplankton biomass per day in a temperate, tropical waters, as soon as in very productive areas, such as estuaries and upwelling [33].

4 Investigation Carried Out from 1981 to 1982 (Kršinić and Viličić [25])

It was the first microzooplankton complexity investigation in this region, but conducted only in the inner part of the Boka Kotorska Bay. High population densities were noted.

The non-loricate ciliates were numerous at the surface layer at low salinity. The maximum of 673 ind. L^{-1} was in April. Similar values were recorded in the eutrophicated Mediterranean areas [36–41].

Authors found a small number (17) of estuarine and neritic species. Despite high near-bottom salinity values (>38), only one open sea species with a single specimen was observed. Maximum of 432 ind. L^{-1} in September at 20 m depth was caused exclusively by abundance of *Codonellopsis schabi*.

Most of the year, nauplii were the dominant component of the total microzooplankton abundance with a maximum of 300 ind. L^{-1} in May at the surface. Among small copepods, typical coastal forms occurred. Unexpectedly, *Oithona nana* was not the dominant species among adult copepods, and was replaced by harpacticoid *Microsetella norvegica* with the highest values known for the Adriatic Sea, and a maximum of 50 ind. L^{-1} in July at the surface.

No significant correlations were observed to exist between nano-microphytoplankton and the microzooplankton groups. The reason could be in high phytoplankton population densities throughout the year, and their uniform distribution through water columns, opposite of microzooplankton seasonal variations and their patched vertical distribution.

5 Investigation Carried Out in Spring 2013 (Lučić [26])

The horizontal and vertical distributions of microzooplankton were studied at three stations along the Boka Kotorska Bay (Fig. 1). Unexpectedly, very low values for all microzooplankton groups were noted, similar to the open sea waters [42–44], and considerably lower than in the productive areas of the Mediterranean [45, 46] and the Adriatic Sea [39–41, 47–49].

Non-loricate ciliates were the most numerous microzooplankton group, with the highest values (178 ind. L^{-1}) at the surface layer that was strongly influenced by fresh water. For many temperate seas, the maximum number of non-loricate ciliates was found in spring–summer period, where these protists reach values over 1,000 ind. L^{-1} [36, 37, 50]. Average and maximal abundances (Table 2) were lower than the previously noted values in the Boka Kotorska Bay: Kršinić and Viličić [25] found 254 ind. L^{-1} in May and a maximum of 673 ind. m^{-3} in September.

Table 2 Average (Avg), standard deviation (SD), and maximal (Max) abundance of the microzooplankton taxa in the Boka Kotorska Bay during spring 2013

	The Kotor Bay		The Tivat Bay		The Herceg Novi Bay	
Taxa	Max	Avg ± SD	Max	Avg ± SD	Max	Avg ± SD
Non-loricate ciliates	178	39.14 ± 44.20	100	40.12 ± 27.83	71	33.67 ± 17.63
Tintinnids	94	20.44 ± 24.41	32	10.91 ± 7.92	33	10.97 ± 8.40
Copepods nauplii	67	26.96 ± 19.29	70	39.08 ± 21.61	69	28.63 ± 19.23
Calanoids copepodites	9	3.86 ± 2.77	34	9.51 ± 9.56	24	7.28 ± 6.37
Oithona like cyclopoids	29	7.54 ± 8.78	21	7.39 ± 6.51	12	3.73 ± 3.96
Oncaea like cyclopoids	25	6.74 ± 7.19	8	3.04 ± 2.57	5	1.03 ± 1.26
Harpacticoids	5	1.41 ± 1.54	9	9.00 ± 3.00	7	1.61 ± 2.11
Appendicularians juvenile	4	1.46 ± 1.23	5	1.85 ± 1.70	3	1.12 ± 0.89
Bivalvia larvae	2	0.93 ± 0.85	4	1.15 ± 1.04	6	1.77 ± 1.64

Table 3 Tintinnids diversity in the Boka Kotorska Bay during spring 2013

Stations	*S*	*N*	*d*	*'H*
Kotor	29	95	6.14	2.11
Tivat	34	55	8.25	2.55
Herceg-Novi	33	55	8.00	2.49

S a total number of founded species, *N* a total abundance of all species, ind. L^{-1}, *d* Margalef's diversity index, *'H* Shannon's diversity index

As for non-loricate ciliates, tintinnid (loricate ciliates) values were low (Table 2). However, tintinnid species diversity was considerably high, especially at the station in the Tivat arm of the Boka Kotorska Bay system (Table 3). In total, 46 tintinnids were identified, among which 20 were estuarine–neritic and 26 were characteristic of the open sea. Twenty-three species were recorded for the first time in Boka Kotorska Bay. These were estuarine or coastal species: *Tintinnopsis campanula* f. *bütschlii*, *Tintinnopsis cylindrica*, *Tintinnopsis fennica*, *Tintinnopsis karajacensis*, *Tintinnopsis mortensenii*, *Tintinnopsis parvula*, *Metacylis joergenseni*, and *Favella taraikaensis,* and characteristic open sea species: *Codonella aspera*, *Undella subcaudata acuta*, *Undella subcaudata subcaudata*, *Dyctocysta lepida*, *Amphorides amphora*, *Amphorides quadrilineata*, *Amphorides quadrilineata* f. *minor*, *Canthariella pyramidata*, *Dadayiella ganymedes*, *Eutintinnus apertus*, *Eutintinnus latus*, *Eutintinnus tubulosus*, *Salpingella acuminata*, *Salpingella glockentoegeri*, and *Salpingella rotundata*. In particular, a large number of oceanic species registered in the deeper layer correlated to high salinity values (>38) below 15 m during this investigations. Higher availability of the potential food sources compared to the area of the open sea station [26] could be the reason for their prolonged stay in the bay.

According to the "Simper" analysis 11 species were representing tintinnids fauna in spring 2013 (Table 4). Among them, *Stenosemella nivalis* was the most numerous species (Fig. 2b). This tintinnid is a typical estuary/coastal species, frequent and numerous in the coastal communities of Mediterranean Sea [42, 51, 52].

Among metazoan fraction of microzooplankton, copepod nauplii were the most numerous metazoans (Table 2). Commonly, nauplii aggregations could be found in the layers of maximum primary production [3]. In the Boka Kotorska Bay, the highest values were noted between 5 and 20 m depth. It seems that the nauplii avoided the influence of fresh water in the surface layer, as well as higher salinity and lower values of the primary production in the near-bottom layer.

The majority of microzooplankton groups had a negative correlation with hydrographic factors (Table 5). The significantly positive correlations were observed between microzooplankton and phytoplankton fraction, especially for nanophytoplankton, in accordance with their well-known relationship within the food web [3]. These results confirm that the food relations have considerably greater influence on microzooplankton abundance variations than hydrographic factors, which is particularly notable in oligotrophic areas [3]. During recent investigations of microzooplankton in the Boka Kotorska Bay, low chlorophyll concentrations and phytoplankton densities were recorded. Similar absences of

Table 4 The "Simper" analysis of tintinnid species in the Boka Kotorska Bay during spring 2013

The Kotor Bay–average similarity 21.27					
Species	Average abundance	Average similarity	Similarity/standard deviation	Contribution %	Cumulative contribution %
Stenosemella nivalis	9.34	11.52	0.70	54.15	54.15
Tintinnopsis levigata	1.43	2.41	0.54	11.35	65.50
Tintinnopsis cylindrica	1.59	2.31	0.43	10.85	76.35
Codonellopsis schabi	0.20	0.87	0.34	4.09	80.44
Tintinnopsis radix	1.79	0.84	0.24	3.93	84.37
Tintinnopsis campanula	0.51	0.50	0.42	2.35	86.72
Eutintinnus latus	1.16	0.48	0.17	2.26	88.98
Tintinnopsis fennica	0.14	0.43	0.26	2.01	90.99
The Tivat Bay–average similarity 30.49					
Stenosemella nivalis	3.05	11.94	1.03	39.17	39.17
Tintinnopsis levigata	1.27	7.00	1.33	22.95	62.12
Tintinnopsis campanula	0.55	2.40	0.60	7.86	69.98
Codonellopsis schabi	0.31	1.73	0.53	5.66	75.65
Tintinnopsis radix	1.01	1.50	0.41	4.91	80.55
Eutintinnus latus	0.31	1.37	0.40	4.48	85.03
Stenosemella sp.	1.03	1.13	0.30	3.70	88.73
Tintinnopsis cylindrica	0.21	0.92	0.44	3.02	91.75
The Herceg Novi Bay–average similarity 23.37					
Stenosemella nivalis	1.85	7.21	0.75	30.84	30.84
Tintinnopsis levigata	2.28	4.03	0.52	17.23	48.08
Tintinnopsis campanula	1.69	3.97	0.51	16.96	65.04
Codonellopsis schabi	0.71	2.57	0.43	10.98	76.02
Dadayiella ganymedes	0.43	1.05	0.36	4.50	80.52

(continued)

Table 4 (continued)

Eutintinnus latus	0.19	0.79	0.27	3.38	83.90
Eutintinnus fraknoi	0.55	0.73	0.30	3.14	87.04
Streenstrupiella steenstrupii	0.23	0.67	0.37	2.85	89.89
Tintinnopsis radix	0.21	0.61	0.38	2.60	92.49

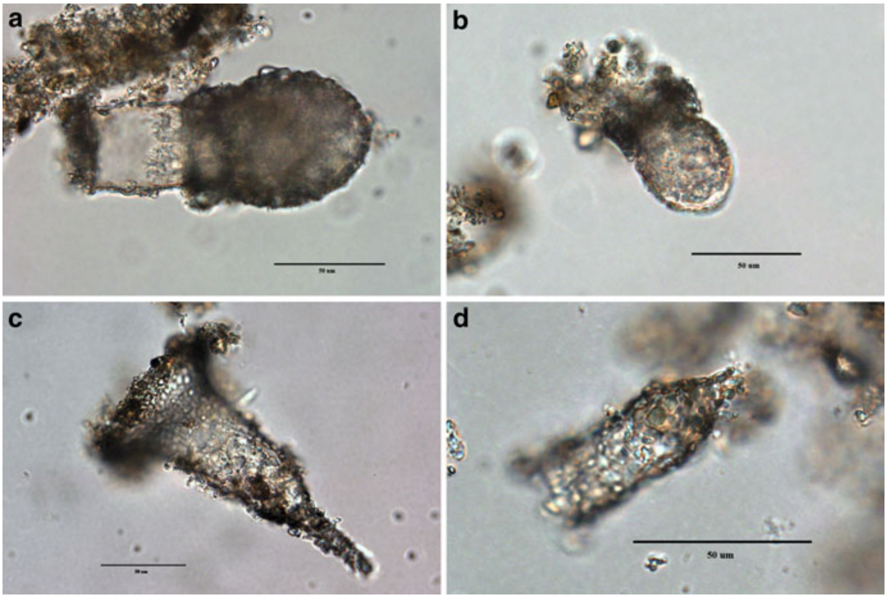

Fig. 2 Dominant tintinnids in Boka Kotorska Bay in Spring 2013: (**a**) *Codonellopsis schabi*; (**b**) *Stenosemella nivalis*; (**c**) *Tintinnopsis campanula*; and (**d**) *Tintinnopsis levigata*

typical phytoplankton spring bloom were observed in other productive areas during the last decade, such as Northern Adriatic [52]. Cabrini et al. [53] in their research in 1994 found higher values of phytoplankton in the Northern Adriatic in January, in contrast to previous years, when the maximum was usually in March or April. Moreover, in the last decade, considerably lower production of previously high-productive areas was frequently recorded [54, 55], pointing to oligotrophic processes of the Adriatic Sea [56]. The authors linked these changes with evident climate change since the mid-1990s that affected the precipitation regime.

