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Distribution changes of plankton communities in the harbour Porto Montenegro (South Adriatic Sea)

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ABSTRACT

Plankton data (phyto, zoo and ichthyo) that were collected monthly from March 2016 to February 2017 in the harbour "Porto Montenegro" and the referent station (Tivat Bay) were analysed to determine if there are any differences in plankton distribution, composition and diversity among sites. In contrast to phytoplankton and zooplankton, whose diversity and spatial distribution are driven considerably by temperature and salinity (phytoplankton) and inter-species interaction, affinity for aggregation with specific water masses (zooplankton), the spatial dynamics of ichthyoplankton is significantly dependent on the aggregation of adult populations, rates of mortality, and physical processes that affect the position and retention of organisms. Anchovy early life stages and the dominance of this species in referent station during all months of investigation, especially in August, caused significant difference among sites. We found that unfavourable conditions for adult fish aggregation in the harbour area "Porto Montenegro" could be the reason for driving the differences in the ichthyoplankton spatial distribution compared with Bay area, while phytoplankton and zooplankton data didn't show significant differences among sites.

Keywords: phytoplankton, zooplankton, ichthyoplankton, abundance, diversity indices

INTRODUCTION

The whole marine environment, from inshore areas, estuaries, fjords and lagoons to the pelagic environments and the open ocean, has become an important venue for tourism and recreation (Orams, 1999). Nautical tourism is a relatively new popular phenomenon, which in the last decade has gained significant relevance in the Montenegrin economy. It is considered to be at its initial developmental stage, while a high performance is expected in the coming years (Nenadović, 2015). The development of nautical tourism, in addition to a series of positive economic effects, brings negative consequences such as the occupation of the marine environment. The presence of sport boats and yachts, in turn, contributes with high loads of pollutants and is currently deteriorating the Adriatic Sea ecosystem. Hence, it is necessary to boost the development of ecological awareness of boaters, particularly in terms of preserving the quality of the sea and islands, as well as coastal areas (Gračan *et al.*, 2016). The development of the modern economy and technology strongly influences the ecological balance of these areas which are particularly vulnerable due to their shallow water column and the presence of weak water currents that increase the residence time of pollutants (Kovačić *et al.*, 2006). Porto Montenegro is a harbour for luxury yachts located in the eastern part of the Tivat Bay, which is situated in Boka Kotorska Bay (Montenegro, South Adriatic Sea). During 2017 the harbour was visited by more than 2200 yachts. Intensive development of nautical tourism in such shallow area influences the plankton abundance and diversity. Changes in food web structure under this anthropogenic influence have already been documented (McClelland & Valiela, 1998). However, the biotic responses to anthropogenic stress are poorly investigated (Dermott *et al.*, 2007). Few investigations regarding to plankton communities were conducted in similar area-port of Bar (Možetič *et al.*, 2017; Vidjak *et al.*, 2018), with emphasis on harmful algal species and indigenous and non-indigenous species.

The aim of this work is to progress towards the understanding of the responses of lower trophic levels, from phytoplankton to ichthyoplankton, to the harbour activities that are taking place in “Porto Montenegro”. This paper presents a comparison of plankton dynamics and structure between the impacted area of “Porto Montenegro” harbour and a reference area in the Tivat Bay.

MATERIAL AND METHODS

Study area

“Porto Montenegro” is a harbour for luxury yachts and it is situated in the eastern part of Tivat Bay in Boka Kotorska Bay (Montenegro). Harbour covers around 0.35 km^2 of sea area, with 700 m length and 500 m width approximately. Maximum depth is around 13 m. Samples for this study were taken from one station in the central area of Tivat Bay (marked as “Bay”), selected as referent station, and two stations (marked as “Harbour”) from the harbour area in the “Porto Montenegro” (Fig. 1).

Data collection and sampling processing

Sampling was carried out with a monthly frequency in the period from March 2016 to February 2017. Samples for chlorophyll *a* concentration and phytoplankton analysis were taken at surface (0.5m) and subsurface (5m) layers with a Niskin bottle (5l), while samples for zooplankton and ichthyoplankton analysis were taken by vertical hauls from 10m depth to the sea surface. Nansen plankton net, 0.55m diameter and 125 µm mesh size was used for zooplankton sampling, while WP2 plankton net, 0.55m diameter and 200 µm mesh size was used for ichthyoplankton sampling.

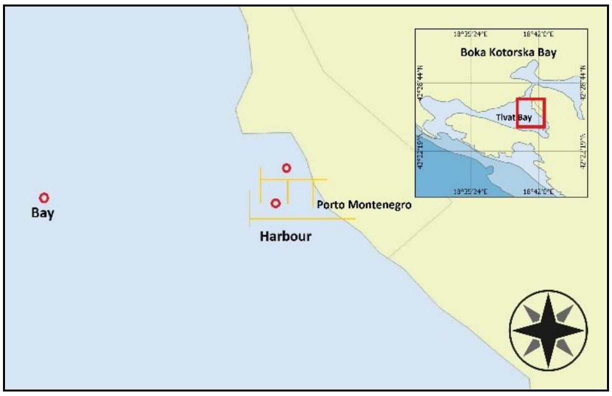


Figure 1. Map of sampling sites

Temperature (°C) and salinity were measured *in situ* with a universal probe "Crison CM35+" at surface and subsurface (5m). Samples (1l) for the determination of chlorophyll *a* (mg/m^3) were filtered onto Glass microfiber filters (47mm and 0.7µm pore size) and then the pigment was extracted in 90% acetone. Chlorophyll *a* concentrations were determined on an Analitic Jena spectrophotometer by measuring the absorbance at four wavelengths and calculated according to Jeffrey *et al*. (1997).

Phytoplankton, zooplankton and ichthyoplankton samples were preserved using 4% neutralized formaldehyde solution. Phytoplankton species were identified and counted using Leica DMI400 B inverted microscope (Heerbrugg, Switzerland) in subsamples of 25 ml after 24h of sedimentation, following Utermöhl (1958). Zooplankton and ichthyoplankton samples were analyzed using stereomicroscope Nikon SMZ800. Phytoplankton abundance was presented as cell/l, zooplankton as ind/m^3. The number of ichthyoplankton eggs and larvae was presented per unit of surface (1 m^2), using the function given by Tanaka (1973).

Data Analysis

The annual pattern of the sea surface temperature (SST), salinity and chlorophyll *a* concentration were evaluated by generalized additive models (GAM), using mean monthly records as a function of time (months). Monthly records were fitted with a logit link function using the R-package mgcv. Differences of biotic and abiotic variables between Bay and harbour areas, were calculated by Boxplots and Tukey HSD post-hoc test at a significance level of $p<0.05$. All data were tested for normality prior to analysis. The structure, i.e. taxonomic composition of plankton between sites, was assessed by non-metric Multi-Dimensional Scaling (MDS) using the R-package vegan. The technique was based on triangular matrix using the Bray Curtis similarity index (Clarke & Warwick 1994). Significant differences in the plankton structure between sites were calculated by a One-way Analysis of Similarities (ANOSIM) at a significance level of $p<0.05$ and R statistic>0.5.

SIMPER analysis was performed to establish percentage contribution of taxa in 90% of total abundance. SIMPER analysis was calculated using package PRIMER v6 (Clarke & Gorley 2006). Nonparametric diversity index according Shannon Wiener (Krebs, 2001) was calculated to describe the taxon richness and the relative abundance of phytoplankton, zooplankton and ichthyoplankton species. Shannon Wiener index accounts for both abundance and evenness of the species present. The proportion of species *i* relative to the total number of species (p*i*) is calculated, and then multiplied by the natural logarithm of this proportion (lnp*i*). The resulting product is summed across species, and multiplied by -1:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Food web interactions in each area were tested by quantifying the link between ichthyoplankton and their potential food items (phytoplankton and zooplankton groups). For this purpose, we employed structural equation modelling (SEM) that allows investigating the strength of links between variables of a path model based on the hypothesis that food items jointly drive the abundance of ichthyoplankton. Path coefficients were determined by simple and partial multivariate regression and Monte Carlo permutation tests (1000 replicates), while the Bayesian Information Criterion (BIC) and Chi-square values were used to assess the robustness of models (Alsterberg *et al.*, 2013). Path analysis was performed using the R-library lavaan.

