

*Full Length Research Paper*

# Seasonal dynamics of plankton communities coupled with environmental factors in a semi arid area: Sidi Saâd reservoir (Center of Tunisia)

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**In this study, we studied the influence of the physical-chemical and biological factors (bacterioplankton and phytoplankton abundances) for zooplankton dynamics in a Sidi Saâd reservoir in Centre of Tunisia. The samplings were carried out in spring, summer, autumn and winter (2005 to 2006) in the deepest station (surface, 5, 10 and 15 m). In this reservoir, the highest density of zooplankton abundance was recorded in summer ( $92.2 \text{ ind L}^{-1}$ ;  $0.43 \times 10^3 \mu\text{g L}^{-1}$ ) and autumn ( $86.9 \text{ ind L}^{-1}$ ;  $0.23 \times 10^3 \mu\text{g L}^{-1}$ ) at a depth of 10 m. The copepods (56% of total zooplankton abundance) and cladocera (42% of total zooplankton abundance) were the most abundant groups. The physico-chemical factors, especially the water temperature ( $r = 0.53$ ,  $p = 0.027$ ,  $n = 16$ ) and dissolved oxygen ( $r = -0.59$ ,  $p = 0.03$ ,  $n = 16$ ), influence directly the zooplankton community. It was suggested that in Sidi Saâd reservoir, both the top-down and bottom-up regulations account for the regulation of zooplankton. The phytoplankton was the factor responsible for the structure and seasonal dynamics of the zooplankton community, which are well related to changes in algae diversity and abundance, noting that cyanobacteria have major impacts. The “top-down” effect of planktivorous fish on the zooplankton is a significant factor affecting the plankton community’s dynamics in this reservoir.**

**Key words:** Sidi Saâd reservoir, water temperature, bacterioplankton, phytoplankton, zooplankton, top-down and bottom-up regulations.

## INTRODUCTION

Plankton community’s seasonal succession is a well-investigated phenomenon in aquatic ecology and several studies have described the patterns and the underlying mechanisms of the seasonal dynamics in freshwater

(Medley and Havel, 2007). Unfortunately, contributions in the semi-arid Mediterranean freshwater area are scarce (Alvarez-Cobelas et al., 2005). The zooplankton succession is largely determined by the interactions and the seasonal cycles of physical-chemical factors such as temperature and dissolved oxygen (Leibold et al., 2004) and biological factors such as competition and predation (Larson et al., 2009), the relative importance which varies in different periods of the year (Sommer et al., 1986) and

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also among aquatic ecosystems and scales (Pinel-Alloul and Ghadouani, 2007).

Zooplankton is an important link in freshwater aquatic ecosystems, grazing on and controlling the phytoplankton (Mitra et al., 2007; Mehner et al., 2008; Li et al., 2009) and bacterioplankton (Wikner et al., 1990). Primary producers in aquatic ecosystems are affected by resources ("bottom-up" effects) and consumers ("top-down" effects) (McQueen et al., 1986, 1989). A recent research suggests that the influence of bottom-up forces is higher in Mediterranean limnosystems (Moss et al., 2004). The "top-down" effect of predators on the lower trophic levels is a significant factor in structuring communities in freshwater ecosystems (McQueen et al., 1986; Vanni et al., 1990). Zooplankton constitutes the food source of organisms at higher trophic levels (Abrantes et al., 2006; Mitra et al., 2007). Therefore, planktivorous fish are well known to impact species composition of zooplankton (Medley and Havel, 2007).

To have a better understanding of the factors responsible for changes in the annual pattern of zooplankton, it is important to better understand the link between changes in environmental parameters, biological factors and zooplankton dynamics. The present study is the first concerning a Sidi Saâd reservoir situated in a semi-arid Mediterranean area, which focuses on the influence of the physical-chemical and biological factors (bacterioplankton and phytoplankton abundances) for zooplankton dynamics.