Thus, the results obtained by Lučić [26] are considerably different from results given by Kršinić and Viličić [25], from researches conducted 30 years earlier. Such differences can also confirm the general change in the plankton position and abundance recorded during the last two decades. However, these hypotheses should

Table 5 "Spearman rank" correlation coefficient between microzooplankton taxa, hydrographic parameters, chlorophyll a concentration, and phytoplankton size-fractions

	Temperature	Salinity	Chl a	Nanophytoplankton	Microphytoplankton
Non-loricate ciliates	−0.253*	−0.057	0.247*	0.443***	0.411***
Tintinnids	−0.451***	−0.018	0.220	0.498***	0.270*
Nauplii	−0.229	−0.024	0.042	0.338**	0.306*
Calanoida copepodites	−0.189	0.062	0.051	0.376**	0.173
Oithona like cyclopoids	−0.382**	−0.002	−0.015	0.419***	0.163
Oncaea like cyclopoids	−0.235	0.098	−0.104	0.087	−0.099
Harpacticoids	−0.573***	−0.081	0.207	0.472***	0.120

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

be taken with caution due to the complexity of the production relations within the water column and also because the recent investigation was carried out over a shorter period.

6 Mesozooplankton

In this investigation, in Boka Kotorska Bay seven phylums of net zooplankton were recorded: Myzozoa, Ctenophora, Cnidaria, Arthropoda, Mollusca, Chordata, and Chaetognatha. Within these phyla 81 taxa were identified, of which 69 in Kotor Bay, 70 in Tivat Bay, and 72 in Herceg Novi Bay.

7 Heterotrophic Dinoflagellates

The link between the occurrences of blooms of dinoflagellates, especially *Noctiluca* sp., with nutrients enrichment of coastal ecosystems has been the subject of frequent discussion among researchers [57]. Blooming *N. scintillans* in the Northern Adriatic in the 1970s was related to the increase of eutrophication [58]. In summer 2009, during our investigation, blooming of *N. scintillans* was observed after large blooms of diatoms in March. High abundance of *N. scintillans* usually occurs after blooming diatoms [59]. A maximum of 64,375 ind. m^{-3} (Figs. 3 and 4)

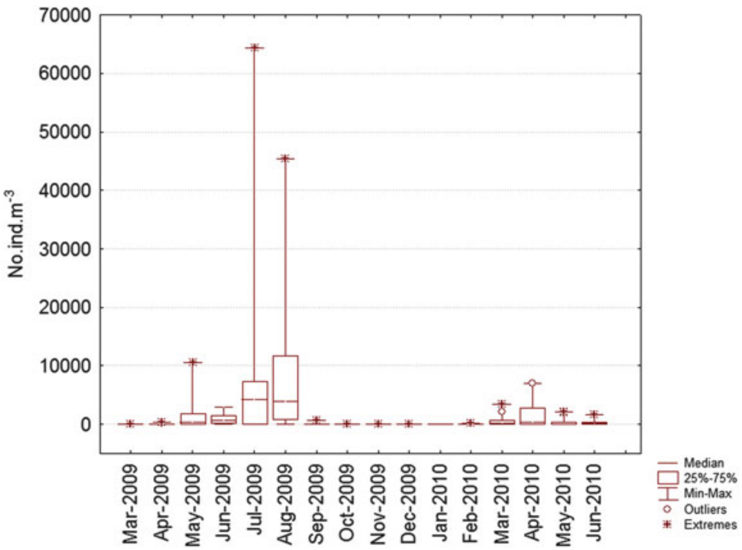

Fig. 3 Temporal variability of *Noctiluca* sp. abundance in Boka Kotorska Bay from March 2009–June 2010

Fig. 4 *Noctiluca scintillans* (photo: S. Ljubimir)

was recorded in the Kotor Bay, where the abundance was 10 times higher than in the Tivat Bay. Abundance in the Herceg Novi Bay did not exceed 180 ind. m^{-3}. In the period from September to February *Noctiluca scintillans* occurred in individual specimens.

These findings are consistent with the values found on the west coast of the Adriatic Sea and in the Gulf of Trieste [60]. So far, the largest number of these dinoflagellates was determined in 1977 and 1980 in the Gulf of Trieste, when the number of *N. scintillans* reached $> 10^6$ ind. m^{-3} [60]. Although *N. scintillans* is recognized as eurythermal and euryhaline species [61], it occurs in large numbers in the Kotor Bay in summer months, while during winter it is either absent or present in very small numbers. This is confirmed by significant positive correlation with temperature [20].

During blooming, *N. scintillans* exceeds biomass of zooplankton feeding on their eggs and is actively competing for the same nutritional resources [60, 62].

8 Cnidarians

Planktonic cnidarians are conspicuous components of pelagic food webs and their distribution and abundance have a large influence on marine communities. Species that have alternating pelagic (medusa) and bottom dwelling (polyp) phases not only play an important role in the transfer of energy from pelagic to benthic systems, but are also likely to be sensitive to environmental changes which can result in extremely high temporal and spatial variability in abundance, resulting in the form of "blooms" [63, 64]. Species belonging to Hydrozoa and Scyphozoa and Siphonophora are carnivores, preying mainly on other planktonic organisms (notably copepods) and even fish [65]. They usually serve as a link between zooplankton and higher trophic levels in the marine food webs [66].

9 Hydrozoans

While earlier studies on hydromedusae in the Central and South Adriatic reported 26 hydrozoan species [67], significantly smaller numbers were determined in the Boka Kotorska Bay: 7 species (6 holoplanktonic, 1 meroplanktonic) during 2002 [17] and 12 taxa (8 holoplanktonic, 4 meroplanktonic) during monthly samplings in 2009 and 2010 [22]. The most recent investigation showed that meroplanktonic species of hydromedusae prevail in the inner parts of the Bay, while holoplanktonic species were more abundant in the outer of the Bay. High variations of hydromedusae abundance among stations are in concordance with their metagenetic biology which is reflected in significant monthly and annual oscillations [63]. Although their median values rarely exceeded 1 ind. m^{-3}, monthly maximum values more than 20 ind. m^{-3} were often noted (Fig. 5). An extraordinarily high number of *Obelia* spp. of 341 ind. m^{-3} (Table 6) recorded in the Tivat Bay during December 2009 coincided with high concentrations of chlorophyll *a*. Such high abundance of this species was not recorded before in the Adriatic coastal ecosystems.

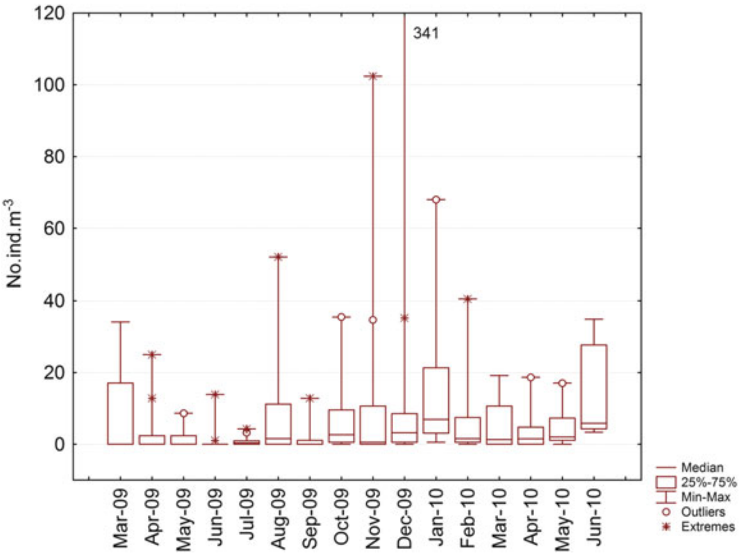

Fig. 5 Temporal variability of hydromedusa abundance in Boka Kotorska Bay from March 2009–June 2010

Table 6 Composition of hydromedusa species in the Boka Kotorska Bay, with their maximum abundance values (max; ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total hydromedusa abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Anthomedusae									
Stauridiosarsia gemmifera	–	–	–	1	0.05 ± 0.18	0.27	–	–	–
Podocorynoides minima	51	1.07 ± 6.11	20.96	4	0.32 ± 0.10	1.88	<1	0.06 ± 0.122	2.20
Hydractinia carica	5	0.17 ± 0.65	3.26	17	1.21 ± 3.26	7.11	2	0.13 ± 0.43	4.95
Leptomedusae									
Obelia spp.	68	2.97 ± 9.17	58.06	341	8.32 ± 50.45	72.06	2	0.30 ± 0.66	11.37
Clytia spp.	1	0.04 ± 0.18	0.69	17	1.09 ± 3.59	6.46	1	0.09 ± 0.23	3.30
Eirene viridula	2	0.06 ± 0.30	1.23	4	0.19 ± 0.67	1.12	–	–	–
Eutima gracilis	1	0.02 ± 0.12	0.31	17	0.66 ± 2.79	3.92	<1	0.01 ± 0.05	0.55
Helgicirrha schulzei	8	0.10 ± 0.85	2.02	2	0.09 ± 0.34	0.52	<1	0.01 ± 0.05	0.55
Trachymedusae									
Liriope tetraphylla	1	0.03 ± 0.18	0.66	2	0.17 ± 0.43	0.99	<1	0.01 ± 0.05	0.55
Aglaura hemistoma	2	0.06 ± 0.32	1.12	4	0.13 ± 0.65	0.78	6	0.81 ± 1.73	31.38
Rhopalonema velatum	–	–	–	1	0.05 ± 0.19	0.30	2	0.31 ± 0.49	12.11
Narcomedusae									
Solmaris spp.	34	0.76 ± 4.08	14.90	17	0.84 ± 3.11	4.85	6	0.80 ± 1.83	30.83

10 Siphonophores

Siphonophores, as a group of complex colonial organisms, have often been poorly surveyed because their fragile body is often broken by traditional sampling nets. Pestorić et al. [22] provided the first detailed report of the composition and abundance of the siphonophoran community for this region. Among six recorded species *Muggiaea kochi*, *Muggiaea atlantica,* and *Sphaeronectes gracilis* were most frequent and abundant, with highest densities in spring–summer period (Fig. 6). This is in accordance with the established general pattern of siphonophoran seasonal distribution in the sea [68, 69].