RESULTS

Hydrographic parameters

Seasonal and spatial pattern of temperature was noticed during the survey (Fig. 2). Maximum temperature value was recorded in July 2016 (26.4°C) in the harbour area while the minimum was recorded in January 2017 (9.3°C) in the Bay area. Salinity values showed an unclear pattern in the investigated period. Minimum value, 17.8, was recorded in October 2016 in surface layers in the harbour area, as well as slightly lower values in the period March-May and November. Maximum salinity value, 37.3, was noticed in bottom layers in December 2016 in the harbour area.

Hydrographic parameters showed slight, non-significant (Kruskal Wallis - KW), variation among sites (Bay and Harbour) (KW-T p=0.96016; KW-S p=0.9646). Generalized Additive Model (GAM) showed that SST variability was higher in the Bay area than in the harbour area, while the annual pattern of salinity was more variable in the harbour area.

Biological parameters

Chlorophyll *a*

Concentration of chlorophyll *a* showed non-significant difference among stations (KW, p=0.8545).

Average values of two stations for chlorophyll *a* are presented for harbour area.

The highest value of chlorophyll *a* was recorded in October 2016 in the Bay area and accounted for 3.626 mg/m^3, whereas the lowest concentration was registered in period July-September at both sites with a minimum of 0.219 mg/m^3 recorded in July 2016 in the Bay area (Fig. 4).

The general trend of chlorophyll *a* concentration obtained by GAM revealed that the maximum values occurred during October at both sites (Fig. 5), and the samples in the harbour area showed less variation in chlorophyll *a* concentration on sampling dates in comparison with the Bay area.

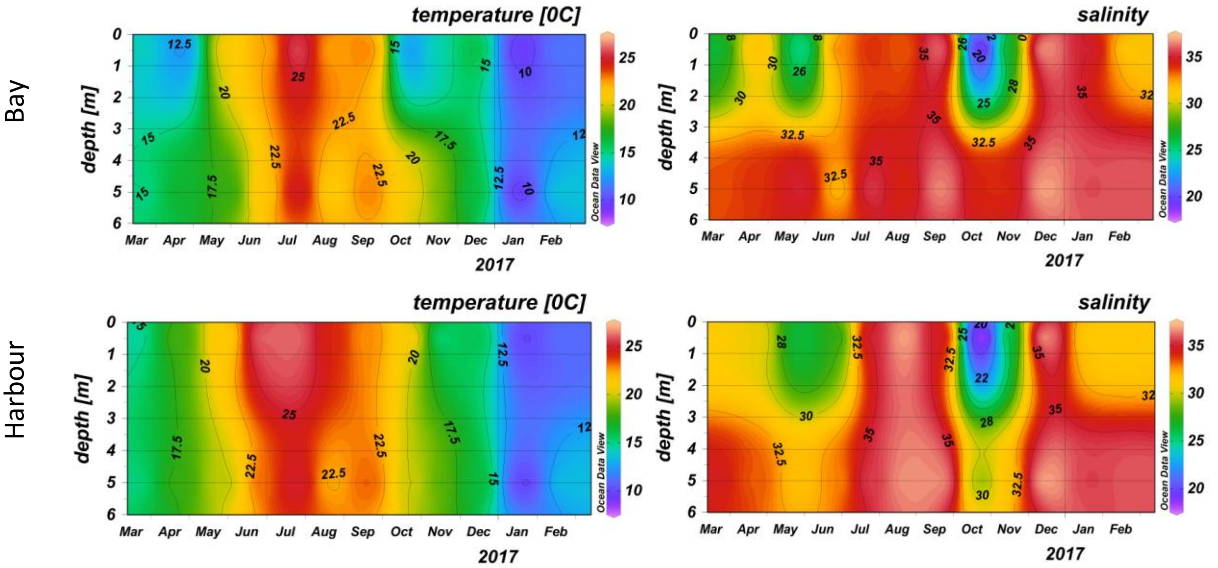


Figure 2. Spatio-temporal variability of temperature (left panels) and salinity (right panels) in the sampling sites during the investigated period (March 2016 to February 2017) Average values of two stations for temperature and salinity are presented for the harbour area.

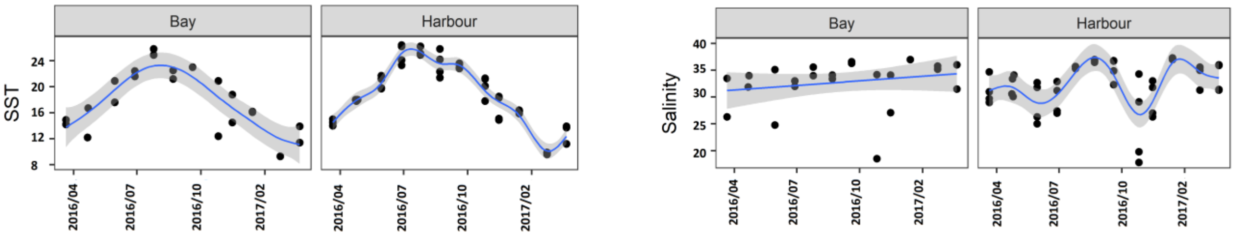


Figure 3. GAM estimates of monthly values of sea surface temperature (SST) and surface salinity in the sampling sites

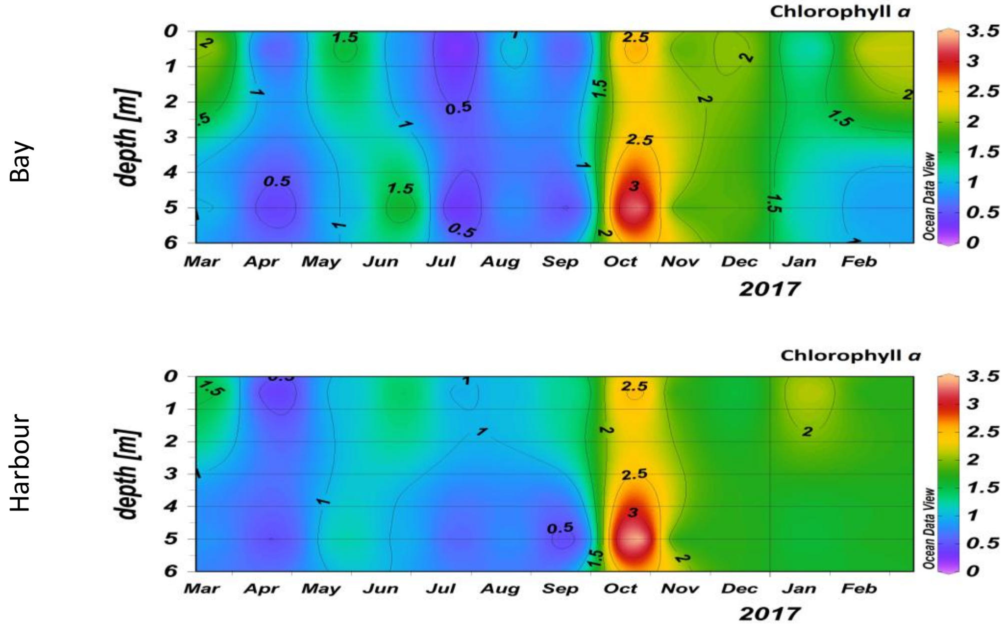


Figure 4. Spatio-temporal variability of chlorophyll *a* (mg/m^3) in the sampling sites during the investigated period (March 2016 to February 2017)

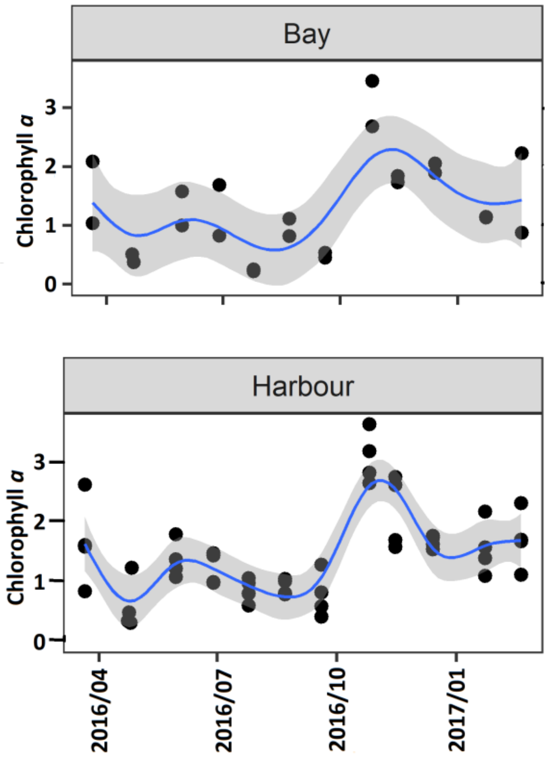


Figure 5. GAM estimates of monthly values of chlorophyll *a* concentration (mg/m^3) in the sampling sites.

