

Influence of Some Environmental Variables on the Zooplankton Community of Aguieira Reservoir (Iberian Peninsula, Portugal): Spatial and Temporal Trends

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AMG and PSS designed the study, performed the statistical analysis, wrote the protocol and wrote the manuscript. Author RP managed the literature searches and reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This research was aimed to assess the spatial and temporal trends in the zooplankton community of Aguieira reservoir at the Mondego catchment (Iberian Peninsula, Portugal) in response to some environmental variables. A total of 24 zooplankton as well as water samples were collected in the months of March (spring), May (early summer), September (late summer) and December (winter) of 2010 and 2011. The data from these samples was obtained by the Descriptive (range, percentage) and multivariate statistics (Non-metric Dimensional Scaling (n-MDS), Bray-Curtis distance,

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Canonical Correspondence Analysis (CCA). Altogether twenty-three zooplankton species were recorded which included Rotifera (12), Cladocera (8) and Copepoda (3). In terms of abundance, Rotifera (*Keratella* spp. and *Polyarthra* sp.) dominated in May and September, while Copepoda (*Copidodiaptomus numidicus* and *Tropocyclops prasinus*) overtook in December and March. Cladocera was the least abundant taxon of which *Daphnia longispina* and *Bosmina coregoni* has shown abundance from December-March whereas *Chydorus sphaericus*, *Ceriodaphnia pulchella* and *Diaphanosoma brachyurum* from May-September. Results of n-MDS exhibited similar spatial and inter-annual patterns with environmental variables and zooplankton community. However, there were differences between the samples collected in the months of March/December and May/September in both the years. Results of CCA revealed water temperature and algal biomass as the main environmental gradients that influenced the zooplankton community. Since some of the observed changes in the zooplankton composition might be influenced by other complex abiotic/biotic interactions. Therefore this study suggests further research to understand the complexity of the interactions between biological, environmental and climatic parameters of the reservoir. Nevertheless, understanding the dynamics and nature of zooplankton communities is crucial for the implementation of good management practices for reservoirs.

Keywords: Zooplankton; Cladocera; Copepoda; Rotifera; reservoir; Iberian Peninsula; Portugal.

1. INTRODUCTION

Zooplankton community is the result of colonisation followed by the species selection processes. Both, colonisation and selection depend on physical and chemical conditions of water in the reservoirs. Water quality is directly influenced by watershed geology, climate and by the degree of human disturbance [1]. Therefore, understanding the dynamics and nature of zooplankton communities may render an important source of information to implement correct management practices. This will in turn maintain water quality of the reservoirs in a perspective of multiple-use approach of these ecosystems. Zooplankton, despite of not being recognised as a biological quality element by the European Union Water Framework Directive, they show quick responses to environmental changes and so regarded as a valuable indicator to evaluate ecosystem integrity. This fact is evident from the zooplankton position in the food web. They form a crucial link in the energy transfer to higher trophic levels being a keystone in ecosystem functioning. Moreover, its size, structure, reproduction and survival, among other characteristics, are affected not only by the environmental variables (e.g., water temperature), but also by both top-down (fish or invertebrates) and bottom-up (nutrient level and phytoplankton) controls. Thus, the zooplankton community structure reflects the variability of environmental factors, disturbance events and ecosystem resilience [2-8].

The present paper is focused on the zooplankton community patterns in the Aguieira reservoir, an impoundment built on the River Mondego

catchment. The aim of this research was: (1) to characterize zooplankton community and (2) to assess how zooplankton community responds to the variations of several environmental parameters.

2. MATERIALS AND METHODS

2.1 Study Site

Aguieira Reservoir (40°19'53, 83°N; 8° 11'47, 76°W) with an altitude of 441 m is located in the Iberian Peninsula, on the Mondego River catchment in Portugal (Fig. 1). In the reservoir region, the climate is influenced by the Mediterranean with warm, dry summers and mild winters. The area of the reservoir is 2000 ha and its total capacity is 423030 x 103 m³. Maximum depth is about 50 m. This reservoir was filled for the first time in 1981, and it is used mainly to generate hydro electrical power and to provide urban water supply. The catchment is occupied with intensive forestry, agriculture, livestock production and by several medium sized towns. The main industrial activities are olive oil and textiles. Further information concerning this reservoir can be found in Anonymous [9].