M. atlantica, a typical boreal species, dominant in the inner Bay of Kotor during spring and summer, while autochthonous Adriatic and Mediterranean species *M. kochi* was more numerous in the outer area of the Bay (Table 7). These results confirm previous shift within the coastal calycophores, with *M. kochi* being replaced by *M. atlantica*, that was observed in the Adriatic Sea in 1996 [70]. In addition, the linear regression of the abundance of *M. kochi* with water temperature revealed a strong positive relationship ($r = 0.388$; $p = 0.0015$), while for *M. atlantica* the correlation was not statistically significant ($r = 0.059$; $p > 0.05$) [22]. The analyses of relationships of the common siphonophores and their potential prey showed significant positive correlations for *M. atlantica* and representative

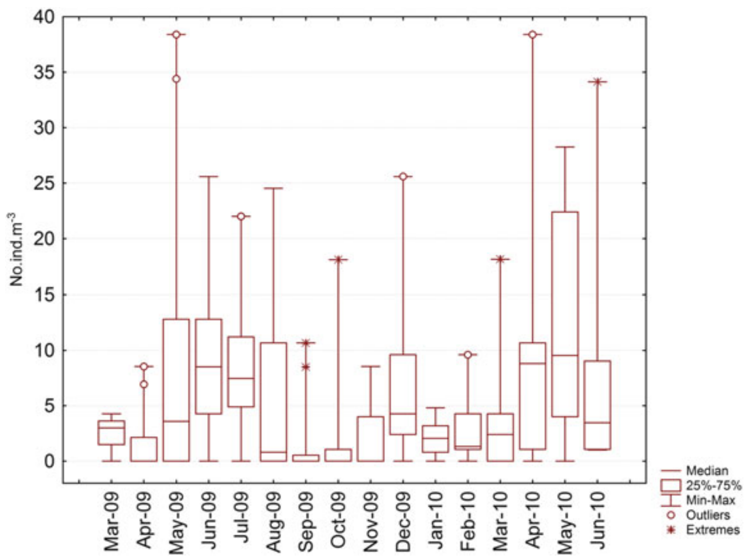

Fig. 6 Temporal variability of siphonophores abundance in Boka Kotorska Bay from March 2009–June 2010

Table 7 Composition of siphonophore species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total siphonophore abundance (mean %)

Species	Kotor Bay			Tivat Bay			Herceg Novi Bay		
	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Lensia subtilis	4	0.06 ± 0.42	0.99	–	–	–	<1	0.06 ± 0.15	1.76
Muggiaea kochi	17	1.53 ± 3.51	25.38	17	1.98 ± 3.89	38.19	13	1.17 ± 3.37	33.68
Muggiaea atlantica	34	3.26 ± 6.77	54.02	21	2.40 ± 4.70	46.27	4	0.84 ± 1.39	24.23
Eudoxoides spiralis	2	0.04 ± 0.30	0.69	–	–	–	<1	0.04 ± 0.12	1.23
Sphaeronectes köllikeri	13	1.09 ± 2.37	18.05	5	0.81 ± 1.51	15.55	13	1.36 ± 3.41	39.07
Sphaeronectes irregularis	4	0.05 ± 0.43	0.86	–	–	–	–	–	–

Table 8 Spearman's rank order correlation coefficients between frequently occurring and abundant siphonophore species and small copepods–copepodites in the Boka Kotorska Bay

	Paracalanus parvus	Calanoida copepodites	*Oithona nana*	Cyclopoida copepodites
Muggiaea kochi	0.118	0.219*	0.061	0.171
Muggiaea atlantica	0.231*	0.247*	0.298**	0.327*
Sphaeronectes köllikeri	−0.014	−0.026	−0.091	−0.112

*p <0.05; ** p < 0.01

small copepods and copepods numerically dominated at all stations (Table 8). *M. kochi* was positively correlated to abundance of calanoid copepodites (Table 8). *Sphaeronectes köllikeri* didn't show significant correlation with analyzed potential pray.

11 Cladocerans

Cladocerans play a major role in freshwater ecosystems, but they are not successful in colonizing the marine environment [71]. There are only eight cosmopolitan species in the world ocean [72] distributed in three genera: Penilia (comprising only *Penilia avirostris*), Evadne, and Podon [73]. Due to cladocerans parthenogenetics reproduction in coastal and estuarine environments they may occur with extent monospecific cladoceran populations that are usually predominant by copepods [74].

Information on the cladoceran population in the Montenegrin coast is scarce [18, 21]. Seven species were found in the Boka Kotorska Bay: *Penilia avirostris, Evadne spinifera, Evadne nordmanni, Pseudevadne tergestina, Pleopis poliphemoides, Podon intermedius, and Podon leuckarti*. Species *Podon leuckarti* was noted only by Vukanić [18] as very rarely recorded single specimens during the warmer period of the year.

The most dominant species in all areas was *Penilia avirostris* (Fig. 8). The highest percentage contribution was observed in Tivat Bay 91.75% while the maximum abundance was noted in the Kotor Bay, where in September reached value of 24,303 ind. m^{-3} (Fig. 7 and Table 9).

This species, whose average abundance for the water column exceeds 20,000 ind. m^{-3}, are characteristic for high eutrophic areas [75–77]. During the summer months, it was the dominant species of zooplankton which confirms its thermophilic nature [72, 73]. A large number (>1,000 ind. m^{-3}) of *P. avirostris* was recorded in the Bay of Kotor in December 2009 (Fig. 7). These findings coincide with the time of the highest concentration of chlorophyll *a* in the study area, which indicates that available food is also an important factor of its abundance [20].

Species *Penilia avirostris, Evadne spinifera*, and *Pseudevadne tergestina* showed significantly positive correlation with hydrological parameters

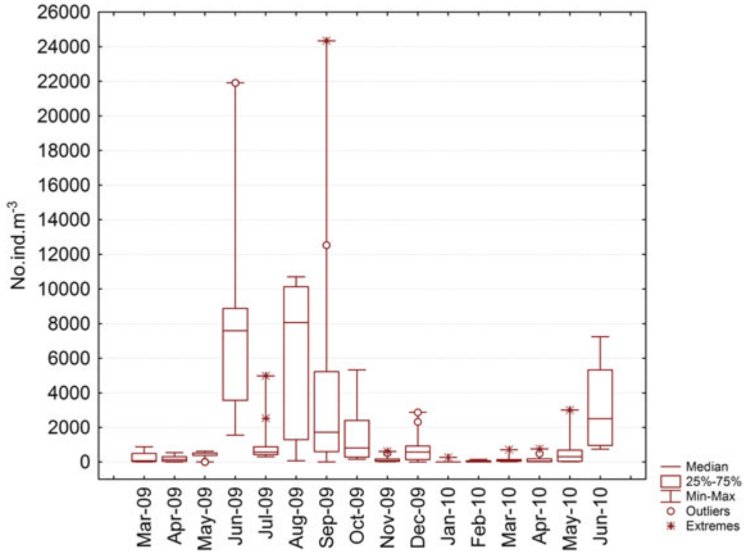

Fig. 7 Temporal variability of cladoceran abundance in Boka Kotorska Bay from March 2009–June 2010

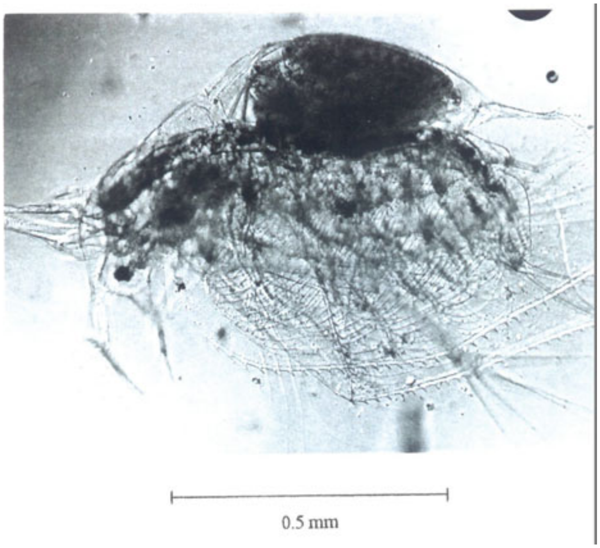

Fig. 8 *Penilia avirostris* (photo: I. Brautović)

Table 9 Composition of cladoceran species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total cladoceran abundance (mean %)

Species	Kotor Bay			Tivat Bay			Herceg Novi Bay		
	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Penilia avirostris	24,303	1,444 ± 3,825	76.21	13,956	1,881 ± 3,247	91.75	7,578	935 ± 2,105	91.74
Evadne. nordmanni	768	30.35 ± 93.8	8.16	68	3.25 ± 11.5	0.97	3	0.23 ± 0.9	0
Evadne spinifera	478	38.48 ± 92.1	1.97	205	21.38 ± 44.4	1.44	51	7.12 ± 16.3	0.77
Pseudevadne tergestina	68	2.80 ± 10.7	0.07	34	2.53 ± 7.0	0.05	6	0.46 ± 1.7	0
Podon intermedius	269	13.03 ± 36.5	2.83	68	6.06 ± 13.7	4.91	26	3.83 ± 7.2	7.49
Pleopis polyphaemoides	1,638	97.31 ± 247.7	10.76	68	4.20 ± 14.4	0.88	–	–	–

(temperature and salinity) while *Evadne nordmanni* had a significant negative correlation with temperature and salinity [20].

12 Copepods

The mesozooplankton community is dominated mainly by copepods, especially in the estuaries and coastal regions [78, 79]. In Boka Kotorska Bay their share ranged from 67% to 81% in the total mesozooplankton densities [20]. Copepods are notable consumers of microplankton, and play a key role in the diet of juvenile stages of many fish species. These keystone trophic links in aquatic ecosystems transfer energy and carbon to higher trophic levels more efficiently than any other zooplankton taxa [80]. Thus, copepods can be considered a particularly successful group in the pelagic environment.