Phytoplankton

The trend of phytoplankton abundance was similar to that of chlorophyll *a* concentration as the lower values occurred in summer 2016 while the minimum abundance was noticed in September 2016 and reached up to 2.5×10^4 cell/l. Maximum abundance was recorded in June 2016 reaching up to 9.55×10^5 cell/l in the Bay area (Fig. 6). During this period, phytoplankton abundance was 3 times higher than in the harbour area. Regarding monthly average values, the higher phytoplankton abundances were noticed in period October-November. ANOVA test showed that there were no significant differences on phytoplankton abundance between stations (p=0.2581).

Diatoms were the most abundant among phytoplankton groups, contributing almost 50% of total abundance. Dinoflagellates were the second most abundant group and contributed with 25% of total phytoplankton abundance. Multidimensional scaling (MDS, Fig. 7) showed that there was no clear difference among species composition between the Bay and the harbour area. One-way ANOVA showed significant differences on the abundance of silicoflagellates among sites, while no significant differences were found in the abundance of other phytoplankton groups (Fig. 8).

Phytoplankton biodiversity

A total of 120 taxa were found during the investigated period (Appendix I), while 100 were found in the Bay area and 99 in the harbour area. Five species accounted for more than 90% of total phytoplankton abundance (SIMPER analysis, Table 1). *Chaetoceros affinis* and *Proboscia alata* were the species that contribute to differentiate the Bay and the harbour areas.

Shannon Wiener index ranged from 0.1033 in June 2016 to 2.0770 in December 2016 (Fig. 9) and there was not statistically significant difference between sites (ANOVA; p=0.8665).

Zooplankton

Total zooplankton abundance showed irregular fluctuation during the sampling period. The maximum abundance value (10371 ind/m^3) was noted in April 2016 in the harbour area (Fig. 10). Two peaks of lower magnitude were recorded in September 2016 and December 2016 in both sites. Significant differences in abundance among sites were not registered (ANOVA, p=0.215).

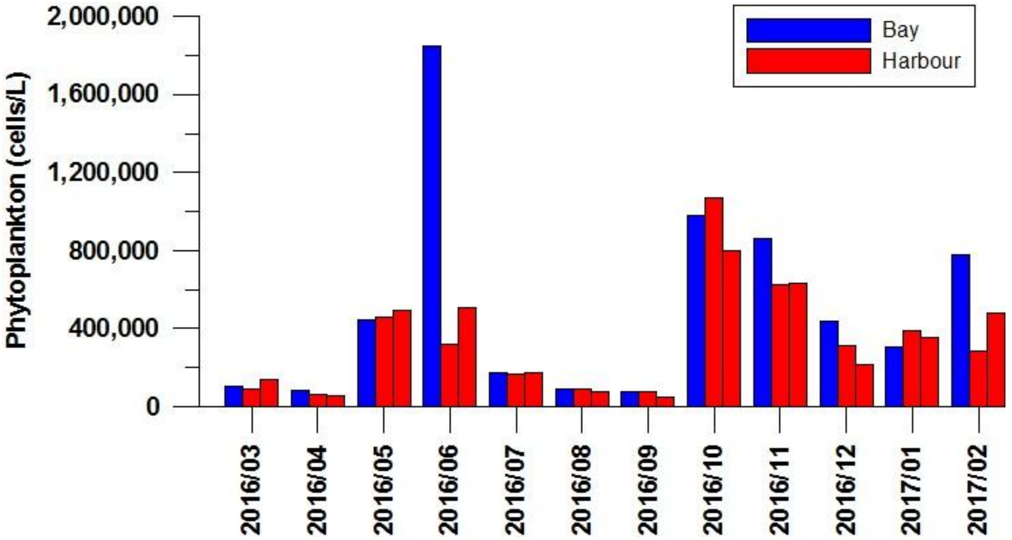
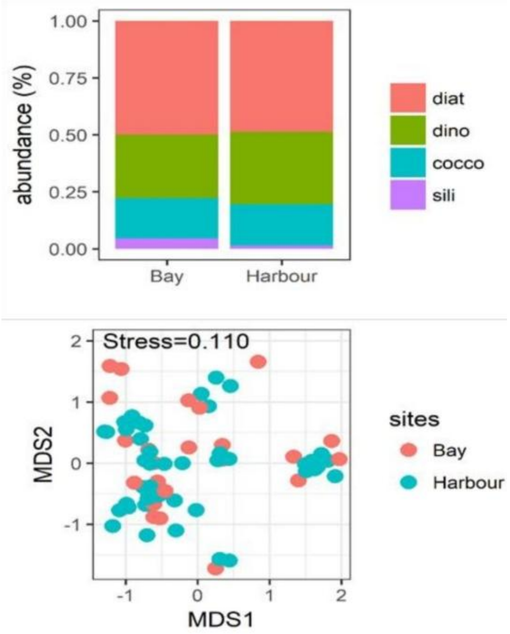


Figure 6. Abundance values of phytoplankton in the sampling stations during the investigated period (March 2016 to February 2017).



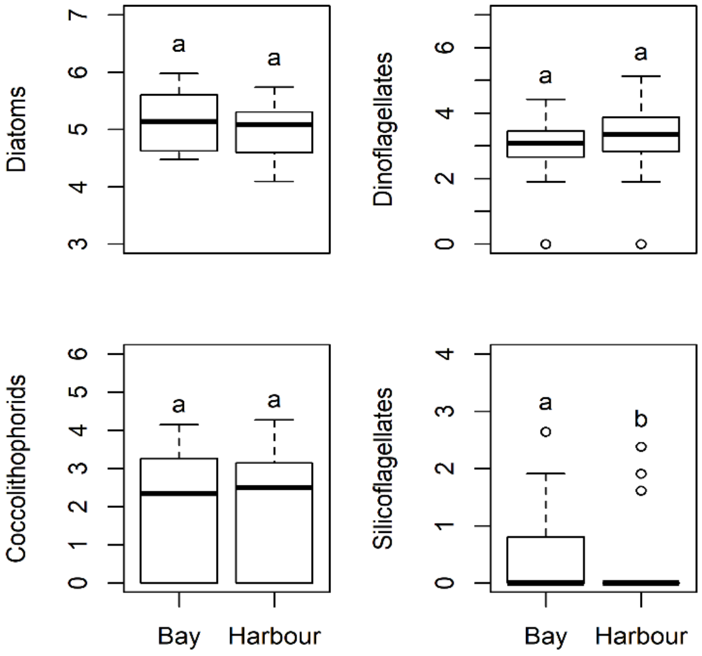


Figure 7. Average contribution (%) of diatoms (diat), dinoflagellates (dino), coccolithophores (cocco) and silicoflagellates (sili) to total phytoplankton abundance (upper panel). Multidimensional scaling of phytoplankton in the sampling areas (MDS) (bottom panel).

Figure 8. Mean value of the abundance of main phytoplankton groups in the sampling areas. Different letters above boxes denote significant differences (right) ($p<0.05$, one-way ANOVA: TukeyHSD test).

Table 1. SIMPER analysis of phytoplankton taxa which are contributing to 90% to total abundance

Bay

Taxa	Average abundance	Contribution %	Cumulative contribution %
Pseudo-nitzschia spp.	136772.8	71.41	71.41
Bacteriastrum hyalinum	37080.25	7.27	78.68
Thalassionema nitzschioides	6186.79	5.74	84.42
Chaetoceros spp.	38632.38	3.50	87.92
Chaetoceros affinis	7603.17	3.33	91.25

Harbour

Taxa	Average abundance	Contribution %	Cumulative contribution %
Pseudo-nitzschia spp.	50632.35	58.93	58.93
Bacteriastrum hyalinum	37634.13	18.45	77.38
Thalassionema nitzschioides	3959.52	6.30	83.68
Chaetoceros spp.	31200.25	4.67	88.35
Proboscia alata	1431.92	2.08	90.43

The most abundant group among zooplankton was copepoda which contributed with 44% to 94% in total abundance during the investigated period. Multidimensional scaling (MDS) showed no clear difference among species composition in the harbour area and the Bay area (Fig. 11). One-way ANOVA showed significant differences on the abundance of Pteropoda and Larvae among sites, while non-significant differences were found in the abundance of other zooplankton groups (Fig. 12).