2.2 Field Sampling and Laboratory Analysis

A total of 24 zooplankton as well as water samples were collected in the months of March (spring), May (early summer), September (late summer) and December (winter) in the years 2010 and 2011 at three sampling sites: P1, P2 and P3 (Fig. 1).

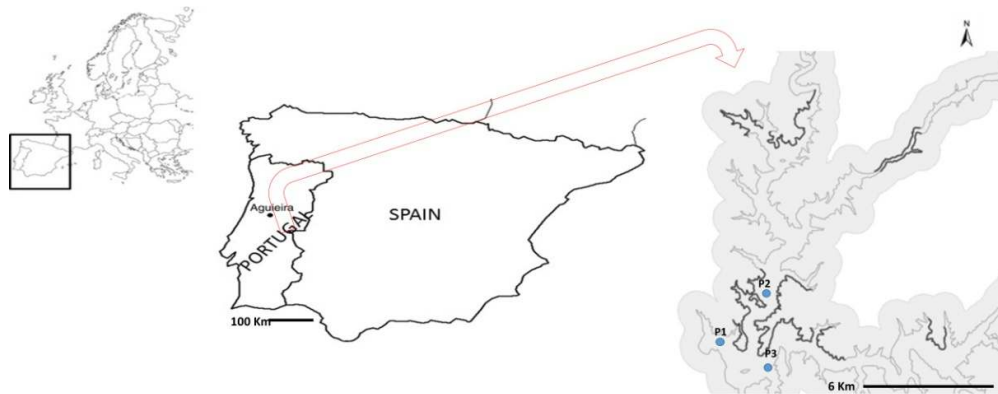


Fig. 1. Agueira Reservoir location and sampling sites
Reservoir's map was adapted from [9]

Chlorophyll a concentrations (CHL a) were calculated from water samples taken with a van Dorn bottle at 2 m intervals in the euphotic zone (the extension of euphotic zone was considered to be about twice the Secchi depth). Chlorophyll a concentrations were determined spectrophotometrically after overnight extraction in 90% acetone [10]. Water temperature, pH and conductivity were determined "in situ" using a multiparameter probe (YSI 6820). Water transparency was estimated as Secchi disk depth (20 cm diameter black and white disk). Zooplankton was collected on each sampling date and site by taking two vertical hauls using a 64 μ m mesh size Wisconsin type net equipped with a flow meter. Hundred litres of water were filtered per each haul. Samples were concentrated to a volume of 100 ml. Animals were anaesthetized with carbonated water and preserved in sugar-saturated formaldehyde (4% final concentration). Depending on the density, zooplankton in 5, 10, 20 ml sub-samples or in total sample, were counted and identified to the genera/species level. Carlson's Trophic State Index (TSI) [11] was computed from Secchi disk transparency (TSI (SD)), and from CHL a concentrations (TSI (CHL)).

2.3 Data Analyses

Non-metric Multidimensional Scaling (n-MDS) was used to determine whether environmental variables and zooplankton community had changed seasonally, yearly and spatially. Bray-Curtis distance was used to measure the dissimilarity between samples. In this method, samples were arranged in a continuum that those close together are similar and those which are far apart are dissimilar. Statistical differences between clusters identified in n-MDS plot were

investigated by a randomization method, ANOSIM [12]. This method employs R statistics to examine the existence of differences between the established groups for each considered factor (groups and differences between sampling sites, seasons and years). To determine the influence of the studied environmental variables on zooplankton composition, a Canonical Correspondence Analysis (CCA) was performed. In both analyses, taxa were included only if they reached a relative abundance larger than 1%. Absolute zooplankton counts were transformed to log (x+1), and rare species were down weighted. In CCA the automatic forward selection procedure by Monte Carlo permutation tests (9999 permutations) was used to remove the redundant environmental variables, allowing the selection of those contributing to the explanation of the whole data set [13].

3. RESULTS

3.1 Environmental Variables

Environmental variables showed similar values during both years in each sampling site (Table 1). Spatial and inter-annual variations in these parameters were not relevant. However, n-MDS ordination (Fig. 2) was able to differentiate two groups: Samples obtained in December and March (winter and spring) from those obtained in May and September (early and late summer) (2D stress: 0.02). ANOSIM test confirmed significant differences between the two groups ($R = 0.829$; $p < 0.001$). The highest values for water temperature, pH, CHL a concentrations were observed in the samples obtained in May and September. Conversely, the highest values of Secchi disk depth were observed in December and March. According to Carlson's Trophic State

Index (the two components together- TSI (SD) and TSI (CHL a), this reservoir was classified as mesotrophic in December and March (the values ranged between 24 and 42 for both components of the index). In May and September, it was eutrophic (values of both components of the index (SD and CHL a reached 57).