Historical data, collected with 250–360 μm mesh size nets, reported 70 copepod species inhabiting the Boka Kotorska Bay and outer station [9]. Recent investigation performed with 125 μm mesh size showed that copepod community of the Boka Kotorska Bay comprised 38 taxa (Table 10), which is 14% of the total of 262 copepod species recorded in the Adriatic Sea [20]. Among them, 10 coastal and estuarine taxa exhibited high dominance and accounted for 99.11% of the total copepod numbers: *Oncaea* spp*., Oithona nana, Acartia (Acartiura) clausi, Paracalanus parvus, Euterpina accutifrons, Centropages kroyeri, Oithona similis, Clausocalanus jobei, Temora stylifera, and Corycaeus* spp. *Cyclopoids Oncaeidae* and *Oithonidae* dominated mesozooplankton community of the Boka Kotorska Bay and accounted for, on average, 68% of the total abundances [20]. This is in accordance with the previous investigations carried out with fine mesh nets which highlighted the importance of small copepod species in structuring coastal ecosystem dynamics [81–84]. Among calanoids, *Acartia* (*Acartiura*) *clausi* was the most numerous in the Kotor Bay, where this species contributed up to 73% (April 2009) of the total mesozooplankton numbers with average abundance of 710 ± 1,357 ind. m^{-3} [20]. High numbers of this species over the spring period were found in other productive enclosed areas, like Kaštela Bay [85], Gruž Bay [86], and Mali Ston Bay [87]. In the Tivat and the Herceg Novi Bays, *Paracalanus parvus* was the most abundant calanoid (average abundance of 422 ± 532 ind. m^{-3} and 399 ± 408 ind. m^{-3}, respectively) with higher values recorded in spring. The only numerically important member of the harpacticoids, *Euterpina accutifrons*, was present throughout the area of the Boka Kotorska Bay, reaching maximum of even 2,526 ind. m^{-3} in the Kotor Bay in March 2010.

The Boka Kotorska Bay, as enclosed coastal area under the great fluctuations caused by influences from the land, is a highly variable system and this variability may reflect in temporal dynamics of the copepod populations. Beside rapid response of individual species to ecosystem perturbations, large fluctuations in overall copepod densities were also recorded. Therefore, total copepod abundances varied from minimum of 800 ind. m^{-3} in the Kotor Bay in January 2010 to the

Table 10 Composition of copepod species in the Boka Kotorska Bay, with their average abundances (av ± SD; ind. m^{-3}) and mean percentage of the total copepod abundance (mean %)

	Kotor Bay		Tivat Bay		Herceg Novi Bay	
Copepod taxa	Av. Abund.	Contr. %	Av. Abund.	Contr. %	Av. Abund.	Contr. %
Calanus helgolandicus	25	<1	10	<1	19	<1
Mesocalanus tenuicornis	5	<1	4	<1	3	<1
Nannocalanus minor	<1	<1	<1	<1	1	<1
Calocalanus pavo					<1	<1
Calocalanus contractus					<1	<1
Calocalanus styliremis					<1	<1
Ischnocalanus plumulosus			<1	<1		
Paracalanus parvus	324	8	422	12	399	19
Paracalanus nanus	1	<1	<1	<1	13	<1
Paracalanus denudatus			<1	<1		
Meynocera clausi	<1	<1	9	<1	6	<1
Clausocalanus jobei	21	<1	42	<1	24	<1
Clausocalanus arcuicornis	9	<1	13	<1	7	<1
Clausocalanus furcatus	1	<1	11	<1	9	<1
Clausocalanus pergens					<1	<1
Ctenocalanus vanus	20	<1	8	<1	38	<1
Pseudocalanus elongatus	<1	<1				
Paraeuchaeta hebes	<1	<1	2	<1	2	<1
Diaixis pygmoea	1	<1	2	<1		
Centropages kroyeri	138	3	44	<1	64	1.7
Centropages typicus	1	<1	4	<1	10	<1
Isias clavipes	2	<1	1	<1	4	<1
Temora stylifera	47	<1	54	<1	52	1.2
Candacia giesbrechti	1	<1	1	<1	4	<1
Labidocera wollastoni	<1	<1	3	<1	3	<1
Acartia clausi	710	12	303	6	358	16
Acartia longiremis			<1	<1	4	<1
Oithona similis	91	2	96	1	106	5
Oithona plumifera	7	<1	17	<1	27	1.6
Oithona nana	1,071	32	1,012	33	399	23
Oithona setigera					<1	<1

(continued)

Table 10 (continued)

Copepod taxa	Kotor Bay Av. Abund.	Kotor Bay Contr. %	Tivat Bay Av. Abund.	Tivat Bay Contr. %	Herceg Novi Bay Av. Abund.	Herceg Novi Bay Contr. %
Microsetella spp.	31	<1	5	<1	1	<1
Macrosetella sp.	3	<1	1	<1	9	<1
Euterpina acutifrons	291	7	236	7	74	3
Goniopsilus rostratus	<1	<1				
Oncaea–cyclopoid	1,196	36	1,109	38	534	25
Saphirina spp.	1	<1	1	<1	1	<1
Corycaeus spp.	8	<1	18	<1	40	1.3

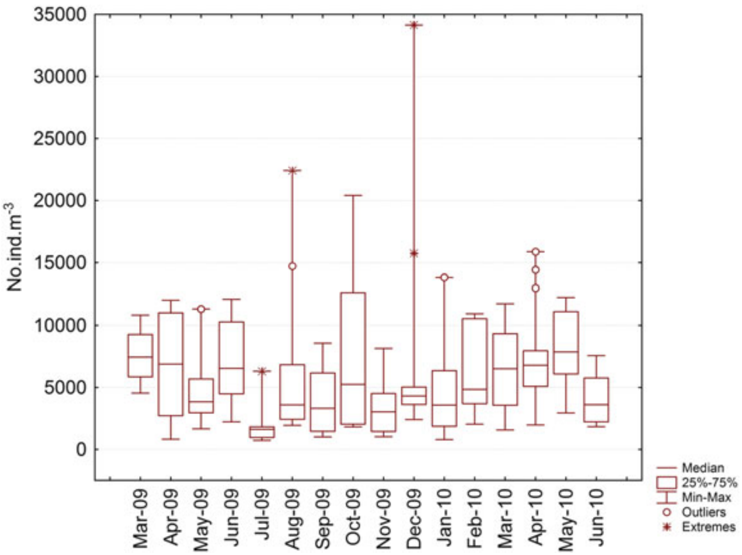

Fig. 9 Temporal variability of copepods abundance in the Boka Kotorska Bay from March 2009–June 2010

maximum of 34,137 ind. m^{-3} recorded in the Tivat Bay in December 2009 [20]. Annual dynamics of the total densities of this group in the Boka Kotorska Bay showed slightly increased values over the spring period (Fig. 9).

Considering influence of the hydrographic properties on the most abundant species (Table 11), negative correlation of the temperature on the abundances of the *Oncaeidae* ($p < 0.05$) and *Euterpina accutifrons* ($p < 0.01$) was recorded, while salinity has been limiting factor on the occurrence of *Oithona nana* ($p < 0.05$).

Table 11 Spearman correlation of copepod species included in 90% of total numbers and independent parameters (temperature, salinity, TNP-total nanophytoplankton, TMP-total microphytoplankton; $*p < 0.05$; $**p < 0.01$; $***p < 0.001$)

	Temperature	Salinity	TNP	TMP
Paracalanus parvus	−0.065	0.043	−0.109	−0.198*
Acartia (Acartiura) clausi	−0.001	−0.038	0.185*	0.031
Oithona nana	−0.091	−0.180*	0.052	0.015
Oithona similis	−0.060	−0.051	0.174	0.062
Oncaeidae	−0.204*	−0.112	−0.062	−0.039
Euterpina acutifrons	−0.283**	−0.176	−0.065	0.063

Furthermore, our findings suggested that *Acartia* (*Acartiura*) *clausi* benefited most from nano- and microphytoplankton blooms ($p < 0.05$).

13 Pteropods

During the study period, four species of plankton pteropods were found: *Limacina trochiformis*, *Heliconoides inflata*, *Creseis virgula,* and *Creseis clava*. In previous investigation of the Boka Kotorska Bay a total of seven species were found [19]. Species *Pneumodermopsis canephora* and *Atlanta helicinoidea* in previous research were cited as very rare, while species *Cymbulia peronii* and *Limacina bulimoides* that were frequent, during our study, were not observed. In the Boka Kotorska Bay, during our research, species *Limacina trochiformis* was noticed for the first time.

Pteropods are characterized by the possibility of high and sudden variations of the population: they can occasionally occur in large numbers, and then disappear completely from plankton [88]. The maximum total abundance of 137 ind. m^{-3} was found in November 2009 and in May 2010 (Fig. 10).

Succession of species is noticeable. Species of the genus *Limacina* prevail in the period from May 2009 to September 2009. Species of the genus *Creseis* occur only in August 2009, and from November 2009 to January 2010, representing 100% pteropod. In the period from February to June 2010, the dominating species was again *Limacina*.

Limacina trochiformis was the dominant species in the area of the Kotor and the Tivat Bays with a percentage contribution of 44% and 59%, while it was absent from the area of the Herceg Novi Bay. A maximum of 128 ind. m^{-3} was recorded in the Kotor Bay. Another quantitatively significant species in the Kotor Bay was *Creseis virgula*, and the maximum number was 136 ind. m^{-3}. *Creseis virgula* dominated in the Herceg Novi Bay with a contribution of 82% (Table 12).

All species of pteropods showed a significant positive correlation with temperature (p <0.001) while in May 2010, when the water temperature of the column was ~ 16°C, a high number of pteropods were accompanied by a higher abundance

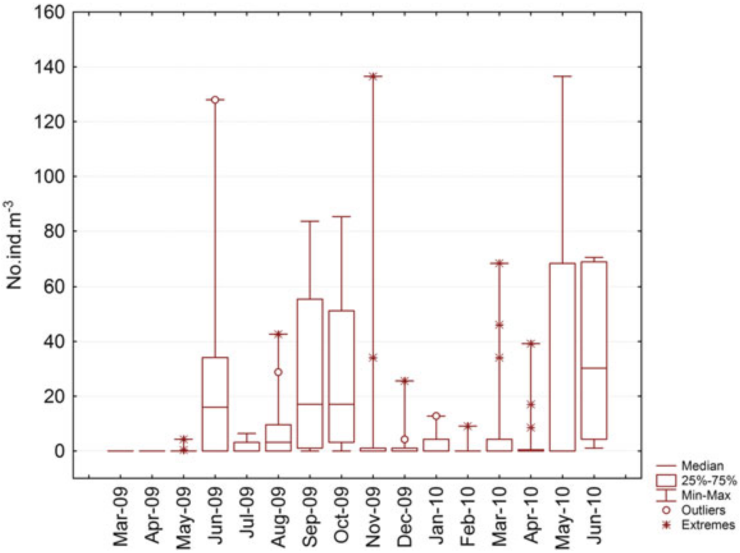

Fig. 10 Temporal variability of pteropod abundance in Boka Kotorska Bay from March 2009–June 2010

of phytoplankton, particularly nanophytoplankton (<20 μm) [20]. Similar situation was observed in the open sea of the Southern Adriatic, in the area of the Jabuka Pit [89].

14 Chaetognaths

Chaetognaths play an important functional role in marine food webs, and within carnivorous zooplankton often dominated in their biomass [90]. As one of the main predators of copepods [91, 92], chaetognaths play an important role of energy transfer through marine food webs. Apart from food availability hydrological conditions also seem to influence chaetognaths distribution.