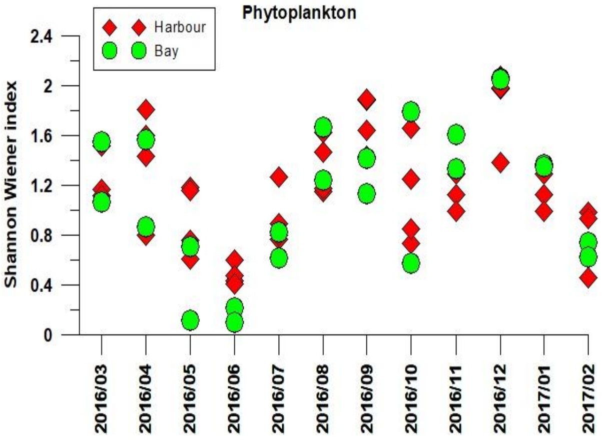


Figure 9. Phytoplankton taxa richness in the sampling stations during the investigated period (March 2016 to February 2017).

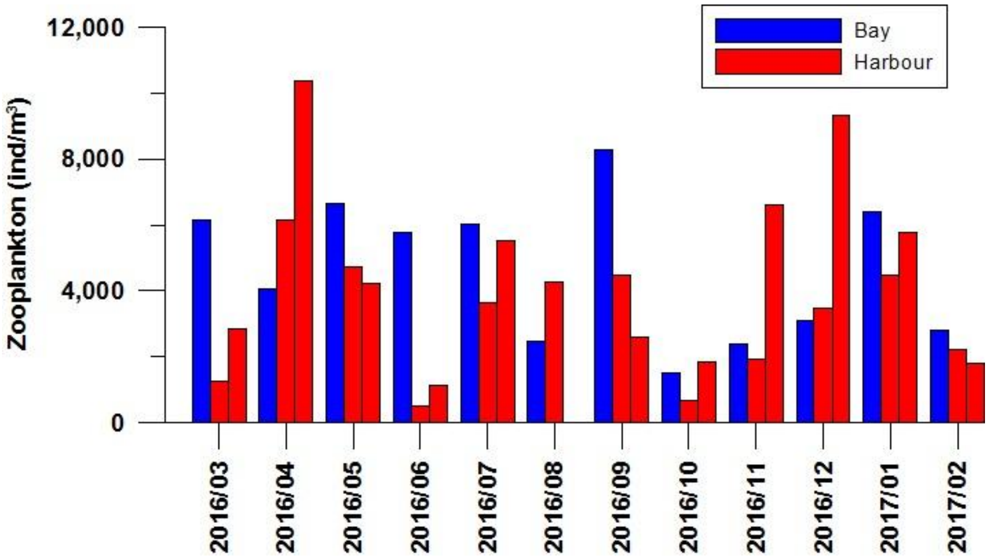


Figure 10. Abundance values of zooplankton in the sampling stations during the investigated period (March 2016 to February 2017).

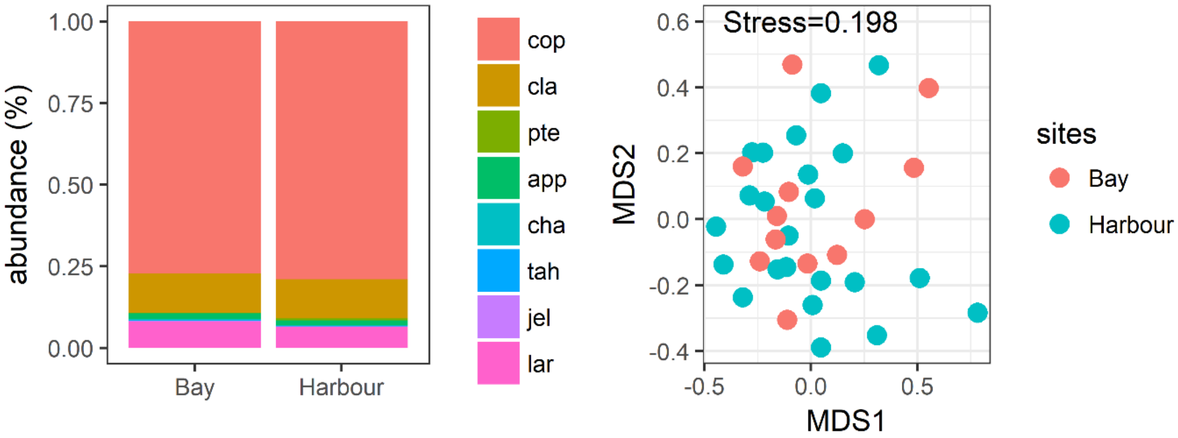


Figure 11. Average contribution (%) of copepods (cop), cladocera (cla), pteropoda (pte), appendicularia (app), chaetognatha (cha), tahliacea (tah), jellyfish (jel) and larvae (lar) to total zooplankton abundance (left panel). Multidimensional scaling of zooplankton in the sampling areas (MDS) (right panel).

Zooplankton biodiversity

A total of 70 taxa within the 11 zooplankton groups were registered, with 63 taxa recorded in the Bay area and 60 taxa in the harbour area (Appendix II). SIMPER analysis showed that the most abundant taxa in the Bay and the harbour area were copepods: cyclopoida (*Oithona nana* and *Onceaidae* like taxa) with 45-56% contribution to total zooplankton abundance among sites, and were followed by harpacticoida *Eutherpina acutifrons* (around 10%) (Table 2). From calanoid copepods in the Bay area under 90% of total abundance contribution takes *Paracalanus parvus* while in the harbour area

Acartia clausi. *Penilia avirostris*, the most abundant cladocera, contributed with 8.6-9.8% among sites to total zooplankton abundance. Meroplankton taxa, bivalvia and gastropods were mainly present in the Bay area and represented almost 20% of total abundance, while in the harbour area, their contribution reached only 6%.

Shannon Wiener index ranged from 0.9037 in June to 2.5350 in February and non-significant difference was found between sites (ANOVA; p=0.7658) (Fig. 13).