3.2 Zooplankton Community

During the sampling period 12 taxa of Rotifera, 8 of Cladocera and 3 of Copepoda were recorded (Table 2). The zooplankton community was dominated in May and September by Rotifera (mainly *Keratella* and *Polyarthra*), whereas Copepoda (mainly *Copidodiaptomus numidicus* and *Tropocyclops prasinus*) were dominant in December and March. Cladocera was the less abundant taxon. It was represented in December and March, mainly by *Daphnia longispina* and *Bosmina coregoni*. Conversely, in May and September by *Chydorus sphaericus*, *Ceriodaphnia pulchella* and *Diaphanosoma brachyurum* (Figs. 3, 4 and 5). n-MDS ordination (Fig. 6) was able to differentiate the occurring shifts between the samples obtained in December and March and those obtained in May and September (2D stress: 0.12). ANOSIM test

confirmed the significant differences between the two groups ($R=0.803$; $p<0.001$).

The diagram depicted on Fig. 7 resulted from CCA analysis applied to the most correlated environmental variables and zooplankton taxa. The ordination space defined by the first two CCA axis accounted for 70% of species-environment relation and represented 45% of the variation in species data. With forward selection and Monte Carlo permutation test, a sub-set of environmental variables that significantly ($p<0.05$) explained the variation in species data was identified. In descending order of significance, the variables included in that sub-set were: water temperature ($P=0.0000$), CHL a ($P=0.004$), Secchi disk depth ($P=0.004$) and conductivity ($P=0.009$). Therefore, some species/genera were found to be associated to the increase of water temperature and of algal biomass (CHL a concentrations). These were all the Rotifera (excepting *Gastropus* sp.) and the Cladocera *Ceriodaphnia pulchella*, *Diaphanosoma brachyurum* and *Chydorus sphaericus*. Whereas, Copepoda and the Cladocera (*Daphnia longispina*, *Bosmina coregoni* and *B. longirostris*) were related to lower water temperature, algal biomass and to the increase in water transparency (higher Secchi disc depth).

Table 1. Minimum-maximum range of environmental variables obtained for 2010 and 2011 from the different sampling sites

Parameter	2010			2011		
	P1	P2	P3	P1	P2	P3
Water temperature (°C)	11.9-23.0	12.2-23.2	12.8-22.8	14.7-25.0	14.2-26.0	13.4-25.3
pH	7.3-9.9	7.2-10.1	7.3-10.0	7.1-9.8	7.2-10.2	7.3-9.7
Conductivity ($\mu\text{S cm}^{-1}$)	70.4-104.5	76.2-100.1	68.8-94.6	64.8-104.5	63.4-102.1	62.0-102.6
Secchi disk (m)	1.5-3.0	1.5-3.0	1.5-3.0	1.2-4.0	1.2-5.0	1.2-5.5
Chlorophyll a ($\mu\text{g L}^{-1}$)	0.4-16.2	0.4-14.2	1.4-15.7	0.5-14.4	0.9-10.7	0.5-5.9