In the world's seas and oceans 47 species of planktonic chaetognaths have been found, 17 of which are present in the Mediterranean and 10 in the Adriatic Sea [93]. The first data for the Adriatic (Gulf of Trieste) chaetognaths fauna was published by Graeffe [94]. There are scarce data about this zooplankton group in the Boka Kotorska Bay. Benović and Onofri [13] presented the first data for the area. They found four species of chaetognaths in the Boka Kotorska Bay (*Flaccisagitta enflata, Parasagitta setosa, Serratosagitta serratodentata,* and *Mesosagitta minima*). Surprisingly, Vukanic and Vukanic [16] registered four new species for the Boka Kotorska Bay (*Parasagitta friderici, Pseudosagitta lyra, Flaccisagitta hexaptera,* and *Sagitta bipunctata*). Pestorić et al. [23] found

Table 12 Composition of pteropod species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total pteropod abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
L. trochiformis	128	4.50 ± 17.45	44.14	68	8.71 ± 18.46	58.88	–	–	–
H. inflata	41	1.47 ± 6.01	22.75	68	4.30 ± 14.32	16.63	51	4.66 ± 13.53	17.67
C. virgula	136	3.69 ± 16.09	33.05	51	3.59 ± 10.33	15.76	77	11.46 ± 22.14	82.33
C. clava	102	1.02 ± 10.13	0.06	17	1.02 ± 3.24	8.73	–	–	–

three coastal species of chaetognaths (*Flaccisagitta enflata*, *Mesosagitta minima,* and *Parasagitta setosa*) thus confirming previous findings [13]. The most dominant species in all areas was *Parasagitta setosa*. The highest percentage contribution was observed in the Tivat Bay, while the maximum abundance was noticed in the Kotor Bay (Table 13). *Flaccisagitta enflata* and *Mesosagitta minima* are more present and abundant in the Boka Kotorska Bay than in other neritic coastal areas. Total densities of chaetognaths showed an upward trend over the spring and summer months (Fig. 11).

Statistical analysis (Spearman correlation) showed significant correlations between different species of chaetognaths and hydrological parameters: a positive correlation with the temperature recorded for juvenile specimens ($r = 0.251$; $p < 0.01$), and salinity for the *Parasagitta setosa* ($r = 0.163$; $p < 0.05$) and *Flaccisagitta enflata* ($r = 0.261$; $p < 0.01$), *Mesosagitta minima* did not significantly correlate with these parameters [23]. Potential pray (small copepods and copepodites) showed strong positive correlation with juvenile stages of chaetognaths and *P. setosa* (Table 14).

The general composition of chaetognaths of the Boka Kotorska Bay did not vary significantly among the three investigated stations. Differences were the highest between the Herceg Novi and the Kotor Bay [23].

15 Pelagic Tunicates

Pelagic tunicates (salps, appendicularians, pyrosomas, and doliolids) are ubiquitous members of all marine pelagic systems, from coastal areas to the deep sea. They are also referred to as gelatinous zooplankton because of their extremely watery body tissue. When abundant, their relatively large size and high water content make them significant contributors to total wet biomass.

All pelagic tunicates are filter feeders filtering the entire size range from very small colloids to large phytoplankton chains in the case of salps and doliolids. The reproduction cycle is complex and includes sexual and asexual generations with high birth rates. Under good food conditions tunicates exhibit population growth rates that rank at the top among the metazoans [95].

16 Appendicularians

Appendicularians are among the most common zooplankton and occur in all oceans. They may therefore act as key top-down regulators in the marine planktonic food web. Appendicularians have a peculiar feeding strategy; they live inside an elaborate multichambered extracellular house, complete with inlet and food-concentrating filters that they secrete from a specialized oikoplastic epithelium [96, 97]. The filter in the house is able to retain particles as small as 0.2 mm.

Table 13 Composition of chaetognath species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total chaetognath abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
P. setosa	204	7.22 + 25.33	75.91	68	9.03 + 17.20	83.22	13	1.69 + 3.38	63.59
F. enflata	68	2.34 + 8.01	22.21	34	3.50 + 8.91	16.34	25	2.40 + 6.73	31.92
M. minima	51	2.48 + 18.57	1.87	10	0.35 + 1.56	0.44	0.8	0.19 + 0.34	4.49

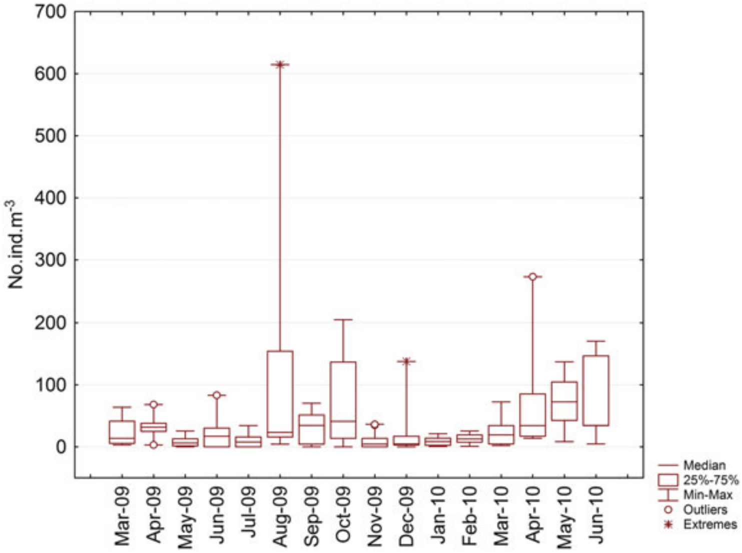

Fig. 11 Temporal variability of chaetognath abundance in the Boka Kotorska Bay from March 2009–June 2010

Table 14 Spearman rank order correlation of chaetognaths and potential pray

	M. minima	*P. setosa*	*F. enflata*	*Sagitta* juv.
Calanoida copepodites	−0.040	0.287***	0.047	0.213**
Cyclopoida copepodites	0.033	0.313***	−0.029	0.158*
Oithona nana	−0.048	0.226**	−0.120	0.154
Appendicularia	0.157	0.310***	−0.023	0.167*

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Earlier studies of the Boka Kotorska Bay revealed the presence of four species [10], while only *Oikopleura dioica* was found in the Kotor Bay [15]. Recently, nine appendicularian species were recorded in the Boka Kotorska Bay: *Oikopleura dioica*, *Oikopleura longicauda*, *Oikopleura fusiformis*, *Oikopleura gracilis*, *Oikopleura intermedia*, *Kowalevskia tenuis*, *Fritillaria pellucida*, *Fritillaria borealis,* and *Fritillaria haplostoma* [20]. The number of species found gradually decreased from the open sea toward the inner waters of the Bay.

Among appendicularians, *Oikopleura dioica* numerically dominated in Kotor Bay, with the maximum of 1,570 ind. m^{-3} recorded in March 2010 (Table 15). In Tivat Bay and Herceg Novi Bay, *Oikopleura longicauda* was the most abundant representative of this group, whose population showed the highest values in October.

Table 15 Composition of appendicularian species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total appendicularian abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
O. dioica	1,570	78.08 ± 219.07	46.35	819	44.19 ± 139.13	19.55	141	19.48 ± 44.26	5.29
O.longicauda	410	30.25 ± 72.45	43.83	205	26.81 ± 47.34	55.71	51	24.65 ± 16.56	73.09
O. fusiformis	205	11.59 ± 36.10	8.31	358	24.71 ± 64.39	15.47	256	36.04 ± 69.96	17.13
O gracilis	34	0.59 ± 3.54	0.15	9	0.39 ± 1.47	0.27	51	5.68 ± 13.72	1.49
O. intermedia	–	–	–	–	–	–	13	0.68 ± 3.42	0.25
Kowalevskia tenuis	–	–	–	–	–	–	6	0.49 ± 1.71	0.67
F. pellucida	68	2.38 ± 9.23	1.15	273	10.06 ± 41.51	9.00	51	7.94 ± 18.57	2.89
F. borealis	26	0.39 ± 2.57	0.21	17	0.53 ± 2.79	0.37	4	0.28 ± 0.98	0.23
F. haplostoma	17	0.17 ± 1.69	0.31	–	–	–	13	1.06 ± 3.41	0.10

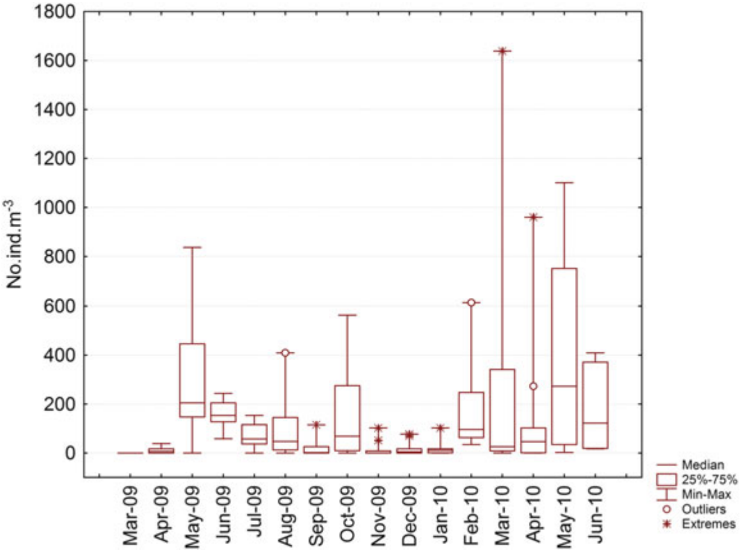

Fig. 12 Temporal variability of appendicularian abundance in the Boka Kotorska Bay from March 2009–June 2010

Significant fluctuations in overall densities of appendicularians were noted in the Boka Kotorska Bay.

Maximum of 1,638 ind. m^{-3} was recorded in March 2010 with generally lower values found over late autumn – early winter period (Fig. 12).

17 Thaliaceans

Thaliaceans were presented by salps and doliolids in Boka Kotorska Bay. High values were noted during summer months and reached maximum value of 461 ind. m^{-3} in August 2009 [20]. Statistical analysis showed significant negative correlations between doliolids and nanophytoplankton [20] which is in agreement with their filter feeding behavior [95].

18 Gelatinous Blooms

Gelatinous carnivorous zooplankton is a conspicuous component of marine ecosystems and is recognized as a valuable indicator of ecosystem functioning [98]. Massive outbreaks of jellyfish are a natural phenomenon, though human-related perturbations appear to exacerbate blooms [99]. Massive increases in their

Fig. 13 *Bolinopsis vitrea* in the Boka Kotorska Bay (photo: V. Mačić)

population size may have a wide range of economic and ecological implications, including reduction and structural changes of mesozooplankton populations, impairment of fish eggs and larvae, alteration of carbon and matter fluxes in food webs, clogging of fish nets, and impact on the tourist industry [100]. Recent decades' evidence indicates that gelatinous zooplankton have increased in abundance throughout the world's oceans and blooms (outbreaks of tens to hundreds of medusa per cubic meter) now occur more frequently in many seas, including the Mediterranean Sea [101].

