

Original Research Article

Zooplankton Community Structure in a Deep Reservoir: Seasonal Trends and Structuring Variables

ABSTRACT

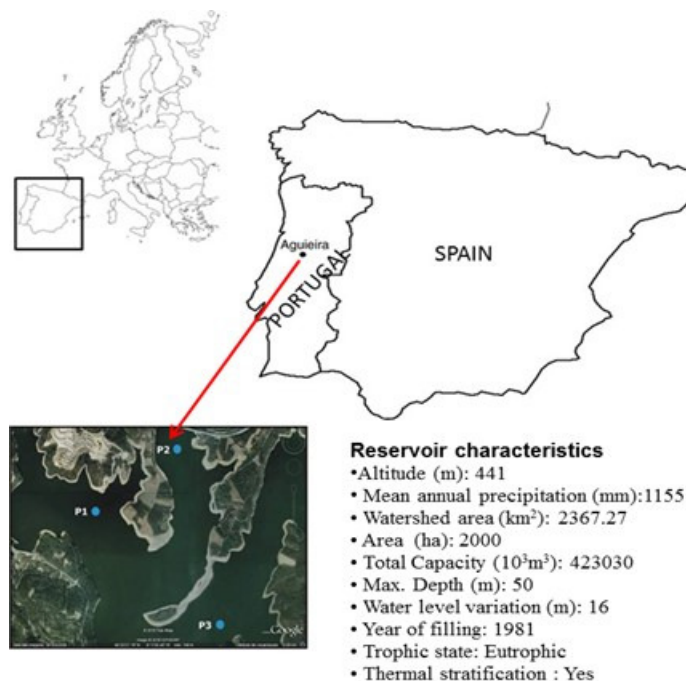
This research was aimed to monitor and characterize the zooplankton community of Aguieira reservoir (40.33 N; 8.19 W). Aguieira trophic state, nutrient concentration (the highest amounts were observed in summer) and water quality, can be correlated to the internal disturbances induced by the intense water level fluctuations. These criteria indeed lead to an increase in the suspended particulate material in the water column. In addition, the input of allochthonous nutrients originated from human activities in the catchment area will increase the phytoplankton biomass (mainly Cyanobacteria) during summer. The phytoplankton community was dominated by the Cyanobacteria, whereas the zooplankton community by the rotifer, *Keratella cochlearis* and by the caldoceran, *Chydorus sphaericus*. In the absence of Cyanobacteria, the subsistence of *Copidodiaptomus numidicus*, *Daphnia longispina* and *Bosmina coregoni* was highly evident. Zooplankton community showed similar spatial and inter-annual patterns. However, n-MDS ordination was able to differentiate between the two identified groups: samples obtained from December-March and from May-September. Canonical correspondence analysis (CCA) identified two main environmental gradients that shape zooplankton community. One being temporal, mainly related to temperature. The other is a trophic gradient which is associated to chlorophyll a concentration, water transparency, nitrates and nitrites. Variance partitioning using CCA revealed that the largest portion (45%) of the total variation observed (70%), was attributed to the interaction between lake and environmental variables.

Keywords: deep reservoir; environmental variables; zooplankton community; seasonal and special trends.