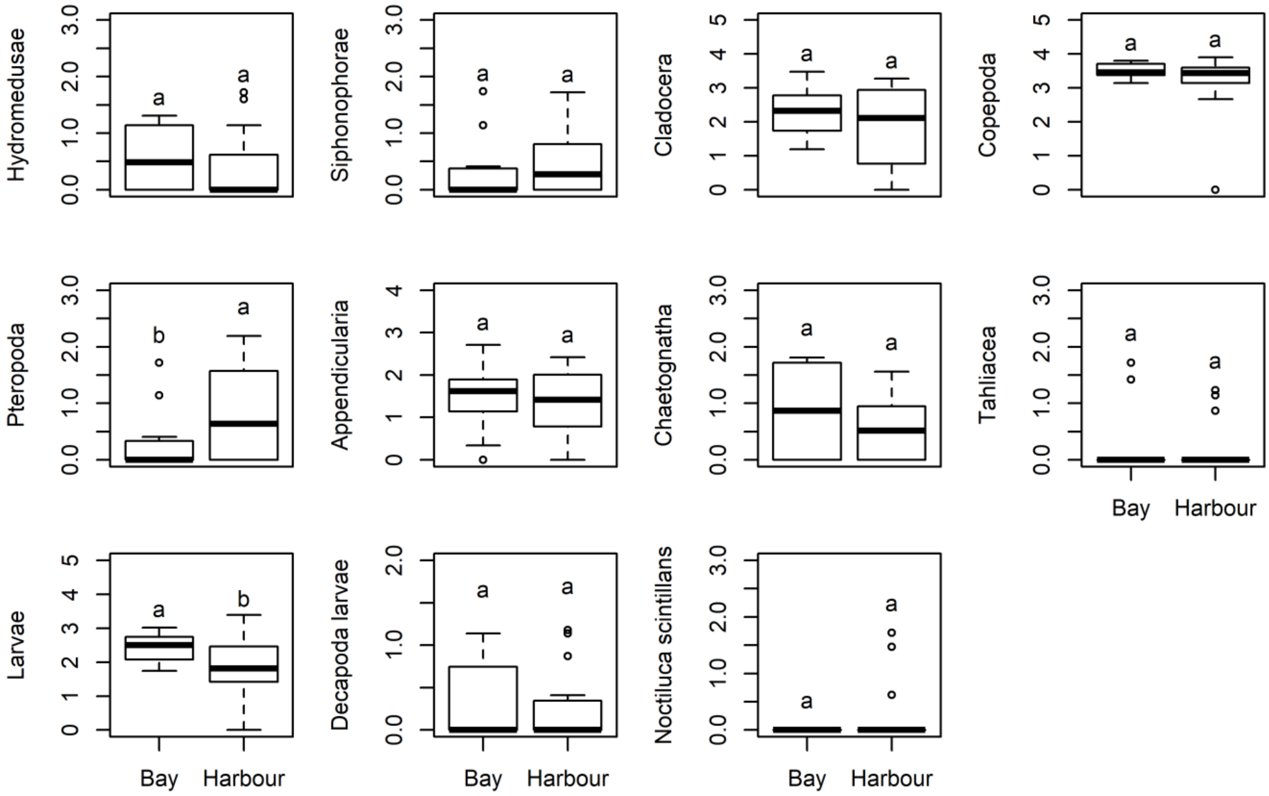


Figure 12. Mean value of the abundance of main zooplankton groups in the sampling areas. Different letters above boxes denote significant differences (p<0.05, one-way ANOVA: Tukey HSD test).

Table 2. SIMPER analysis of zooplankton taxa which are contributing to 90% to total abundance

Bay

Taxa	Average abundance	Contribution %	Cumulative contribution %
Oithona nana	452.27	26.36	26.36
Oncaeid copepods	567.47	19.1	45.47
Bivalvia larvae	270.93	15	60.47
Euterpina acutifrons	177.07	10.81	71.28

Penilia avirostris	490.67	8.65	79.93
Paracalanus parvus	110	4.26	84.2
Gastropoda larvae	74.67	4.13	88.33
Centropages kroyeri	61.6	2.91	91.24

Harbour

Taxa	Average abundance	Contribution %	Cumulative contribution %
Oithona nana	624.83	29.35	29.35
Oncaeid copepods	256.53	26.74	56.09
Euterpina acutifrons	201.96	11.16	67.25
Penilia avirostris	363.47	9.83	77.08
Acartia clausi	98.86	4.87	81.95
Bivalvia larvae	152.18	4	85.95
Oikopleura longicauda	51.56	2.28	88.24
Gastropoda larvae	71.82	2	90.23

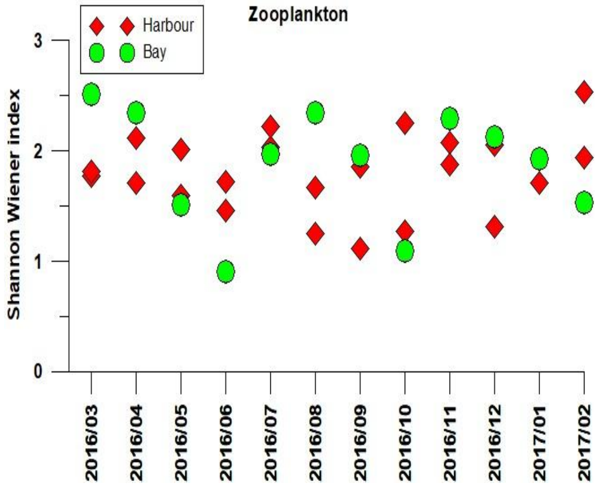


Figure 13. Zooplankton taxa richness in the sampling stations during the investigated period (March 2016 to February 2017).

Ichthyoplankton

During the investigated period, a total of 30 ichthyoplankton taxa with 22 taxa recorded in the Bay area and 16 taxa in the harbour area (Appendix III), belonging to 17 families and 24 genus were found. In addition to the aforementioned, 6 species remained undetermined due to the lack of adequate literature, or due to insufficient degree of accuracy in the determination process.

Dominant species during the spring were *Engraulis encrasicolus* and *Diplodus annularis*, while total abundance for all species ranged from 4 to 27 eggs/larvae/m^2 of sea surface. During the summer period, the abundance was higher, especially for *E. encrasicolus*, *D. annularis*, *Serranus hepatus* and *Scomber japonicus*. Total abundance of ichthyoplankton ranged from 4 to 114 eggs/larvae/m^2 with maximum value of 168eggs/larvae/m^2 in August for all investigated period (Fig. 14). Autumn was characterized by the spawning of similar species as in the summer, with a moderate decrease in spawning intensity, and with dominance of *E. encrasicolus* and *S. japonicus*. Total abundance ranged from 4 to 43 eggs/larvae/m^2. During the winter, only few species were present in plankton samples, with very low spawning intensity that ranged from 4 to 8 eggs/m^2. It is worth mentioning that during December 2016, which is not the standard spawning period, we registered anchovy eggs at moderate abundances (4 eggs/m^2) in the Bay area (Fig. 14).

Detailed analyses of species richness and abundance in the harbour area compared to the Bay area showed no significant differences, with exception of anchovy early life stages and the dominance of this species in all months of investigation, especially in August 2016 which caused statistically significant differences among areas (Fig 15).

Comparative analysis of the results of the presence and abundance of taxa in the investigated areas are given in the Figures 15, 16 and 17.

Ichthyoplankton biodiversity

Diversity indices ranged from 0 to 1.4920 for Shannon Wiener index and showed non-significant difference among sites (ANOVA, p=0.1773) (Fig. 16). The highest value of diversity index was noted in July 2016 at the Bay area. Analysis of the composition of ichthyoplankton taxa in both harbour and Bay area, showed that April 2016 and July 2016 are periods with the greatest number of taxa and the highest species richness. During the spring, eight different taxa were found at all three stations while during summer period eight taxa were noted at one, referent station.

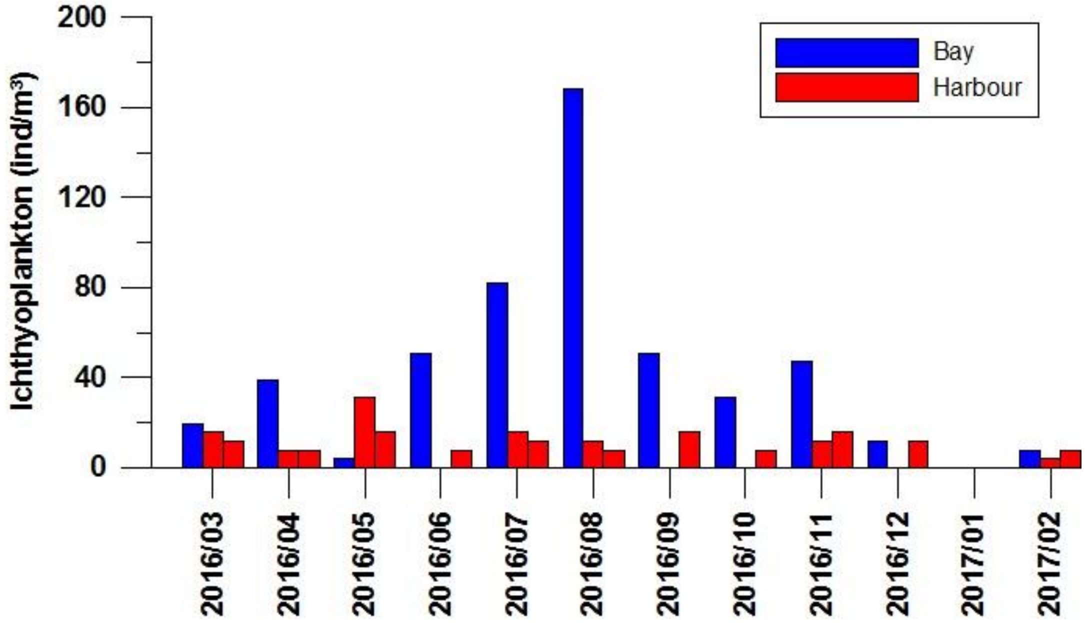


Figure 14. Abundance values of ichthyoplankton in the sampling stations during the investigated period (March 2016 to February 2017).