The first examples of jellyfish outbreaks in the Boka Kotorska Bay happened just recently, wither dense aggregate of the ctenophora *Bolinopsis vitrea* (Fig. 13) observed in spring 2009 [24]. The ctenophore *B. vitrea* previously has been rarely observed in the Mediterranean Sea [102]. Ctenophores were found in the inner part of the Bay, below 5 m depth only. This mass occurrence of *B. vitrea* had a great impact on the Bay ecosystem. Their predation on copepods reduced grazing pressure on phytoplankton, favoring an uncommon bloom of the latter. It is evident that *B. vitrea* are capable of altering rapidly the composition and biomass of coastal plankton communities when present in large masses. This first evidence of such events for this species may indicate changes in the functioning of marine ecosystems.

During the last few years, previously unknown outbreaks of some schyphomedusa species have been reported in the Boka Kotorska Bay. *Discomedusa lobata* is a rare schyphomedusa (Fig. 14), known from the Eastern Atlantic Ocean and the Mediterranean Sea. It is commonly found in the Gulf of Trieste [103]. The first reliable record of this species in the Boka Kotorska Bay was in 2013 when its specimens were found sporadically from early March to mid-July in the inner part of the Bay. The first bloom, estimated at 100 individuals per 10 m^2, was noted in April 2014, with another in mid-May, and followed by blooms in February and March 2015 (Pestorić, personally communication).

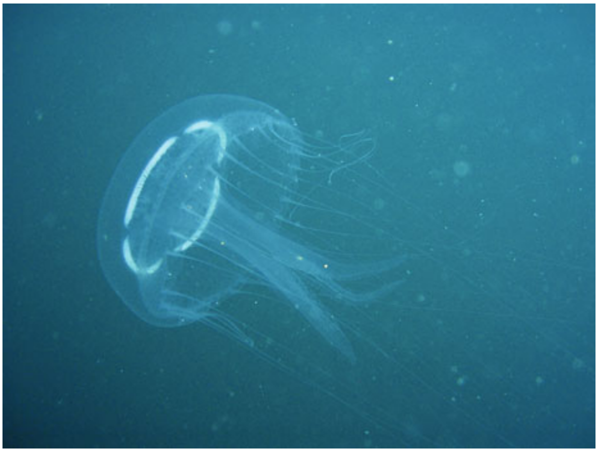

Fig. 14 *Discomedusa lobata* in the Boka Kotorska Bay (photo: V. Mačić)

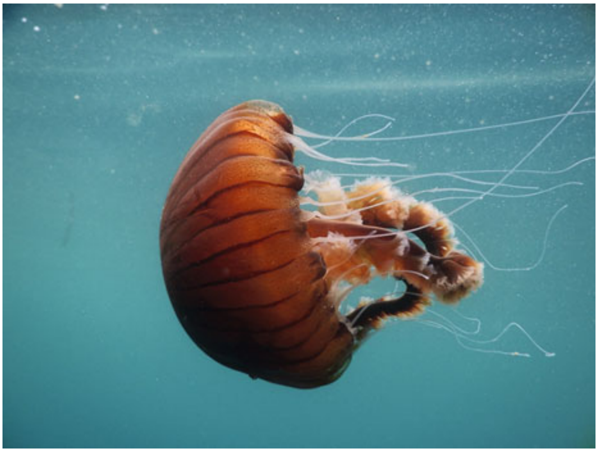

Fig. 15 *Chrysaora hysoscella* in the Boka Kotorska Bay (photo: V. Mačić)

Chrysaora hysoscella (Fig. 15) was found for the first time in the Boka Kotorska Bay in 2002 [17] as individual organism. In higher abundances *Chrysaora hysoscella* was observed during April 2014, while in March 2015 this species was noted in aggregation with *Discomedusa lobata* in low salinity area near fresh water source. In period from February to early May 2015 *C. hysoscella* was continuously present in the Bay in small number (Pestorić, personal communication).

Among native schyphomedusae found in the Mediterranean, which may grow to a larger size, is the species *Drymonema dalmatinum* [104]. Despite its conspicuous size this medusa has been very rarely observed in any Mediterranean area. Stiasny [105] suggested an ~30-year periodicity for this species based on records of *Drymonema* in the Adriatic since its description till 1940. There is no information about this species for Adriatic Sea in the period 1937–1984 [106]. On the other side, there were several observations since 2000 in the Northern, Central, and Southern Adriatic with majority of sightings in the Southern Adriatic. In the North-Eastern

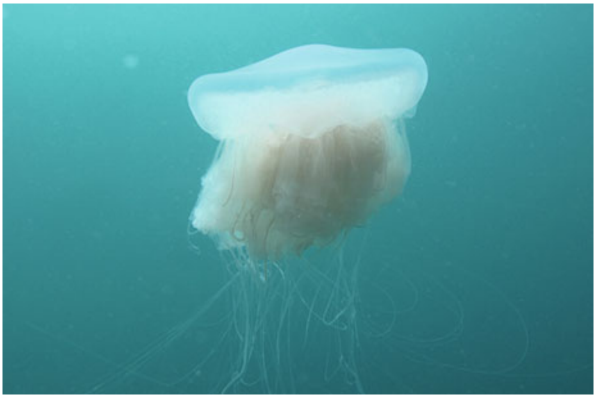

Fig. 16 *Drymonema dalmatinum* in the Boka Kotorska Bay (photo: V. Mačić)

part of the Kotor Bay *Drymonema dalmatinum* (Fig. 16) was noted four times in 2001 and once in 2014 [106].

19 Merozooplankton

Many juveniles and adults stages of marine organisms are part of benthos, but gametes or larvae are released into the water column [107]. These planktonic gametes and larvae grow in water column through one or more larval stages and make the most of meroplankton including different taxa and forms of planktonic larvae of benthic and planktonic species [108, 109]. That kind of development allows better distribution in the greater distances [110].

Average monthly abundance of meroplankton was the highest in the Kotor Bay with 973 ind. m^{-3} in February 2010 [20]. In the Tivat Bay, the highest mean monthly abundance of 533 ind. m^{-3} was recorded in April 2009. In the Herceg Novi Bay, the maximum number of meroplanktonic organisms was recorded in April 2009 with 281 ind. m^{-3} [20].

Throughout the year, average percentage of meroplanktonic larvae in zooplankton in the Kotor Bay was 2.3%. The highest value (~50%) was observed in the area of the Kotor Bay in February [20]. Bivalvia larvae dominated during research all areas accounting for more than 50% of the total meroplankton. That is common occurrence in shallow coastal areas where benthic communities are well developed [84]. Highest percentage of Bivalvia in the total meroplankton number was recorded in the Kotor Bay (62%), followed by the Tivat (52%), and the Herceg Novi Bays (30%) (Table 13). Gastropods accounted for 23% of the total number of meroplanktonic organisms in the Kotor Bay, followed by the Tivat with 27% in total number and 22% for the Herceg Novi Bay. Among other meroplankton, only decapods were significant in number. They were dominant in the Herceg Novi Bay (38%). Furthermore, Polychaetes and fish larvae were represented with 1% in the total number. Other meroplanktonic organisms have occasionally occurred in small numbers (Table 16). Historical data show that some species of decapods are higher

Table 16 Composition of meroplankton taxa in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av $\pm$ SD; ind. m^{-3}), and mean percentage of the total meroplankton abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Bivalvia	5051.73	178.3 ± 549.02	62.66	477.87	86.43 ± 116.58	52.07	256.00	41.27 ± 81.61	30.95
Gastropoda	409.6	50.37 ± 88.48	23	341.33	60.38 ± 91.86	27	51.20	13.94 ± 17.55	22
Decapoda larvae	51.20	7.06 ± 11.38	9.04	80.77	9.74 ± 15.80	14.57	173.60	19.24 ± 44.96	37.94
Polychaeta	68.27	5.32 ± 15.48	2.46	68.27	6.65 ± 14.07	3.5	12.8	1.82 ± 3.42	2.57
Pisces	51.20	2.57 ± 7.77	0.9	8.53	1.79 ± 2.89	1.38	38.40	3.83 ± 10.12	3.44
Bipinnaria	136.53	3.15 ± 14.56	0.8	102.4	5.71 ± 18.54	0.99	–	–	–
Ova Pisces	68.27	1.88 ± 7.45	0.48	25.60	1.61 ± 5.54	0.37	9.60	1.22 ± 2.66	1.06
Ophiopluteus	40.96	2.03 ± 7.45	0.31	34.13	0.93 ± 5.06	0.03	–	–	–
Echinopluteus	34.13	0.43 ± 3.40	0.01	34.13	1.21 ± 5.59	0.05	–	–	–

in number during spring and summer [111], which concurs with the results of our investigation. There is a strong link between phytoplankton bloom and development of certain meroplanktonic organisms [107].

20 Conclusions

The study indicates that fast-occurring changes in hydrographic and production parameters in the enclosed and eutrophic Boka Kotorska Bay significantly influence the density of zooplankton populations.

These variations are particularly strongly affected the composition and abundance of microzooplankton. Non-loricate ciliates were the most numerous microzooplankton, with the highest values at the surface, which is strongly influenced by a layer of fresh water. Tintinnid values were low and similar to those recorded in the open Adriatic Sea. Tintinnid species diversity was considerably high, and twenty-three species were recorded for the first time in Boka Kotorska Bay.

Copepods were the most numerous mesozooplankton group, dominated by small cyclopoids species (Oncaea like cyclopoids and *Oithona nana*). High abundance of the cladocera *Penilia avirostris* during summer are in accordance with the eutroficated status of area, and were among the highest values noted for the Adriatic.

Comparing our results with a previous research of the Boka Kotorska Bay some changes in the composition and abundance of zooplankton were observed: dominance of small copepod species; prevalence of alien species *Muggiaea atlantica* over to indigenous species *M. kochi*, especially in the inner part of the Bay; changes in the composition and abundance of meroplanktonic hydromedusans fauna; the first recorded mass occurrence of ctenophore *Bolinopsis vitrea* in the Mediterranean Sea; and frequent and more numerous before rare schyphozoan species. Our results suggest the possibility of permanent fauna changes in the Boka Kotorska Bay that could be associated with global warming and generally climate change.

Acknowledgments We would like to thank our colleague Vesna Mačić, PhD, who provided us with beautiful photos of jellyfish made in Boka Kotorska Bay and to Igor Brautovic, PhD, and Stijepo Ljubimir, PhD, who provided us photos of zooplankton species.