1. INTRODUCTION

Freshwater resources are scarce in Portugal where in the climates are characterised by irregular precipitation regimes. Therefore, reservoirs can provide large amount of water for agriculture and urban supply, energy generation, fishing and recreational purposes. Hence these freshwater systems may have significant effect on watershed geology, climate, soil, land slope and intrinsic factors such as age of the reservoirs, water level fluctuations, morphometry and water residence times [1,2]. Anthropogenic activities in the catchment area and in the reservoir vicinity cause intensification of surface runoff with an increase in eutrophication, thus threatening water quality. Runoff rates depend mainly on land use, vegetation cover and landscape mosaic [3, 4, 5, 6, 7, 8]. Zooplankton constitutes a crucial link in the energy transfer to higher trophic levels being a keystone on ecosystem functioning. Moreover, its size structure, reproduction and survival, among other characteristics, are affected by both top-down (fish or invertebrates) and bottom-up (nutrient level and phytoplankton) controls. Thus, the observed community structure reflects the fluctuation of environmental factors, disturbance events and ecosystem resilience. Besides, zooplankton shows quick responses to environmental changes [9, 10, 11, 12, 13, 14]. Aguieira Reservoir (Latitude: 40°19'53, 83"N; Longitude: 8° 11'47, 76"W) is located in the Iberian Peninsula, in Portugal on the Mondego River catchment (see Figure 1). The reservoir is used to generate hydroelectrical power and to provide urban water supply. Due to this, accentuated water level fluctuations occur. The catchment is occupied with intensive forestry, agriculture and livestock production and with several medium sized towns. Therefore, the aim of the present research was: (1) to characterise zooplankton community and (2) to assess how zooplankton community respond to the variations of several environmental parameters.

34



35

36

37 **Fig. 1. Aguireira Reservoir and sampling sites.**

38 **2. MATERIAL AND METHODS**

39

40 **2.1 Field sampling and laboratory analysis**

41 Samples were collected seasonally from March 2010 to December 2011 at three sampling points: P1, P2,
 42 P3 (see Figure1). Euphotic zone data was obtained. The depth of this zone was considered to be 2.5
 43 times the Secchi disk depth. Integrated water samples were obtained at 2 m intervals along the euphotic
 44 zone with a Van Dorn bottle. Samples were pooled together and the total sample was used for chlorophyll
 45 *a*, (CHL *a*) nitrites, nitrates, ammonia and phosphorus determination. These variables were estimated
 46 according to [15]. Water temperature, pH, conductivity and dissolved oxygen (DO) were determined “in
 47 situ” using a multiparameter probe (YSI 6820). Zooplankton were collected on each sampling date by
 48 taking two vertical hauls using a 64 µm mesh size Wisconsin type net equipped with a flowmeter. Animals
 49 were anaesthetised with carbonated water and preserved in sugar-saturated formaldehyde (4% final
 50 concentration). Depending on density, zooplankton in 5, 10, 20 ml sub-samples or in total sample were
 51 counted and identified to the species level. Carlson’s Trophic State Index (TSI) [16] was computed from
 52 Secchi disk transparency (TSI (SD)), and CHL *a* concentrations (TSI (CHL)).

53

54 **2.2 Data analysis**

55 Non-metric Multidimensional Scaling (n-MDS) was used to determine if environmental variables and
 56 zooplankton community had changed with sampling sites over seasons and years. Bray-Curtis distance
 57 was used to measure the dissimilarity between samples. In this method samples were arranged in a
 58 continuum that those close together are similar and those which are far apart are dissimilar. Statistical
 59 differences between clusters identified in n-MDS plot were investigated by a randomization method,
 60 ANOSIM [17]. This method employs R statistics to examine the existence of differences between the
 61 established groups for each considered factor (groups and differences between sampling sites, seasons
 62 and years). To determine the influence of the studied environmental variables on the zooplankton species
 63 composition, a Canonical Correspondence Analysis (CCA) was performed. In both analyses, taxa were
 64 included only if they reached a relative abundance larger than 1%. Absolute zooplankton counts were
 65 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 [18].

3. RESULTS

3.1 Environmental variables

Environmental variables showed similar values during both years in each sampling site (see Table 1). Spatial and inter-annual variations in these parameters were not relevant. However, seasonal variations were observed. n-MDS ordination (see Figure 2) was able to differentiate between the two identified groups: samples obtained in December, January and March from those obtained in May and September (2D stress: 0.02). ANOSIM test confirmed significant differences between the two groups ($R = 0.829$; $p < 0.001$). The environmental variables that showed clear seasonal variations and contributed for these differentiations were temperature, Secchi disk depth, CHL *a* concentrations and pH. The highest values for temperature, pH, CHL *a* concentrations were observed in the samples obtained in May and September. Conversely, the lowest values of Secchi disk depth were observed in January 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 winter (the values ranged between 24 and 42). In summer it was eutrophic (values of both components of the index reached 57).