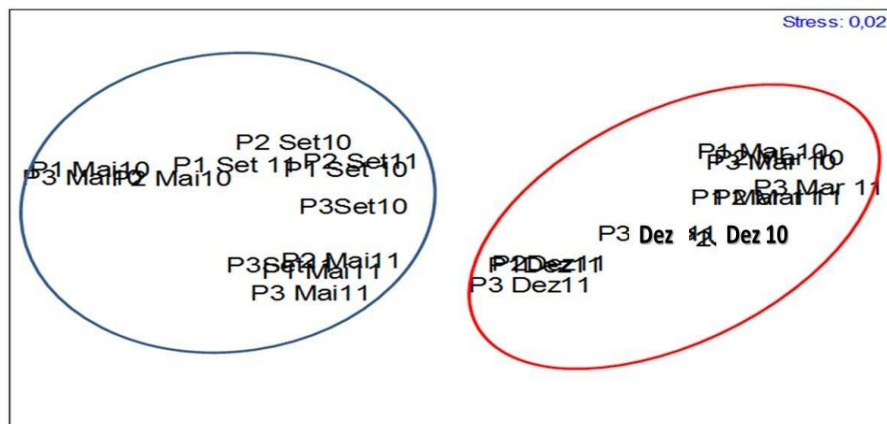


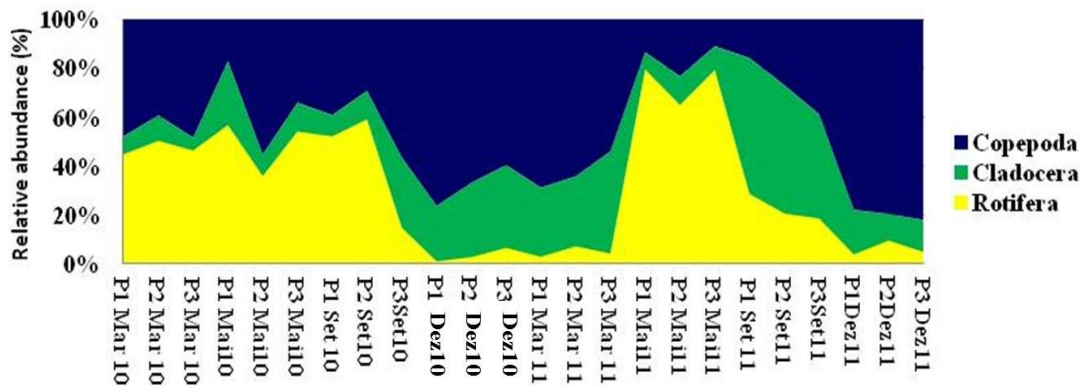
Fig. 2. Results of n-MDS ordination considering environmental variables

Sampling sites: P1, P2, P3

Dez, Mar, Mai, Set: Samples obtained in December, March, May and September, respectively

Table 2. Taxonomic composition of zooplankton community between 2010 and 2011

Rotifera	Cladocera	Copepoda
<i>Asplanchna priodonta</i>	<i>Alona</i> sp.	<i>Acanthocyclops robustus</i>
<i>Brachionus</i> sp.	<i>Bosmina coregoni</i>	<i>Copidodiaptomus numidicus</i>
<i>Conochilus</i> sp.	<i>Bosmina longirostris</i>	<i>Tropocyclops prasinus</i>
<i>Filinia</i> sp.	<i>Ceriodaphnia pulchella</i>	Nauplii
<i>Gastropus</i> sp.	<i>Chydorus sphaericus</i>	
<i>Hexarthra mira</i>	<i>Daphnia longispina</i>	
<i>Keratella cochlearis</i> f. <i>cochlearis</i>	<i>Daphnia parvula</i>	
<i>Keratella cochlearis</i> f. <i>tecta</i>	<i>Diaphanosma brachyurum</i>	
<i>Ploeosoma</i> sp.		
<i>Polyarthra</i> sp.		
<i>Synchaeta</i> sp.		
<i>Trichocerca</i> sp.		

**Fig. 3. Relative abundance (%) of Rotifera, Copepoda and Cladocera in the sampling sites from March to December 2010 and 2011**

4. DISCUSSION

During the period of study, zooplankton community followed a pattern strongly influenced by two gradients. The first was the temporal gradient that is related to temperature, and the other was the trophic gradient, related to algal biomass (CHL a), which ultimately influenced Secchi disk depth (Figs. 4, 5, 6 and 7). A seasonal succession was apparent in this zooplankton community, with species dominating under changing suitable conditions respectively. In March and December (winter and early spring), *Tropocyclops prasinus*, *Copidodiaptomus numidicus*, *Daphnia longispina* and *Bosmina coregoni* were more abundant, and some of them became virtually absent in May and September (early and late summer), being replaced by Rotifera, *Ceriodaphnia pulchella*, *Diaphanosma brachyurum* and *Chydorus sphaericus*, which are more thermophilic and typical for more eutrophic environments [14,15]. This shift was also influenced by algal biomass

and composition: In May and September, phytoplankton community was dominated by Cyanobacteria [16,17(authors' unpublished data)]. The conditions created by late spring and summer temperatures and irradiance combined with a plausible higher level of nutrients must have been provided the ecological optimum for Cyanobacterial dominance [18,19]. It is well known that either because of low nutritional value or by clogging the feeding apparatus or by producing toxins, Cyanobacteria may be important drivers in zooplankton composition and abundance [20-22]. In the presence of Cyanobacteria, zooplankton composition changed frequently, where large Cladocera (such as *Daphnia longispina*) and herbivorous Copepoda (such as *Copidodiaptomus numidicus*) are often replaced by Rotifera and other zooplankters specializing on small particle feeding, whose food preferences are mostly detritus-bacteria [2]. Similar results were observed in other reservoirs influenced by Mediterranean climate [23-26].