References

1. Roemmich D, McGowan J (1995) Climatic warming and the decline of zooplankton in the California current. Science 267:1324–1326
2. Kiørboe T (1997) Population regulation and role of mesozooplankton in shaping marine pelagic food webs. Hydrobiology 363:13–27

3. Calbet A (2008) The trophic roles of microzooplankton in marine systems. ICES J Mar Sci 65:325–331
4. Beaugrand G, Brander KM, Lindley JA, Souissi S, Reid PC (2003) Plankton effect on cod recruitment in the North Sea. Nature 426:661–664
5. Beaugrand G (2005) Monitoring pelagic ecosystems using plankton indicators. ICES J Mar Sci 62:333–338
6. Eloire D, Somerfield PJ, Conway DVP, Halsband-Lenk C, Harris R, Bonnet D (2010) Temporal variability and community composition of zooplankton at station L4 in the Western Channel: twenty years of sampling. J Plankton Res 32:657–679
7. Car L (1896) Copepodni plankton iz Jadranskog mora. Glasnik hrvatskog naravoslovnog društva 8:145–150
8. Gamulin T (1938) Prilog poznavanju planktonskih kopepoda Boke Kotorske. Oceanografski institut, Godišnjak 1:110–122
9. Vukanić D (1971) Kopepodi Bokokotorskog zaliva. Stud Mar 5:21–60
10. Vukanić D (1979) La recherches sur la Zooplanktons dans la baie de Kotor. Nova Thalassia 3 (1):249–255
11. Vukanić V (2010) Studies on Copepoda in Bay of Kotor–Coastal waters of Southern Adriatic. Nat Montenegrina 9(3):457–467
12. Vukanić D, Dutina M (1983) Sastav i brojnost planktonskih veslonožaca za vrijeme cvatnje Dinoflagelata u Kotorskom zalivu s osvrtom na hidrografske karakteristike. Stud Mar 13–14:127–139
13. Benović A, Onofri V (1983) Prilog poznavanju mrežnog zooplanktona Kotorskog zaliva. Stud Mar 13–14:119–125
14. Vukanić D, Dutina M, Vuksanović N (1989) Contribution to the investigations of the ecological characteristics and plankton of the bay of Kotor. Period Biol 94(1):125–126
15. Skaramuca B, Bender A (1983) Zimsko–proljetni aspekt populacije *Apendiculariaa* u Kotorskom zalivu. Stud Mar 13–14:111–117
16. Vukanić V, Vukanić D (2004) Zooplankton studies in the Boka Kotorska Bay during 2002 – Chaetognatha. Rapp Comm Int Mer Mediterr 37:459
17. Vukanić V (2006) A zooplankton study of the Boka Kotorska Bay during 2002 - hydromedusae (Cnidaria). Nat Montenegrina 5:37–47
18. Vukanić V (2006b) One-year observation on the population structure of Cladocera in Boka Kotorska Bay (Coastal waters of Southern Adriatic). Proceedings of MWWD Conference, , Antalya, Turkey, 6–10 November 2006.
19. Vukanić V (2007) Thecosome pteropod on the Bokakotorska Bay (Southern Adriatic). Rapp Comm Int Mer Mediterr 38:633
20. Pestoric B (2013) Dynamics of zooplankton communities in Boka Kotorska Bay. Dokoctoral thesys, University of Belgrade, Faculty of Biology, p 208
21. Pestorić B, Lučić D, Joksimović D (2011) Cladocerans spatial and temporal distribution in the coastal south Adriatic waters (Montenegro). Stud Mar 25:101–120
22. Pestorić B, Krpo-Ćetković J, Gangai B, Lučić D (2012) Pelagic cnidarians in the Boka-Kotorska Bay (Montenegro, South Adriatic). Acta Adriat 53(2):291–302
23. Pestorić B, Miloslavić M, Drakulović D, Lučić D (2014) Chaetognaths in Boka Kotorska Bay. Stud Mar 27(1):109–130
24. Lučić D, Pestorić B, Malej A, Lopez-Lopez L, Drakulović D, Onofri V, Miloslavić M, Gangai B, Onofri I, Benović A (2012) Mass occurrence of the ctenophore *Bolinopsis vitrea* (L. Agassiz, 1860) in the nearshore soutern Adriatic Sea (Kotor Bay, Montenegro). Environ Monit Assess 184:4777–4785
25. Kršinić F, Viličić D (1989) Microzooplankton in the Kotor Bay (the southern Adriatic). Stud Mar 20:1–20
26. Lučić P (2014) Microzooplankton in the costal region of the South Adriatic Sea and in the Boka Kotorska Bay. Master Thesis. University of Zagreb, Faculty of Science, Division of Biology, p 63

27. Kršinić F (1980) Comparison of methods used in microzooplanktonresearch in neritic waters of the eastern Adriatic. Nova Thalassia 4:91–106
28. Giesbrecht W (1892) Systematik und Faunistik der pelagische Copepoden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. Zoologische Station zu Neapel, XIX. Monographie, Friedländer & Sohn, Berlin, p 831
29. Sars GO (1924) Copépodes particulièrement bathypélagiques provenent des Campagnes Scietifiques du Prince Albert Ier de Monaco. Résultats de Campagnes Scientifiques Accomplies par le Prince Albert I. Monaco 69:1–408
30. Rose M (1933) Faune de France, v. 26: Copépodes pélagiques. Paris, Librairie de la Faculté des Sciences, p 374
31. Park T (1995) Taxonomy and distribution of the marine calanoid family Euchaetidae. Bull Scripps Inst Oceanogr Univ California 29I-IX:1–203
32. Razouls C, de Bovée F, Kouwenberg J, Desreumaux N (2005–2011) Diversity and geographic distribution of marine planktonic copepods. Available at: http://copepodes.obs-banyuls.fr/en.
33. Calbet A, Landry MR (2004) Phytoplankton growth, microzooplankton grazing, and carbon cycling in marine systems. Limnol Oceanogr 46:1824–1830
34. Calbet A, Saiz E (2005) The ciliate–copepod link in marine ecosystems. Aquat Microb Ecol 38:157–167
35. Sherr EB, Sherr BF (2002) Significance of predation by protists in aquatic microbial food webs. Antonie Van Leeuwenhoek 81:293–308
36. Sanders RW (1987) Tintinnids and other microzooplankton–seasonal distribution and relationship to resources and hydrography in a Maine estuary. J Plankton Res 9:65–77
37. Dolan JR, Coats DW (1990) Seasonal abundances of planktonic ciliates and microflagellates in mesohaline Chesapeake Bay waters. Estuar Coast Shelf Sci 31:157–175
38. Revelante N, Gilmartin M, Smodlaka N (1985) The effects of Po River induced eutrophication on the distribution and community structure of ciliated protozoan and micrometazoan populations in the northern Adriatic Sea. J Plankton Res 7:461–471
39. Kršinić F (1995) Changes in the microzooplankton assemblages in the northern Adriatic Sea during 1989 to 1992. J Plankton Res 17:935–953
40. Bojanić N, Šolić M, Krstulović N, Marasović I, Ninčević Ž, Vidjak O (2001) Seasonal and vertical distribution of the ciliated protozoa and micrometazoa in Kaštela Bay (central Adriatic). Helgol Mar Res 55:150–159
41. Fonda Umani S, Milani L, Borme D, de Olazabal A, Parlato S, Precali R, Kraus R, Lučić D, Njire J, Totti C, Romagnoli T, Pompei M, Cangini M (2005) Inter-annual variations of planktonic food webs in the northern Adriatic Sea. Sci Total Environ 353(1–3):218–231
42. Dolan JR (2000) Tintinnid ciliate diversity in the Mediterranean Sea: longitudinal patterns ralated to water column structure in late spring-early summer. Aquat Microb Ecol 22:69–78
43. Pitta P, Giannakourou A (2000) Planctonic ciliates in the oligotrophic Eastern Mediterranean: vertical, spatial distribution and mixotrophy. Mar Ecol Prog Ser 194:269–282
44. Kršinić F, Grbec B (2006) Horizontal distribution of tintinnids in the open waters of the South Adriatic (Eastern Mediterranean). Sci Mar 70:77–88
45. Cariou JB, Dolan JR, Dallot S (1999) A preliminary study of tintinnid diversity in the NW Mediterranean Sea. J Plankton Res 21:1065–1075
46. Dolan JR, Montagnes DJS, Agatha S, Coats DW, Stoecker DK (2013) The biology and ecology of tintinnid ciliates: models for marine plankton. Wiley-Blackwell, Chichester, UK
47. Revelante N, Gilmartin M, Smodlaka N (1985) The effects of Po River induced eutrophication on the distribution and community structure of ciliated protozoan and micrometazoan populations in the northern Adriatic Sea. J Plankton Res 7:461–471
48. Rudenjak–Lukenda M (1990) Annual vertical distribution of microzooplankton in the Bay of Mali Ston, Southern Adriatic (1983–1984). Acta Adriat 31:99–116

49. Vidjak O, Bojanić N, Kušpilić G, Ninčević Gladan Ž, Tičina V (2007) Zooplankton community and hydrographical properties of the Neretva Channel (eastern Adriatic Sea). Helgol Mar Res 61:267–282
50. Nielsen TG, Kiørboe T (1994) Regulation of zooplankton biomass and production in a temperate, coastal ecosystem. 2. Ciliates. Limnol Oceanogr 39:508–519
51. Kršinić F (2010) Tintinnids (Tintinnida, Choreotrichia, Ciliata) in the Adriatic Sea, Mediterranean. Part II ecology. Acta Adriat (special edition), p 113
52. Monti M, Minocci M, Milani L, Fonda Umani S (2012) Seasonal and interannual dynamics of microzooplankton abudances in the Gulf of Trieste (Northern Adriatic Sea, Italy). Estuar Coast Shelf Sci 115:149–157
53. Cabrini M, Fornasaro D, Cossarini G, Lipizer M, Virgilio D (2012) Phytoplankton temporal changes in a coastal northern Adriatic site during the last 25 years. Estuar Coast Shelf Sci 115:113–124
54. Bernardi Aubry F, Cossarini G, Acri F, Bastianini M, Bianchi F, Camatti E, De Lazzari A, Pugnetti A, Solidoro C, Socal G (2012) Plankton communities in the northern Adriatic Sea: patterns and changes over the last 30 years. Estuar Coast Shelf Sci 115:125–137
55. Čalić M, Carić M, Kršinić F, Jasprica N, Pećarević M (2013) Controlling factors of phytoplankton seasonal succession in oligotrophic Mali Ston Bay (south-eastern Adriatic). Environ Monit Assess 185(9):7543–7563
56. Mozetič P, Solidoro C, Cossarini G, Socal G, Precali R, Francé J, Bianchi F, De Vittor C, Smodlaka N, Fonda Umani S (2010) Recent trends towards oligotrophication of the northern Adriatic: evidence from chlorophyll *a* time series. Estuaries Coasts 33:362–375
57. Smayda TJ (1980) Phytoplankton species succession. In: Morris I (ed) The physiological ecology of phytoplankton, Blackwell Scientific Publications, Oxford, p 493–570
58. Boni L (1983) Red tide off the coast of Emilia Romagna (north-western Adriatic sea) from 1975 to 1982. Informatore Botanico Italiano 15:18–23
59. Dela-Cruz J, Ajani P, Lee R, Tim Pritchard T, Suthers I (2002) Temporal abundance patterns of the red tide dinoflagellate Noctiluca scintillans along the southeast coast of Australia. Mar Ecol Prog Ser 236:75–88
60. Fonda Umani S, Beran A, Parlato S, Virgilio D, Zollet T, De Olazabel A, Lazzarini B, Cabrini M (2004) Noctiluca scintillans (Macartney) in the Northern Adriatic Sea: long-term dynamics, relationships with temperature and eutrophication, and role in the food web. J Plankton Res 26(5):545–561
61. Elbrächter M, Qi ZY (1998) Aspect of Noctiluca (Dinophyceae) population dynamics. In: Anderson DM, Cembella AD, Hallegraeff MG (eds) Physiological ecology of harmful algal blooms. NATO ASI Series, vol. G 41. Springer-Verlag, Berlin, pp 315–335
62. Nakamura Y (1998) Biomass, feeding and production of Noctiluca scintillans in the Seto Inland Sea, Japan. J Plankton Res 20:2213–2222
63. Boero F, Bouillon J, Gravili C, Miglietta MP, Parsons T, Piraino S (2008) Gelatinous plankton: irregularities rule the word (sometimes). Mar Ecol Prog Ser 356:299–310
64. Brotz L, Cheung WLW, Kleisner K, Pakhomov E, Pauly D (2012) Increasing jellyfish populations: trends in large marine ecosystems. Hydrobiologia 690(1):3–20
65. Purcell JE, Arai MN (2001) Interactions of pelagic cnidarians and ctenophores with fish: a review. Hydrobiologia 451:27–44
66. Bouillon J, Medel MD, Pages F, Gili JM, Boero F, Gravili C (2004) Fauna of the Mediterranean hydrozoa. Sci Mar 68(2):1–449
67. Babnik P (1948) Hidromeduze iz srednjeg in južnog Jadrana v letih 1939. in 1940 (in Slovenian with English summary). Acta Adriat 3:1–76
68. Purcell JE (1981) Dietary composition and diel feeding patterns of epipelagic siphonophores. Mar Biol 65:83–90
69. Graham WM, Page's F, Hamner WM (2001) A physical context for gelatinous zooplankton aggregations: a review. Hydrobiologia 451:199–212