85 **Table1. Minimum-maximum range of environmental variables obtained for 2010 and 2011 in the different sampling sites.**
86

Parameter	2010			2011		
	P1	P2	P3	P1	P2	P3
Temperature (° C)	11.9-23.0	12.2-23.2	12.8-22.8	14,7-25,0	14.2	13.4
pH	7,3-9,9	7,2-10,1	7,3-10,0	7,1-9,8	7.21	7.3
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	94.6
Secchi disk(m)	1,5-3,0	1,5-3,0	1,5-3,0	1,2-4,0	2.5	2.5
NO ₂ (mg L ⁻¹)	<0,01-0,08	<0,01-0,11	<0,01-0,06	<0,01-0,03	0.04	0.03
NO ₃ (mg L ⁻¹)	<4,4-5,4	<4,4-5,5	<4,4-5,5	<4,4	5,5	4,9
NH ₄ (mg L ⁻¹)	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
P ₂ O ₅ (mg L ⁻¹)	<0,23	<0,23	<0,23	<0,23	<0,23	<0,23
Chlorophyll <i>a</i> ($\mu\text{g L}^{-1}$)	0,36-16,21	0,36-14,20	1,40-15,68	0,52-14,43	0,89-10,69	0,53-5,88

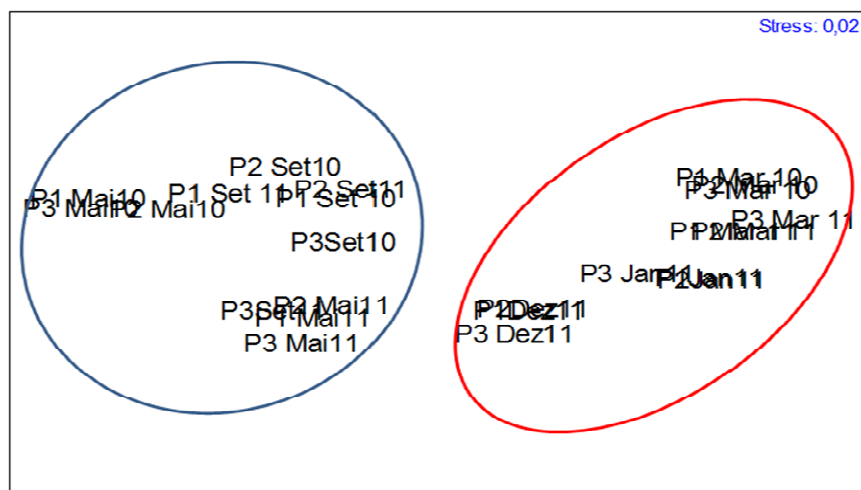


Fig. 2. Results of n-MDS ordination considering environmental variables.

Sampling sites: P1, P2, P3

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

3.2 Zooplankton community

During the sampling period 12 taxa of Rotifera, 7 of Cladocera and 3 of Copepoda were recorded (see Table 2). Zooplankton community showed similar spatial and inter-annual patterns (see Figures 3 and 4). From all the zooplanktonic species found in Aguieira (see Table 2) the most abundant in both the years were the rotifers, *Keratella cochlearis* (both in May 2010/2011) and *Polyarthra* sp. (mainly in 2010); the Cladocera, *Bosmina coregoni* and *Chydorus sphaericus* (in September) and the Copepoda, *T. prasinus* and *Copidodiaptomus numidicus* (mainly in December and January). *Daphnia* and other coarse mesh filter-feeder zooplankters always showed low abundance.

Table 2 Composition of zooplankton community between 2010 and 2011.

ROTIFERA	CLADOCERA	COPEDODA
<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>Hexarthra mira</i>	<i>Chydorus sphaericus</i>	
<i>Keratella cochlearis</i>	<i>Daphnia longispina</i>	
<i>Keratella cochlearis f. tecta</i>	<i>Daphnia parvula</i>	
<i>Ploeosoma</i> sp.	<i>Diaphanosma brachyurum</i>	
<i>Polyarthra</i> sp.		
<i>Synchaeta</i> sp.		
<i>Trichocerca</i> sp.		