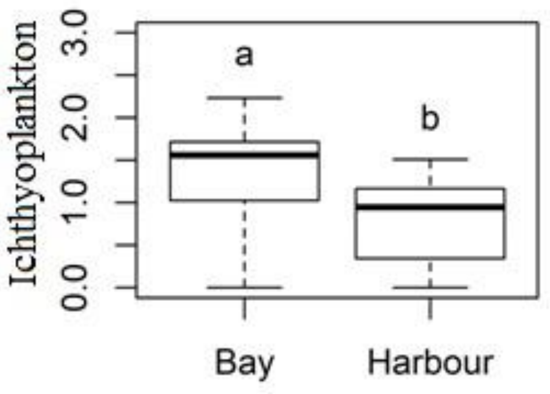


Figure 15. Mean value of the abundance of main ichthyoplankton groups in the sampling areas. Different letters above boxes denote significant differences ($p<0.05$, one-way ANOVA: TukeyHSD test).

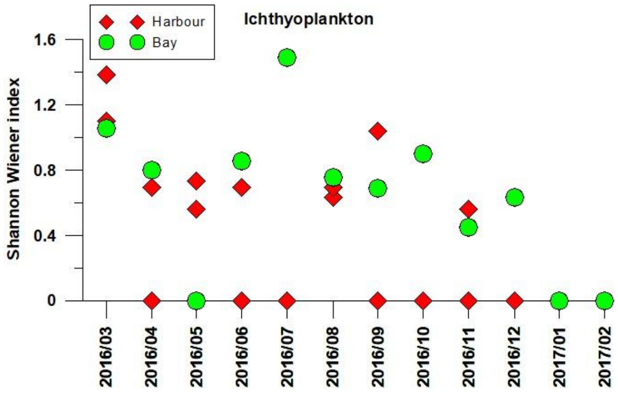


Figure 16. Ichthyoplankton taxa richness in the sampling stations during the investigated period (March 2016 to February 2017).

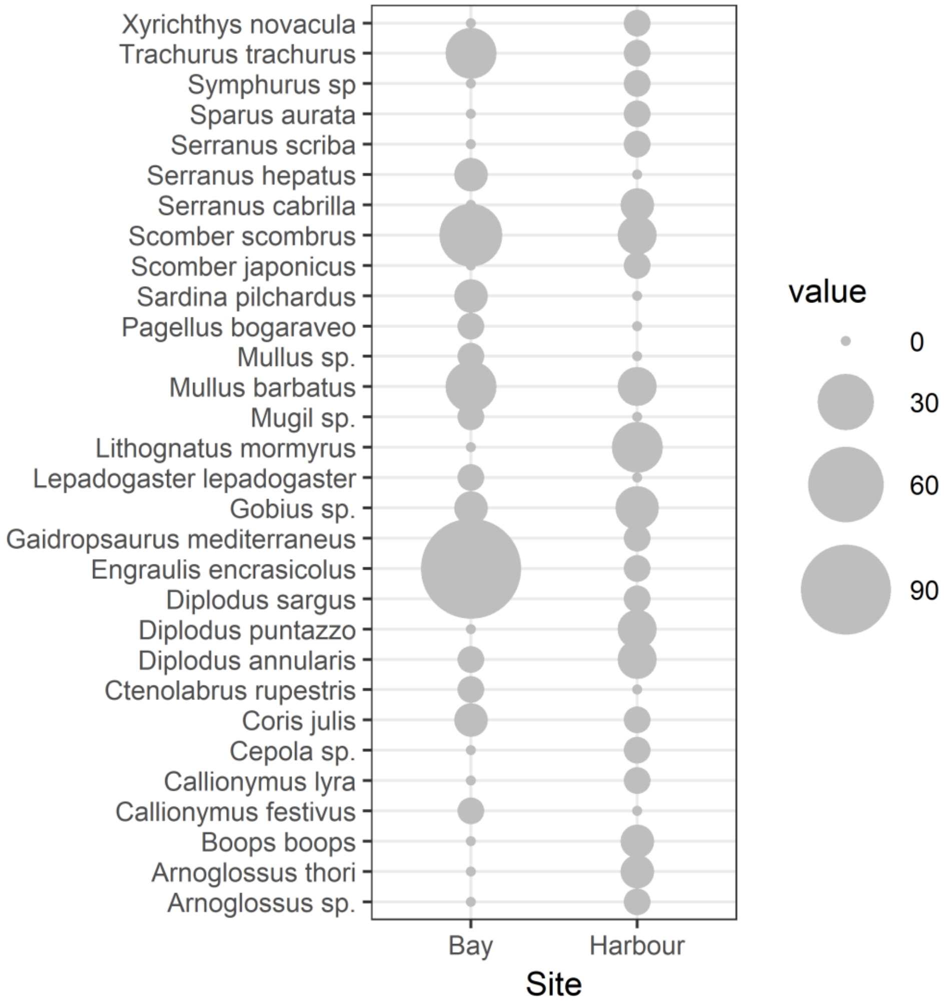


Figure 17. Ichthyoplankton taxa composition – comparative overview in the Bay and the harbour areas (ind/m^2).

Food-web relationship

SEM models uncovered that the strength of links in the food web network has markedly changed among sites and has displayed an increase of significant interactions in the Bay area (Fig. 18, Table 1). In the Bay area and harbour area correlation of phytoplankton groups (dinoflagellates and coccolithofores) and temperature was significantly positive due to its higher value in warmer period. Correlation with salinity showed some differences between sites.

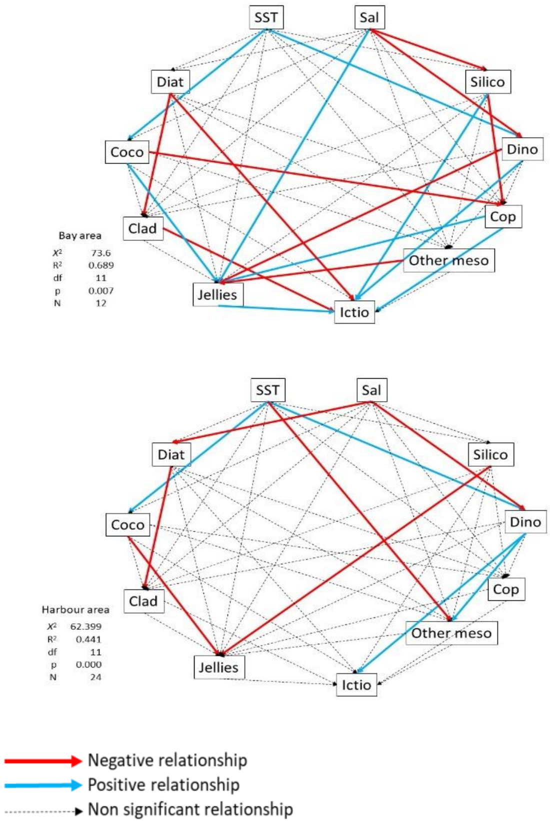


Figure 18. Path diagram showing significant positive (blue, thick lines), negative (red, thick lines) and non-significant (dashed lines) interconnections between hydroclimate (SST and salinity) and plankton components. Jellies include Hydromedusae, Ctenophora, Siphonophorae. Other mesozooplankton include Pteropoda, Appendicularia, Chaetognatha, Tahliacea, Larvae, Decapoda larvae.

The main food drivers in the Bay area for zooplankton are diatoms for cladoceran species, and silicoflagellates and coccolithofores for copepods. Jellies showed significant negative correlation with dinoflagellates and other mesozooplankton groups while positive significant correlation is noted between jellies and coccolithofores and copepods. In the harbour area weaker food web connection was presented. Ichthyoplankton was strongly coupled to jellyfish, copepods, silicoflagellates and dinoglagellates in the Bay area. In contrast, dinoflagellates abundance was the only food item associated with ichthyoplankton in the harbour area.