70. Kršinić F, Njire J (2001) An invasion by Muggiaea atlantica Cunningham 1982 in the northern Adriatic Sea in the summer of 1997 and the fate of small copepods. Acta Adriat 42(1):49–59
71. Atienza D, Saiz E, Skovgaard A, Trepat I, Calbet A (2008) Life history and population dynamics of the marine cladoceran *Penilia avirostris* (Branchiopoda: Cladocera) in the Catalan Sea (NW Mediterranean). J Plankton Res 30:345–357
72. Onbé T (1977) The biology of marine cladocerans in a warm temperate water. In: Proc symp warm water zoopl spec publ natn inst oceanogr. UNESCO, Goa, pp 383–398
73. Marazzo A, Valentin JL (2001) Spatial and temporal variations of *Penilia avirostris* and *Evadne tergestina* (Crustacea, Branchiopoda) in a Tropical Bay, Brazil. Hydrobiologia 445:133–139
74. Tang KW, Chen QC, Wong CK (1995) Distribution and biology of marine cladocerans in the coastal waters of southern China. Hydrobiologia 307(1–3):99–107
75. Fonda Umani S, Franco P, Ghirardelli E, Malej A (1992) Outline of oceanography and the plankton of the Adriatic Sea. In: Colombo G, Ferrari I, Ceccherelli VV, Rossi R (eds) Marine eutrophication and population dynamics. Olsen & Olsen, Fredensborg, pp 347–365
76. Wong CK, ChangALC, Tang, KW (1992) Natural ingestion rates and grazing impact of marine cladoceran *Penilia avirostris* Dana in Tolo Harbour, Hong Kong. J Plankton Res 14:1757–1765
77. Lipej L, Mozetič P, Turk V, Malej A (1997) The trophic role of the marine cladoceran *Penilia avirostris* in the Gulf of Trieste. Hydrobiologia 360:197–203
78. Leandro SM, Morgado F, Pereira F, Queiroga H (2007) Temporal changes of abundance, biomass and production of copepod community in a shallow temperate estuary (Ria de Aveiro, Portugal). Estuar Coast Shelf Sci 74:215–222
79. Marques SC, Azeiteiro UM, Martinho F, Viegas I, Pardal MA (2009) Evaluation of estuarine mesozooplankton dynamics at a fine temporal scale: the role of seasonal, lunar and diel cycles. J Plankton Res 31(10):1249–1263
80. Howlett R (1998) Sex and the single copepod. Nature 394:423–424
81. Kršinić F, Lučić D (1994) Mesozooplankton sampling experiments with the 'Adriatic' sampler: differences of catch between 250 and 125 μm mesh netting gauze. Estuar Coast Shelf Sci 38:113–118
82. Calbet A, Garrido S, Saiz E, Alcaraz M, Duarte CM (2001) Annual zooplankton succession in coastal NW Mediterranean waters: the importance of the smaller size fractions. J Plankton Res 23:319–331
83. Gallienne CP, Robins DB (2001) Is Oithona the most important copepod in world's oceans? J Plankton Res 23:1421–1432
84. Miloslavić M, Lučić D, Žarić M, Gangai B, Onofri I (2015) The importance of vertical habitat gradients on mesozooplankton distribution in a semi-enclosed marine environment (South Adriatic Sea). Mar Biol Res 11(5):462–474
85. Vidjak O, Bojanić N, Kušpilić G, Marasović I, Ninčević GŽ, Brautović I (2006) Annual variability and trophic relations of the mesozooplankton community in the eutrophicated coastal area (Vranjic Basin, eastern Adriatic Sea). J Mar Biol Assoc UK 86:19–26
86. Viličić D, Kršinić F, Carić M, Jasprica N, Bobanović-Ćolić S, Mikuš J (1995) Plankton and hydrography in a moderately eastern Adratic Bay (Gruž Bay). Hydrobiologia 304:9–22
87. Lučić D, Kršinić F (1998) Annual variability of mesozooplankton assemblages in Mali Ston Bay (Southern Adriatic). Period Biol 100:43–52
88. Rampal J (1975) Les thécosomes. Systématique et evolution. Ecologie et biogéographie méditerranéennes. These Doctoral. Université Aix-Marseille I, pp. 1-485.
89. Batistić M, Kršinić F, Jasprica N, Carić M, Viličić D, Lučić D (2004) Gelatinous invertebrate zooplankton of the South Adriatic: species composition and vertical distribution. J Plankton Res 26(4):459–474

90. Reeve MR, Cosper TC, Walter MA (1975) Visual observations of the process of digestion and the production of faecal pellets in the chaetognath *Sagitta hispida* Conant. J Exp Mar Biol Ecol 17:39–46
91. Pearre S Jr (1974) Ecological studies of three West-Mediterranean chaetognaths. Invest Pesquera 38:325–369
92. Stuart V, Verheye HM (1991) Diel migration and feeding patterns of the chaetognath, *Sagitta federici,* off the west coast of South Africa. J Mar Syst 49:493–515
93. Ghirardelli E, Specchi M (1965) Chaetognathes et Cladodocceres du Golfe de Trieste (Recherches préliminaires). Rapp Comm Int Mer Méditerr 18:403–407
94. Graeffe E (1905) Ubersicht der Fauna des Golfes von Triest, X. Vernes. Arb. Zool. Inst, Wien 15:317–332
95. Bone Q (1998) The biology of pelagic tunicates. Oxford University Press, Oxford
96. Spada F, Steen H, Troedsson C, Kallesoe T, Spriet E, Mann M, Thompson EM (2001) Molecular patterning of the oikoplastic epithelium of the larvacean tunicate Oikopleura dioica. J Biol Chem 276:20624–20632
97. Thompson EM, Kallesøe T, Spada F (2001) Diverse genes expressed in distinct regions of the trunk epithelium define a monolayer cellular template for construction of the oikopleurid house. Dev Biol 238:260–273
98. Official Journal of the European Union (2010) Commission decision on criteria and methodological standards on good environmental status. 232/14 of 1 September 2010
99. CIESM 2001 Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series 14, Monaco, p 112
100. Boero F (2013) Review of Jellyfish blooms in the Mediterranean and Black Sea. Studies and reviews. General Fisheries Commission for the Mediterranean. No. 92. FAO, Rome, p 53
101. Licandro P, Conway DVP, Daly Yahia MN, Fernandez de Puelles ML, Gasparini S, Hecq JH, Tranter P, Kirby RR (2010) A blooming jellyfish in the northeast Atlantic and Mediterranean. Biol Lett. doi:10.1098/rsbl.2010.0150
102. Shiganova T, Christou ED, Bulgakova JV, Siokou-Frangou I, Zervoudaki S, Siapatis A (2004) Distribution and biology of Mnemiopsis leidyi in the northern Aegean Sea, and comparison with indigenous Bolinopsis vitrea. In: Dumont H, Shiganova T, Niermann U (eds) Aquatic invasions in the Black, Caspian, and Mediterranean Seas, NATO Science Series, 4, Earth and Environmental Sience, Kluwer, Dordrecht, pp 113–135
103. Rottini-Sandrini L, Bratina E, Avian M (1986) Aspetti ultrastrutturali della gametogenesi in *Discomedusa lobata* (Claus). Nova Thalassia 8(suppl 2):59–66. In Italian; English abstract
104. Haeckel E (1880) System der Acraspeden. Zweite Halfte des System der Medusen. Verlag von Gustav Fischer, Jena, p 361–672
105. Stiasny G (1940) Über *Drymonema dalmatinum* Haeckel. Zool Jb Abt Anat 66:437–461
106. Malej A, Vodopivec M, Lucic D, Onofri I, Pestoric B (2014) The lesser-known medusa Drymonema Dalmatinum Haeckel 1880 (Scyphozoa, Discomedusae) in the Adriatic Sea. Ann Ser Hist Nat 24(2):79–86
107. Highfield JM, Eloire D, Conway D, Lindeque PK, Attrill MJ, Somerfield PJ (2010) Seasonal dynamics of meroplankton assemblages at station L4. J Plankton Res 32:681–691
108. Marcus NH, Boero F (1998) Minireview: the importance of benthic-pelagic coupling and the forgotten role of life cycles in coastal aquatic systems. Limnol Oceanogr 43(5):763–768
109. Pechenik JA (1999) On the advantages and disadvantages of larval stages in benthic marine invertebrate life cycles. Mar Ecol Prog Ser 177:269–297
110. Livi S, Cordisco C, Damiani C, Romanelli M, Crosetti D (2006) Identification of bivalve species at an early developmental stage through PCR-SSCP and sequence analysis of partial 18S rDNA. Mar Biol 149:1149–1161
111. Lučić D (1998) Annual variability of decapod larvae community in the shallow waters of the southern Adriatic. Acta Adriat 39(1):29–30