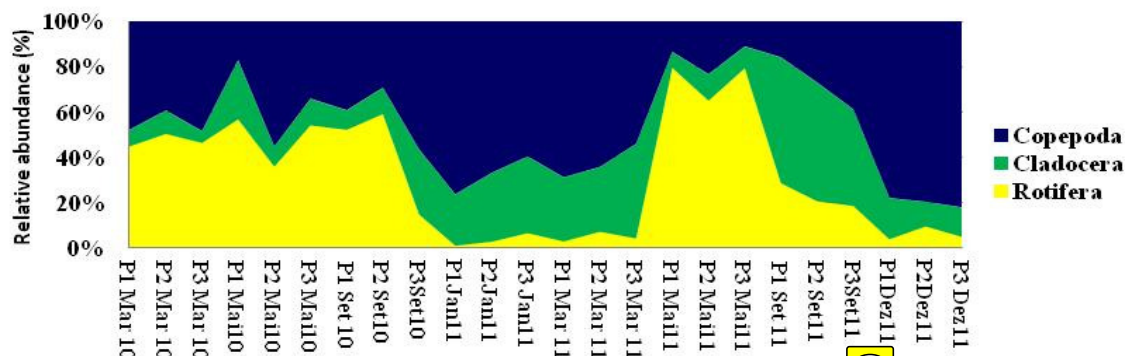


Fig. 3. Relative abundance (%) of Rotifera, Copepoda and Cladocera.