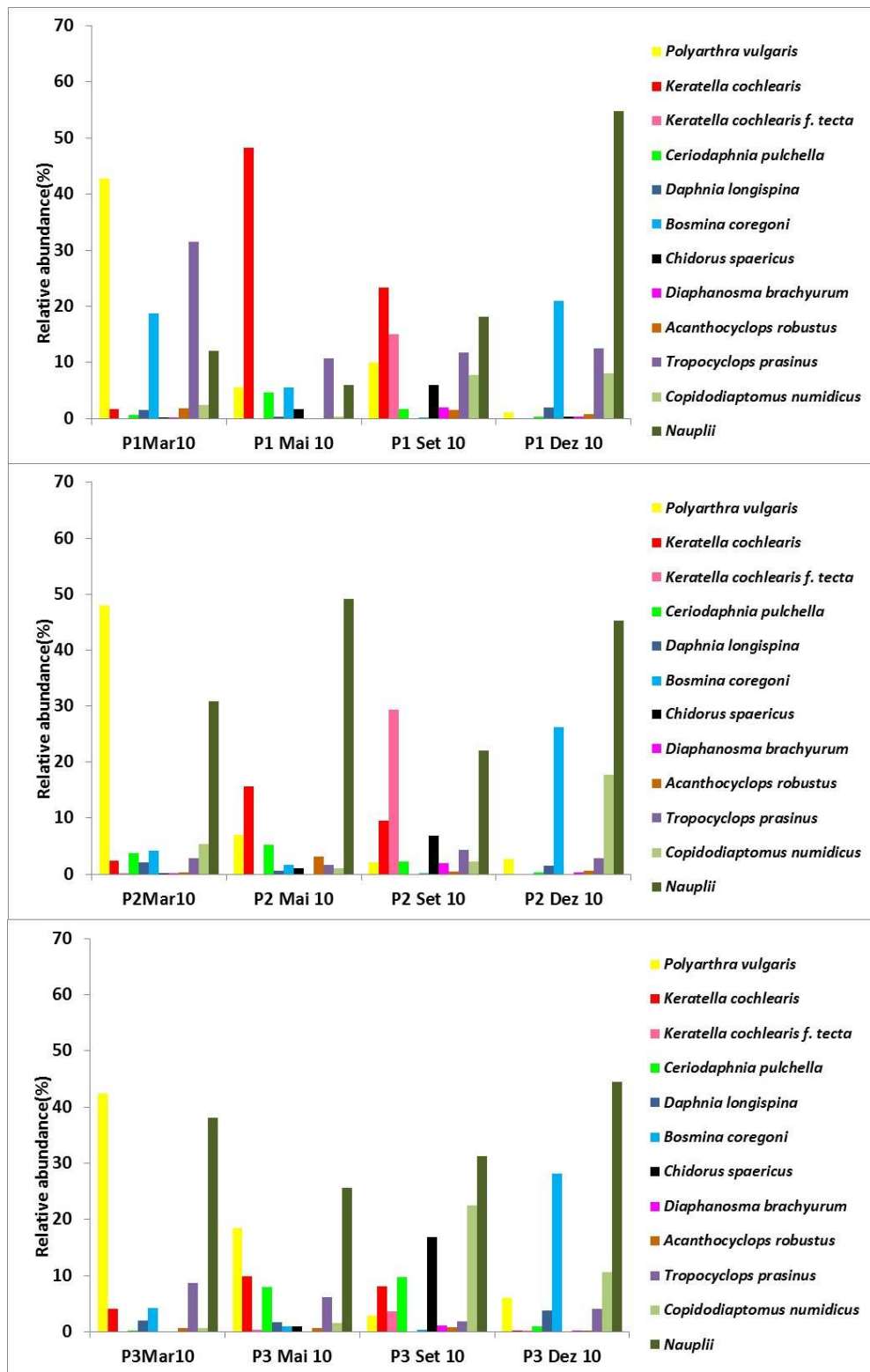


Fig. 4. Spatial-temporal variation of relative abundance and composition of the most abundant zooplankton taxa in March, May, September and December 2010