DISCUSSION

Closed coastal systems such as harbours are excellent test areas to observe the effects of anthropogenic disturbance on the food web functioning (Buyukates, 2010). Given that the analysis of hydrographical parameters did not show any significant differences, investigated sites can be seen as a part of a whole, relatively homogeneous system. While water temperature was typical for the months in which the samples were collected, water salinity showed a high influence of freshwater during October, which is associated with positive impacts on productivity (Drakulović *et al.*, 2017). Accordingly, during this period we found the maximum concentration of chlorophyll *a* (as a proxy of phytoplankton biomass). Chlorophyll *a* concentration is often higher after rainfall episodes, particularly if the rain has flushed nutrients into the water column (Drakulović *et al.*, 2016, Kraus *et al.*, 2016, Đurović *et al.*, 2018). Phytoplankton is very sensitive to the changes in the environment and therefore, provides good insight into water quality before it becomes visible on higher trophic levels and the negative effects of eutrophication begin to be noticeable (Brettum & Andersen, 2005). Mean abundance of phytoplankton was parallel to chlorophyll *a* concentration, with the exception of the abundance peak registered in June. This temporal decoupling was likely caused by the specific phytoplankton community structure during June (Nusch & Palme, 1975), the size frequency distribution of the algal cells (Watson & McCauley, 1988), and by the seasonal shifts within the plankton community (Vanni *et al.*, 1993). During this month, phytoplankton abundance in the Bay area was dominated by species from genus *Pseudo-nitzschia*. The presence of diatom species from the *Pseudo-nitzschia* genus warns on the possibility of producing domoic acid, since their abundance was higher in comparison to other toxic species. Ujević *et al.* (2010) stated that *Pseudo-nitzschia* spp. was widely distributed across the Adriatic Sea during both warm and cold climate conditions within the phytoplankton community throughout the investigated period. Although the highest value of this genus was registered in the Bay area, their presence is evident throughout the investigated period in the harbour area. Similar results, i.e. diatoms dominance throughout the annual cycle was noted in Boka Kotorska Bay (Drakulović *et al.*, 2012; Krivokapić *et al.*, 2018). Diatoms dominance has been previously recorded in the northern Adriatic Sea (Viličić *et al.*, 2009) and in the eastern part of Adriatic (Bužančić *et al.*, 2016). Dominant diatom species are characterized for nutrient enriched area (Mochemadkar *et al.* 2013; Revelante *et al.*, 1980). In turn, the total number of phytoplankton taxa was in concordance with data previously recorded in Tivat Bay (Drakulović *et al.*, 2012).

Minimal values of diversity indices were recorded in period when higher growth of some phytoplankton species was noted, during the summer at referent site with predomination of species from genus *Pseudo-nitzschia*. In contrast, the highest indexes were noted during the winter. Result coincided with previous research of Boka Kotorska Bay (Drakulović *et al.*, 2012) and the northern Adriatic (Bosak *et al.*, 2009) in which the highest value of diversity indexes was noticed when abundance of phytoplankton was lower.

Regarding the mesozooplankton community, copepods were the most abundant group through all investigated period. Copepods dominate zooplankton biomass especially in estuaries and coastal regions (Leandro *et al.*, 2007; Marques *et al.*, 2009). Copepods are significant consumers on microphytoplankton and play a key role in the diet of juvenile stages of many fish species (Pestorić *et al.*, 2016). Thus, they represent the most efficient way of transporting energy from the lower to the higher trophic levels (Howlett, 1998). Cyclopoida, Oncaeaidae and Oithonidae dominated mesozooplankton community in both areas. This is in accordance with previous investigations carried out with fine mesh size nets which highlighted the importance of small copepod species in structuring coastal ecosystem dynamics (Pestorić *et al.*, 2016; Kršinić & Lučić, 1998; Calbet *et al.*, 2001). The investigated area is exposed to wide environmental fluctuations caused by the influence from the land and human activities. This environmental variability causes rapid response of individual species as well as a high fluctuation in zooplankton density. Accordingly, the magnitude of zooplankton abundance varied widely during our study (the maximum was twenty times higher than the minimum value) and it is in concordance with the variability recorded during the previous investigations (Pestorić *et al.*, 2016). Similarly, the total number of zooplankton taxa found during the investigated period coincided with the previous research in the Tivat Bay (Pestorić *et al.*, 2016). Variability of diversity in the northern Adriatic (Cataletto *et al.*, 1995) and areas of the eastern Adriatic coast, such as the Bay of Kaštela (Vidjak *et al.*, 2006), the Gulf of Trieste (Camatti *et al.*, 2008) and the Neretva Canal (Vidjak *et al.*, 2007) are in line with the Shannon index values obtained in our research. Also, range of diversity indices is in accordance with values noted in southern Adriatic (Barbone *et al.*, 2014).

Qualitative composition of ichthyoplankton showed that among the harbour area species diversity remains relatively high, although a total intensity of spawning was relatively low. The shallow conditions in the harbour area likely limited the spawning of many species. Species diversity was relatively high during the whole period of investigation, especially when compared with similar studies which were conducted in much wider areas (Tsikliras & Koutrakis, 2011; Marques *et al.*, 2006; Avsar & Mavruk, 2011).

The influence of sea currents and other water movements on the position of ichthyoplankton is of crucial importance for understanding and definition of possible centres of spawning, and the fishery oceanography is a direction in which further research should be directed so the spatial and temporal occurrence of plankton communities can be studied adequately. However, in the very limited area of marina Porto Montenegro, the surface currents are very slow, especially during the summer season, so they do not have a decisive role in the position of ichthyoplankton. Due to the significant diversity of species, but also the dominance of certain species whose abundance was significant (*E. encrasicolus, D. annularis, S. hepatus, S. japonicas*), this research confirmed previous observation that the area of Boka Kotorska Bay is an adequate area for the spawning and nursery for several pelagic fish species (Mandić *et al.*, 2013).

Taken together, the monitoring of water quality for recreation, the establishment and functioning of shellfish farms, the discharge of active sewage in the Boka Kotorska Bay area, the impact of different pollutants in the area of the Bay (PAP RAC document), but also the growing development of nautical and cruise tourism (number of ships), highlight the notion that the ecological status of the area is still at a good level. However, the growing number of threats can lead to unpredictable consequences for the marine underwater world, especially for the most vulnerable developmental stages of marine organisms that are critical in the food chain.

Food webs are a useful framework to assess the magnitude and importance of trophic relationships in an ecosystem (Link, 2002). To understand food web structure and dynamics, knowledge of limiting factors for different organisms is crucial (Mohammadian *et al.*, 1997). The plankton food web in this study is strongly influenced by spatial variability in presence and abundance of predator taxa such as gelatinous groups and ichthyoplankton taxa. Statistically significant difference in abundance of ichthyoplankton taxa and hydromedusae among sites and their smaller abundance and rarely presence in the harbour area is the reason of weaker food web links in the harbour area.

In contrast to phytoplankton and zooplankton, whose diversity and spatial distribution are driven by temperature and salinity, inter-species interaction, affinity for aggregation with specific water masses, spatial distribution and abundance of ichthyoplankton is significantly dependent on the aggregation of the adult population, rates of mortality, and physical processes in the sea that affect the position and retention of ichthyoplankton. Unfavourable conditions for adult fish aggregation in the harbour area can be the reason why statistical analyses showed visible differences in ichthyoplankton spatial distribution compared to phytoplankton and zooplankton species.

To better understand the importance of plankton both as a food source and as a driving mechanism of the lower food web dynamics in such systems, detailed research should be conducted. It is important to continually monitor these kinds of systems to detect any significant changes due to human induced activities (Buyukates, 2010)

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APPENDIX I List of phytoplankton taxa (+ presence in the samples; - absence in the samples)

Station	**Bay**	**Harbour**
Diatoms		
Achnanthes brevipes	-	+
Amphiprora sulcata	+	-
Amphora ostrearua	+	-
Asterionellopsis glacialis	+	+
Asterionellopsis glacialis	-	+
Asterolampra marylandica	+	-
Asteromphalus flabellatus	+	+
Bacteriastrum hyalinum	+	+
Cerataulina pelagica	+	+
Ch.affinis	+	+
Ch.curvisetus	-	+
Ch.divergens	-	+
Ch.diversus	+	+
Ch.lorenzianus	+	-
Ch.convolutus	+	+
Chaetoceros spp	+	+
Cocconeis scutellum	+	+
Coscinodiscus perforatus	+	-
Coscinodiscus spp.	+	+
Cyclotella spp.	-	+
Cylindrotheca closterium	-	+
Dactyliosolen blavyanus	-	+
D. fragilissimus	+	+
Detonula pumila	+	+
Diploneis bombus	+	+
Entomoneis pulchra	-	+
Guinardia striata	+	+
G. flaccida	+	+
Gyrodinium fusiforme	+	-
Hemiaulus hauckii	+	+
H. sinensis	+	+
H.zoodiacus	+	-
Hemiaulus spp.	-	+
Leptocylindrus danicus	+	+
L. mediterraneus	+	+
L. minimus	-	+
Licmophora flabellata	+	+
L. paradoxa	+	+
Lioloma pacificum	+	+
Melosira bnummulides	+	+
Navicula spp.	+	+
Nitzschia longissima	+	+
N. incerta	+	+
Pleurosigma elongatum	+	+
P. angulatum	+	+
P. formosum	+	+
Proboscia alata	+	+
Pseudo-nitzschia spp.	+	+