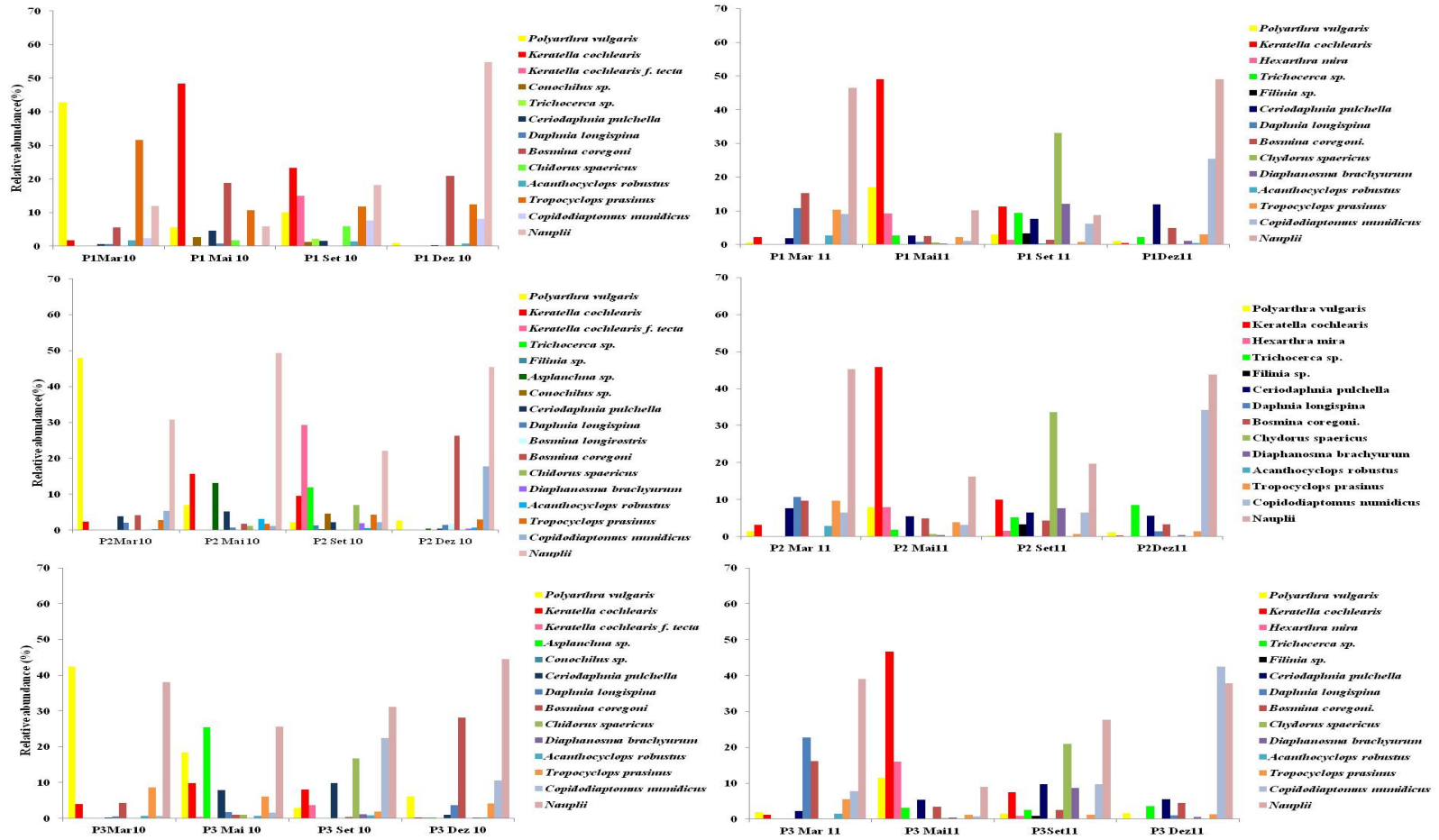


FIG. 4 . Spatial-temporal variation of zooplankton relative abundance and composition.

n-MDS ordination (see Figure 5) was able to differentiate between the identified samples obtained in December-March and those obtained in May-September (2D stress: 0.12). ANOSIM test confirmed the significant differences between the two groups ($R = 0.803$; $p < 0.001$). These differences can be explained by the increase of *Daphnia longispina*, *C. numidicus* and *Bosmina coregoni* during December-March period. These species prefer lowest temperatures and lowest densities of filamentous algae.

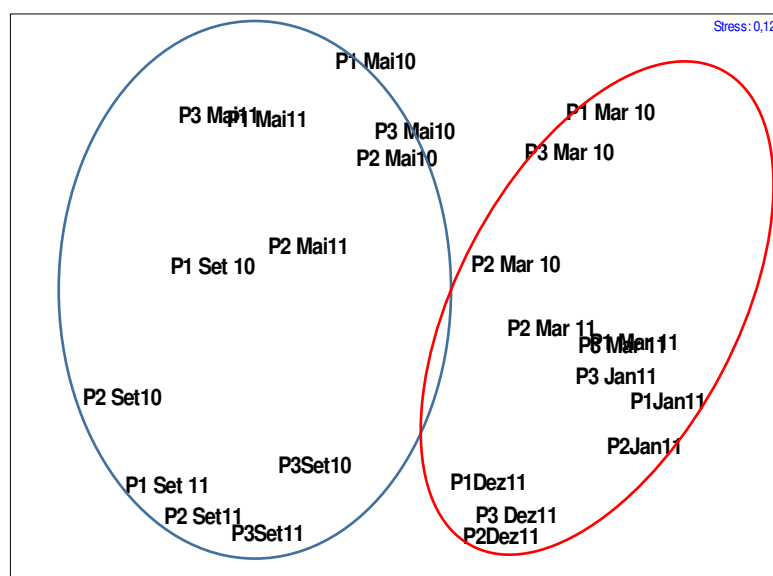


Fig. 5. Results of n-MDS ordination considering zooplankton.

P1, P2, P3 - sampling sites.

Jan, Dez; Mar, Mai Set-Samples obtained in January, December, March, May and September, respectively.

CCA revealed two gradients that influenced plankton community (see Figure 6). First is the temporal gradient related to temperature ($P = 0.0000$) and the other is the trophic gradient associated to algal biomass CHL a ($P = 0.004$), Secchi disk depth ($P = 0.04$), conductivity ($P = 0.009$), nitrates ($P = 0.014$) and nitrites ($P = 0.029$). The ordination space defined by the first two CCA axes accounted for 70% of species-environment relation and represented 45% of the variation in species data.