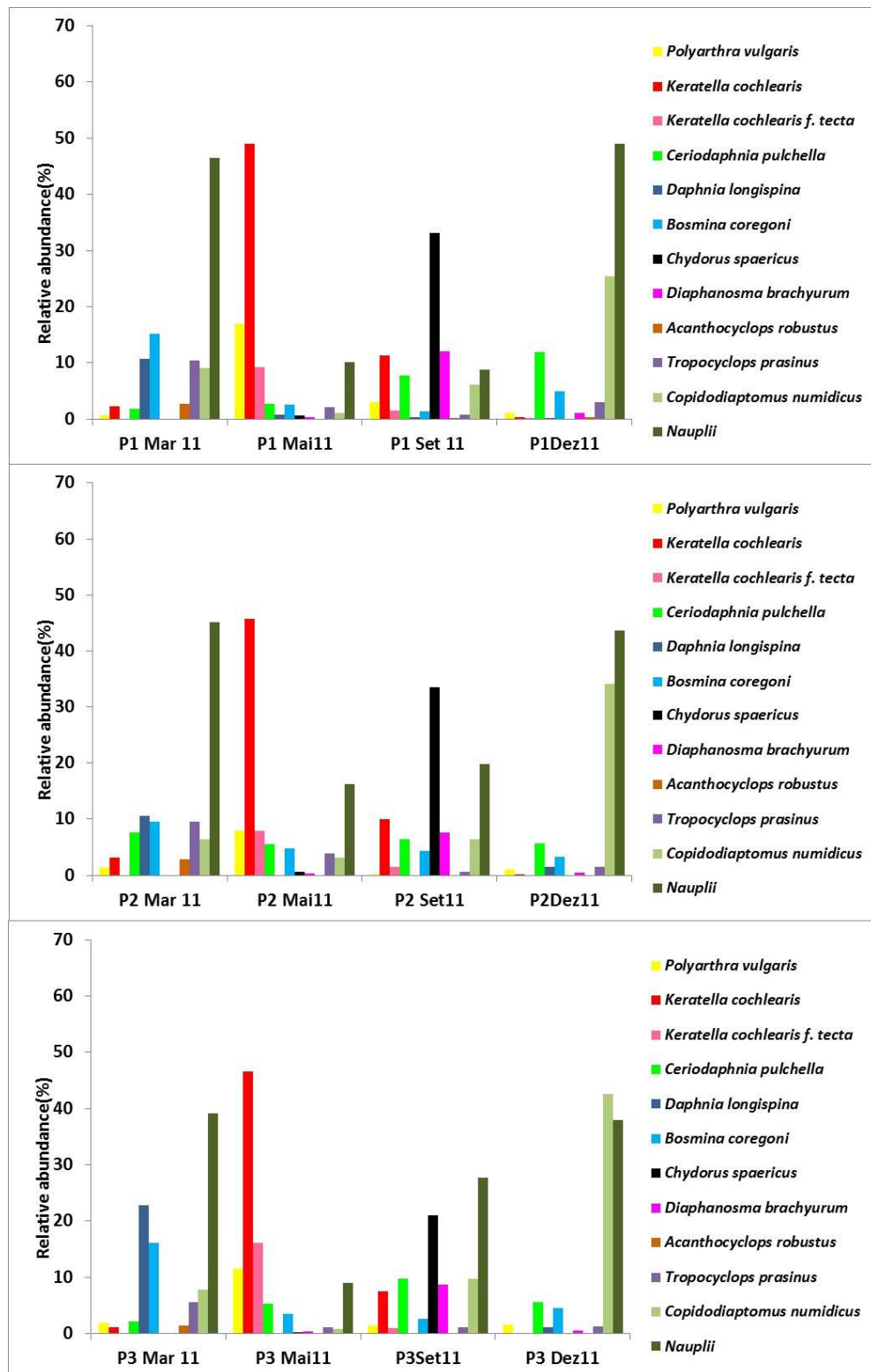


Fig. 5. Spatial-temporal variation of relative abundance and composition of the most abundant zooplankton taxa in March, May, September and December, 2011