Pseudosolenia calcar avis	+	+
Rhizosolenia setigera	+	+
Rh. imbricata	-	+
Thalassionema frauenfeldii	+	+
Th. nitzschioides	+	+
Thalassiosira rotula	+	+
Thalassiosira spp.	+	+
Trieres mobiliensis	+	-
Dinoflagellates		
Alexandrium spp.	+	-
Ceratoperidinium falcatum	-	+
Dinophysis acuminata	+	+
D. acuta	-	+
D. caudata	+	+
D. fortii	-	+
D. mitra	+	-
Diploneis lenticula	+	+
Diplopsalis spp.	-	+
Gonyaulax digitale	+	+
G. polygramma	+	+
G. spinifera	+	-
Gonyaulax spp.	+	+
Gyrodinium fusiforme	+	+
Gymnodinium spp.	+	+
Gyrodinium fusiforme	+	+
Gyrodinium spp.	+	+
Hermesinum adriaticum	+	+
Lingulodinium polyedra	+	+
Oxytoxxum scolopax	+	+
Ornitocercus magnificus	-	+
Oxytoxum reticulatum	+	-
O. sceptrum	+	+
Oxytoxum spp.	+	-
O. tesselatum	+	-
Phalacroma rotundatum	+	+
Prorocentrum cordatum	+	+
P. micans	+	+
P. scutellum	+	-
P. triestinum	+	+
Protoperidinium conicum	+	+
P. crassipes	+	+
P. pellucidum	+	+
P. diabolum	+	+
P. divergens	+	+
P. globulum	+	-
P. pallidum	+	-
P. pellucidum	-	+
P. steinii	+	+
Protoperidinium spp.	+	+
P. tuba	+	+
Pyrocytis lunula	+	+
Scrippsiella spp.	+	+
Tripos carriense	+	-
T. furca	+	+
T. fusus	+	+
T. horridum	+	+
T. kofoidii	+	+
T. macroceros	+	+

T. massiliense	-	+
T. muelleri	+	+
T. ranipes	+	-
Tryblionella compressa	+	+
Coccolithophores		
Calciosolenia brasiliensis	+	+
Calyptrosphaera oblonga	+	+
Helicosphaera walichii	+	+
Rhabdosphaera tignifer	+	+
Syracosphaera pulchra	+	+
Silicoflagellates		
Octactis octonaria	+	+
Dictyocha fibula	-	+

APPENDIX II List of zooplankton taxa (+ presence in the samples; - absence in the samples)

Station	Bay	Harbour
Protozoa		
Noctiluca scintillans	+	+
Hydromedusae		
Podocorynoides minima	+	+
Lizzia blondina	+	-
Obelia spp.	-	+
Helgicirrha schulzei	+	-
Aglaura hemistoma	+	+
Solmaris sp	+	+
Siphonophorae		
Muggiaea kochii	-	+
Muggiaea attlantica	+	+
Sphaeronectes koellikeri	+	+
Ostracoda	+	+
Cladocera		
Penilia avirostris	+	+
Evadne spinfera	+	+
Evadne tergestina	+	+
Evadne nordmanni	+	-
Podon intermedius	+	+
Pleopis polyphemoides	+	+
Copepoda		
Calanus helgolandicus	+	+
Paracalanus parvus	+	+
Mecynocera clausi	+	+
Clausocalanus juv.	+	+
Clausocalanus arcuicornis	+	+
Clausocalanus jobei	+	+
Ctenocalanus vanus	+	+
Paraeuchaeta hebes	+	+
Diaixis pygmoea	-	+
Centropages typicus	+	-
Centropages kroyeri	+	+
Isias clavipes	+	+
Temora stylifera	+	+
Labidocera wollostoni	+	+
Candacia giesbrechti	+	+
Acartia clausi	+	+
Oithona nana	+	+
Oithona plumifera	-	+
Oithona similis	+	+
Onceaeidae like	+	+
Euterpina acutifrons	+	+
Microsetella spp.	+	+
Macrosetella sp.	+	+
Sapphirina spp.	+	+
Corycaeidae spp.	+	+
Pteropoda		
Limacina trochiformis	-	+
Limacina bulboides	+	+
Creseis acicula	+	-
Creseis virgula	+	+
Appendicularia		
Oikopleura longicauda	+	+
Oikopleura fusiformis	+	+
Fritillaria borealis	-	+

Fritillaria pellucida	-	+
Fritillaria haplostoma	+	+
Fritillaria sp.	-	+
Oikopleura sp.	+	+
Chaetognatha		
Mesosagitta minima	+	-
Parasagitta setosa	+	+
Flaccisagitta enflata	+	-
Thaliacea		
Doliolidea	-	+
Thalia democratica	+	+
Larvae		
Bivalvia	+	+
Gastropoda	+	+
Polychaeta	+	+
Ophiopluteus	+	+
Bipinaria	+	+
Ova Engrauslis	-	+
Ova pisces	+	+
larvae *Pisces*	+	+
larvae *decapoda*	+	+

APPENDIX III List of ichthyoplankton taxa (+ presence in the samples; - absence in the samples)

Station	**Bay**	**Harbour**
Arnoglossus sp.	-	+
Arnoglossus thori	-	+
Boops boops	-	+
Callionymus festivus	+	-
Callionymus lyra	-	+
Cepola sp.	-	+
Coris julis	+	+
Ctenolabrus rupestris	+	-
Diplodus annularis	+	+
Diplodus puntazzo	-	+
Diplodus sargus	+	+
Engraulis encrasicolus	+	+
Gaidropsaurus mediterraneus	-	+
Gobius sp.	+	+
Lepadogaster lepadogaster	+	-
Lithognatus mormyrus	-	+
Mugil sp.	+	-
Mullus sp.	+	-
Mullus barbatus	+	+
Pagellus bogaraveo	+	-
Sardina pilchardus	+	-
Scomber japonicus	-	+
Scomber scombrus	+	+
Serranus hepatus	+	-
Serranus cabrilla	-	+
Serranus scriba	-	+
Sparus aurata	-	+
Symphurus sp	-	+
Trachurus trachurus	+	+
Xyrichthys novacula	-	+

Promjene u distribuciji zajednica planktona u marini Porto Montenegro (južni Jadran)

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SAŽETAK

Podaci planktona (fitoplanktona, zooplanktona i ihtioplanktona) su analizirani od marta 2016. do februara 2017. godine u luci "Porto Montenegro" i na referentnoj poziciji (područje Tivatskog zaliva) kako bi se utvrdile moguće razlike u rasprostranjenosti, sastavu i raznovrsnosti planktonskih grupa između ispitivanih oblasti. Za razliku od fitoplanktona i zooplanktona, čija raznovrsnost i prostorna rasprostranjenost značajno zavise od temperature i saliniteta (fitoplankton), interakcije među vrstama, afiniteta za grupisanje po specifičnim vodenim slojevima (zooplankton); prostorna dinamika ihtioplanktona značajno zavisi od grupisanja odraslih populacija, stope smrtnosti i fizičkih procesa koji utiču na položaj i zadržavanje organizama. Juvenilni stadijumi i dominantnost inćuna u svim mjesecima istraživanja, posebno u avgustu, na referentnoj poziciji uzrokovali su značajnu razliku između oblasti istraživanja. Utvrđeno je da su nepovoljni uslovi za grupisanje odraslih riba u području marine "Porto Montenegro" mogli biti razlog statističke razlike u prostornoj distribuciji ihtioplanktona u odnosu na područje zaliva, dok fitoplankton i zooplankton nisu pokazali značajne razlike među oblastima istraživanja.

Ključne riječi: fitoplankton, zooplankton, ihtioplankton, brojnost, indeksi diverziteta