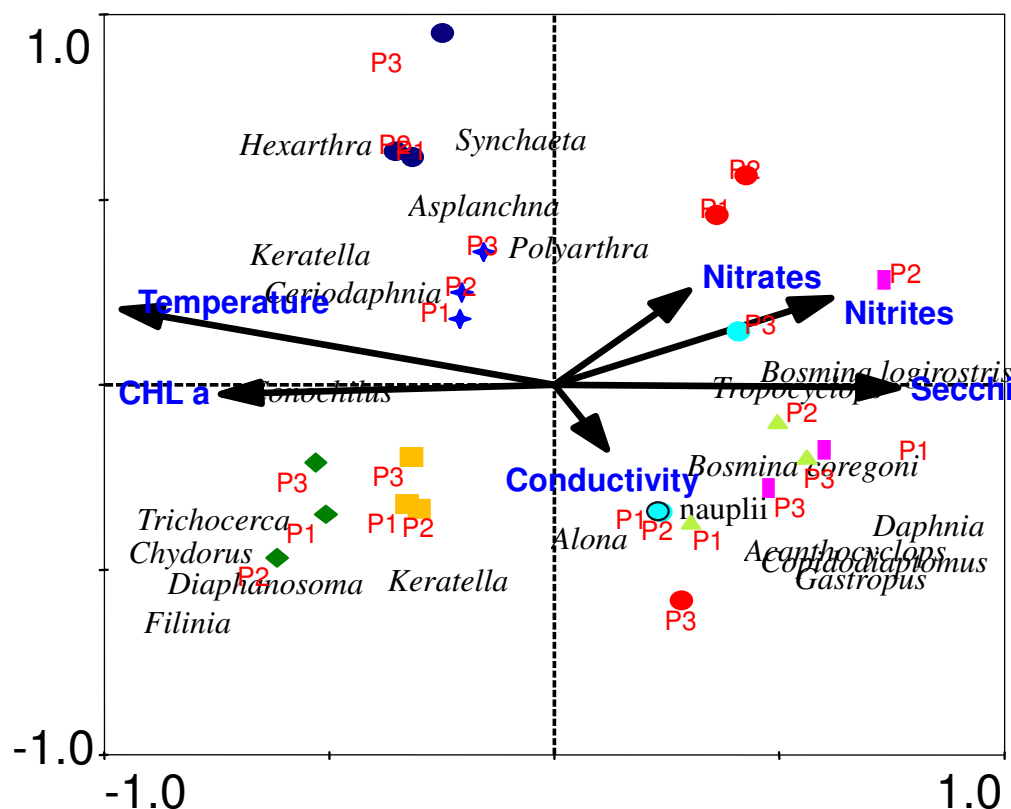


Fig. 6. Results of CCA.

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

4. DISCUSSION

The highest values for pH, CHL *a* concentrations were observed both in May and September and were related to the presence of blooms of Cyanobacteria. The blooms were mainly composed of *Raphidopsis mediterranea*, *Anabaena cylindrica* and *Gophosphaeria lacustris*, which were recorded for the first time in this reservoir by [19]. The increase in pH during this period is a consequence of high consumption of CO₂ by these microorganisms leading to the alkalization of the euphotic zone. The conditions created by late spring-summer temperatures and irradiance combined with high levels of nutrients provided the ecological optimum for cyanobacteria dominance [20, 21]. The trophic state of this reservoir, varying between meso-eutrophic and eutrophic state, might be a consequence of the disturbance caused by extreme and aperiodic water level fluctuations (because of hydroelectricity production). The exposure of littoral sediments to cycles of drying and wetting might have implications on nutrient cycling. This assumption is supported by the results obtained from [22] and [23] in reservoirs where water level fluctuations were accentuated and refilled over a short period of time. According to these authors, littoral sediments that were periodically exposed, experiencing cycles of drying and wetting, have less capacity to adsorb nutrients than those that remain inundated. Zooplankton composition and abundance was similar in all sampling sites. Slight differences such as the higher abundance of the copepod, *T. prasinus* in P1 in March 2010, can be explained by spatial variations on fish predation pressure [24]. The obtained results evidenced that zooplankton communities can be regarded as “reservoir mirrors”. In fact, when cyanobacteria blooms occurred, Rotifera (*Keratella* sp. and *Polyarthra* sp.) were dominant. In this period, Copepoda (*Chydorus sphaericus* and *Ceriodaphnia*) and Copepoda were also present, but in much smaller densities. Therefore, specialists on small particle