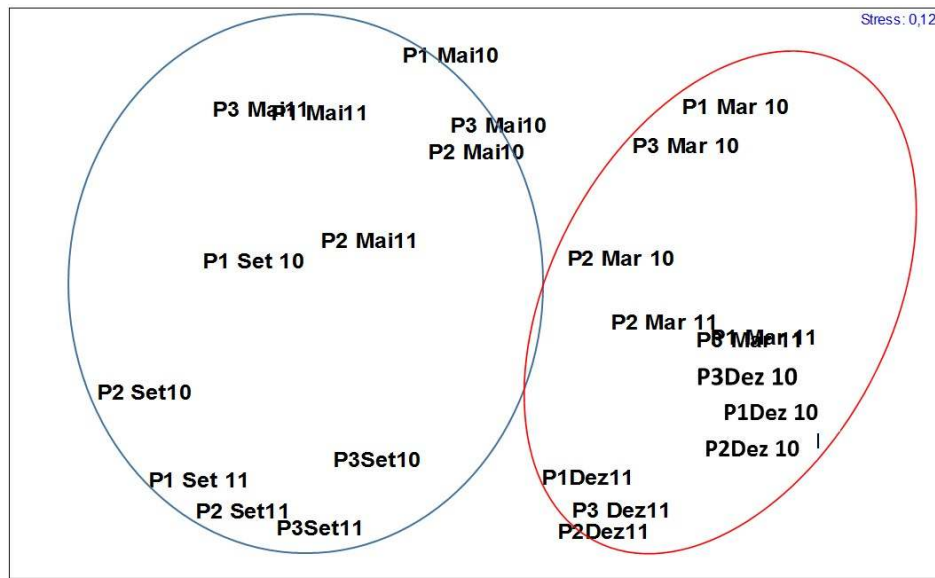


Fig. 6. Results of n-MDS ordination considering zooplankton

P1, P2, P3 - sampling sites.

Dez, Mar, Mai Set-Samples obtained in December, March, May and September, respectively

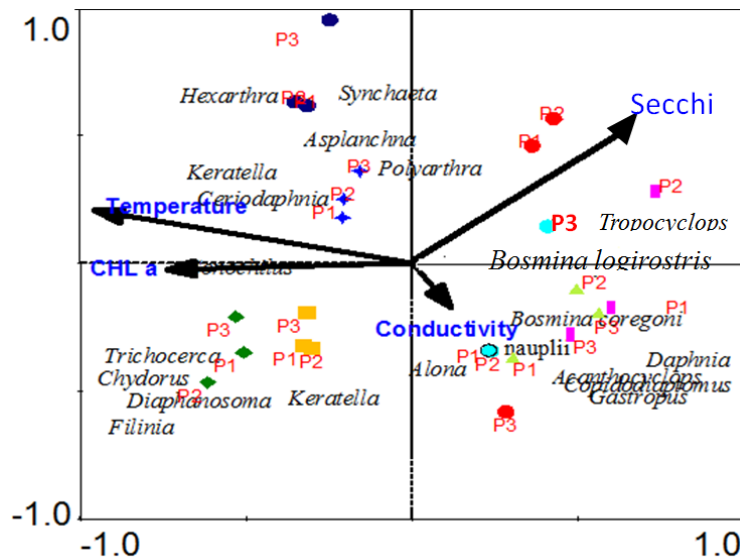


Fig. 7. Results of CCA

Scatters with samples: March 2010 – red circles; May 2010 – blue stars; September 2010 – yellow squares; December 2010 – pink rectangles; March2011 – green triangles; May 2011 – dark blue circles; September 2011 –green diamonds; December 2011– light blue circles

5. CONCLUSION

The preliminary results of the present study suggest that temperature had a direct and strong influence on the zooplankton community patterns. However, a wide range of physical,

chemical and biotic interactions are likely to influence zooplankton abundance and community structure. Therefore, it is necessary to be cautious when relating the observed shifts exclusively with temperature and in the presence of Cyanobacteria. Some of the observed

changes might be influenced by the other complex abiotic/biotic interactions independently of those studied in the present approach. Thus, further research will be required in order to understand the complexity of the interactions between biological, environmental and climatic parameters in this reservoir.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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