feeding, for those the food preferences are mostly detritus-bacteria, are favored in these environmental conditions. Whereas cyanobacteria are known to negatively affect mesh filter-feeders (large herbivores) such as *Daphnia*, either by being of low nutritional value, by clogging the feeding apparatus or by producing toxins [25, 9, 26, 27]. Besides, large herbivores have larger generations, lower tolerance to turbidity and higher temperatures [28, 29, 30]. Therefore, *Daphnia longispina*, *C. numidicus* and *Bosmina coregoni* were abundant in December, January and March.

5. CONCLUSION

The results of the present study conclude that the water temperature, pH, CHL *a*, and Secchi disk depth explained to an extent of the variability, abundance and composition of zooplankton community. But the other factors such as the anthropogenic disturbance degree reflected in the water level fluctuations, climate change, biotic interactions also seemed to play an important role in structuring the zooplankton community. It is important that the further limnological studies may actually contribute to fully assess the relative importance of all these different variables. The obtained data constitute a preliminary study and might be a basis to develop management plans to mitigate some negative impacts resulting from anthropogenic activities in this reservoir. Furthermore, data obtained in this study will allow monitoring the efficiency of those plans by detecting changes in this community, which can be related to changes in water quality and in the overall ecosystem health.

REFERENCES

1. Harper D. Eutrophication of freshwaters - principles, problems and restoration, 1st ed. London: Chapman & Hall; 1992.
2. Wetzel RG. Limnology - Lake and River Ecosystems, 3rd ed. New York: Academic Press; 2001.
3. Johnes P, Moss B, Phillips G. The determination of total nitrogen and total phosphorus concentrations in freshwater from land use, stock headage and population data: Testing of a model for use in conservation and water quality management, *Freshwater Biology*. 1996; 36: 451-73.
4. Rybak J. Long-term and seasonal dynamics of nutrient export rates from lake watersheds of diversified land cover pattern. *Verh. Internat. Verein Limnol*. 2000; 27: 3132-136.
5. Hallisey R, McGarrigle ML, Donnelly K. The relationship between in-stream total phosphorus and the characteristics of the surrounding catchment, Rappa River catchment, Co. Mayo, Ireland. *Verh. Internat. Verein. Limnol.* . 2001; 27: 3556-560.
6. Szyper H, Goldyn R. Role of catchment area in the transport of nutrients to lakes in the Wielkopolska National Park in Poland, *Lakes and Reservoirs: Research and Management*. 2002; 7: 25-33.
7. Leigh C, Watkinson A, Burford MA, Irstea UM. Effects of extreme inflows on the water quality and phytoplankton of seven reservoirs in subtropical Australia. *Inland Waters*. 2015; 5(3): 240-52.
8. Gough R, Cohen Y, Fenner N, Cannon J, Freeman C. Relationships between reservoir water quality and catchment habitat type. *International Journal of Environmental Technology and Management*. 2016; 19(1): 16-39.
9. Lampert W. Sommer U. *Limnoecology - the ecology of lakes and streams*. New York: Oxford University Press; 1997.

10. Jeppesen E, Jensen JP, Sondergaard M, Lauridsen T. Trophic dynamics in turbid and clear water lakes with special emphasis on the role of zooplankton for water clarity. *Hydrobiologia*. 1999; 408: 217-31.
11. Pereira R, Soares AMVMR, Ribeiro F, Gonçalves F. Assessing the trophic state of Linhos lake: a first step towards ecological rehabilitation. *Journal of Environmental Management*. 2002; 64: 285–97.
12. Abrantes N, Nogueira A, Gonçalves F. 2009 - Short-term dynamics of cladocerans in a eutrophic shallow lake during a shift in the phytoplankton dominance. *Annales de Limnologie - International Journal of Limnology*. 2009; 45: 237-45.
13. Obertegger U, Borsato A, Flaim G. Rotifer-crustacean interactions in a pseudokarstic lake: influence of hydrology. *Aquatic Ecology*. 2010; 44: 121-130.
14. Haberman J, Haldna M. Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: long term study of Lake Võrtsjärv. *J. Limnol.* 2014; 73(2): 263-73.
15. APHA. Standard Methods for the Examination of Water and Wastewater, 17th ed. Washington: American Public Health Association; 1989.
16. Carlson RE. A trophic state index for lakes. *Limnol. Oceanogr.* 1977; 22: 361-69.
17. Clarke KR, Warwick RM. Change in marine communities: An approach to statistical analysis and interpretation. Natural Environmental Research Council, UK; 1994.
18. Ter Braak CJF. Ordination. In: Jongman RHG, Ter Braak CJF, van Tongeren OFR, editors. *Data Analysis in Community and Landscape Ecology*. Cambridge :University press; 1995.
19. Oliveira MRL, Monteiro MT. “Blooms” de Cyanophyceae na Albufeira da Aguieira: Efeitos na qualidade da água e no zooplâncton. *Relat. Téc. Cient. INIP*. 1992; 61.
20. Barone R, Castelli G, Naselli-Flores L. Red sky at night cyanobacteria delight: the role of climate in structuring phytoplankton assemblage in a shallow, Mediterranean lake (Biviere di Gela, southeastern Sicily). *Hydrobiologia*. 2010; 639:43–53.
21. Huber V, Wagner C, Gerten D, Adrian R. To bloom or not to bloom: contrasting responses of cyanobacteria to recent heat waves explained by critical thresholds of abiotic drivers. *Oecologia*. 2009; 169(1): 245-56.
22. Fabre A. Experimental studies on some factors influencing phosphorus solubilisation in connection with the drawdown of a reservoir. *Hydrobiologia*. 1988; 159: 153-158.
23. Watts CJ. Seasonal phosphorus release from exposed, re-inundated littoral sediments of two Australian reservoirs. *Hydrobiologia*. 2000; 431: 27-39.
24. Winfield IJ, Townsend CR. The role of cyprinids in ecosystems. In: IJ Winfield Editor. *Cyprinid fishes, systematics, biology and exploitation*. London: Chapman e Hall; 1992.
25. Geller W, Müller H. The Filtration Apparatus of Cladocera: Filter Mesh-Sizes and their Implications on Food Selectivity. *Oecologia*. 1981; 49: 316-321.

- 315 26. Łotocka M. Toxic effect of cyanobacterial blooms on the grazing activity of *Daphnia magna* Straus.
316 Oceanologia. 2001; 43: 441-53.
317
- 318 27. Sarnelle O, Gustafsson S, Hansson LA. Effects of cyanobacteria on fitness components of the
319 herbivore *Daphnia*. Journal of Plankton Research. 2010: 32(4):471-77.
320
- 321 28. Caramujo MJ, Boavida MJ. The crustacean communities of River Tagus reservoirs. Zooplankton
322 structure as reservoir trophic state indicator. Limnética. 2000: 18: 37-56.
323
- 324 29. Geraldés AM, Boavida MJ. What factors affect the pelagic cladocerans of the meso-eutrophic Azibo
325 reservoir? Annales de Limnologie – International Journal of Limnology. 2004: 40: 101-11.
326
- 327
- 328 30. Castro BB, Antunes SC, Pereira R, Soares AMVM, Gonçalves F. Rotifer community structure in three
329 shallow lakes: seasonal fluctuations and explanatory factors. Hydrobiologia, 2005: 543: 221-32.