## MATERIALS AND METHODS

### Study site

The Sidi Saâd reservoir (35° 31'40" N and 09° 59' 30"E) was constructed in 1981 and located in about thirty kilometers South of Kairouan city (Center of Tunisia) (Figure 1). This reservoir has a surface of 1800 ha, a volume of 209 millions m<sup>3</sup> and a catchments area of 8650 Km<sup>2</sup>. Sidi Saâd reservoir was mainly destined to protect the city of Kairouan against the violent floods of the river, besides its use for irrigation of agricultural land. This reservoir was constructed on Zéroud river.

### Physical-chemical and biological factors

The samples were collected in spring (March to May), summer (June to August), autumn (September to October) and winter (December to January) (2005 to 2006) in the deepest area of this reservoir at the surface, 5, 10 and 15 m. Water samples for physico-chemical analyses were collected using a 1-L Van Dorn bottle at the same depth and preserved in cold, dark conditions; except for temperature, pH, dissolved oxygen and water transparency which were measured *in situ*. Water temperature, dissolved oxygen concentration and pH were measured using a multiparameter probe (Multi 340i/SET). Water transparency was estimated using a Secchi disc. The concentration of the suspended matter was determined by measuring the dry weight of the residue after filtration through a Whatman GF/C membrane. Nutrient concentrations were analyzed by standard colorimetric techniques with an automatic BRAN and LUEBBE type 3 analyzer and

determined colorimetrically using a UV-visible (6400/6405) spectrophotometer. Air temperature, evaporation, precipitation and wind speed were obtained from the meteorology service.

Phytoplankton samples were taken using a 1-L Van Dorn bottle, simultaneously with the samples for chemical analysis. Phytoplankton enumeration was performed with an inverted microscope using the Utermöhl (1958) method after fixation with a Lugol's solution. Identification of algal taxa followed Bourrelly (1985) and Baker (1991, 1992). Quantification of chlorophyll *a* was filtered using Whatman GF/C filters and pigment extraction was performed on water subsamples (0.5 L) with 90% acetone (Lorenzen, 1967). The concentrations were determined by the spectrophotometry based on the absorbance at 750 and 663 nm.

Bacterioplankton samples (50 ml) were collected from the surface water and preserved in 4% formaldehyde solution. In the laboratory, 1 ml aliquots from the bacterioplankton samples were filtered through 0.2 µm nucleopore membranes in replicates. Membranes were stained for 5 min with fluorochrome 4'6' diamidino-2 phenylindole (DAPI) (Porter and Feig, 1980). For control filters, 0.2 µm filtered distilled water was used applying the following protocol. Bacterial density (cells l<sup>-1</sup>) was counted in a Zeiss epifluorescence microscope (Booth, 1993). The planktivorous fish data were provided by the ministry of agriculture of Tunisia. Fish specimens were sampled in Sidi Saâd reservoir using seine-net. The data were expressed by biomass (Kg per hectare).

### Zooplankton

Zooplankton samples were collected by filtering 20 L (5-L Van Dorn bottle) integrated water through a 55 µm Nylal mesh, preserved with formalin 4% solution and coloured with Bengal Pink. The zooplankton was enumerated and counted under a binocular microscope type Leica in Doffus chambers. The taxonomic identification was carried out according to Dussart (1969), Koste (1978), Pourriot and Francez (1986), Korovchinsky (1992). Zooplankton was analyzed in terms of abundance (ind L<sup>-1</sup>) and biomass (µg L<sup>-1</sup>). For biomass estimations of zooplankton, 100 individuals (if possible) per genus/ species were measured and biomass was calculated according to Bottrell et al. (1976). The level of community structure was assessed according to the diversity index as described by Shannon and Weaver (1949); it is the most popular index. This index was calculated from the annual average density of zooplanktonic species:

$$H' = -\sum_{i=1}^s \times \log_2 \frac{n_i}{N}$$

Where,  $n_i$  is the relative abundance of taxon,  $i$  and  $N$  is the total number of individuals.

### Trophic index

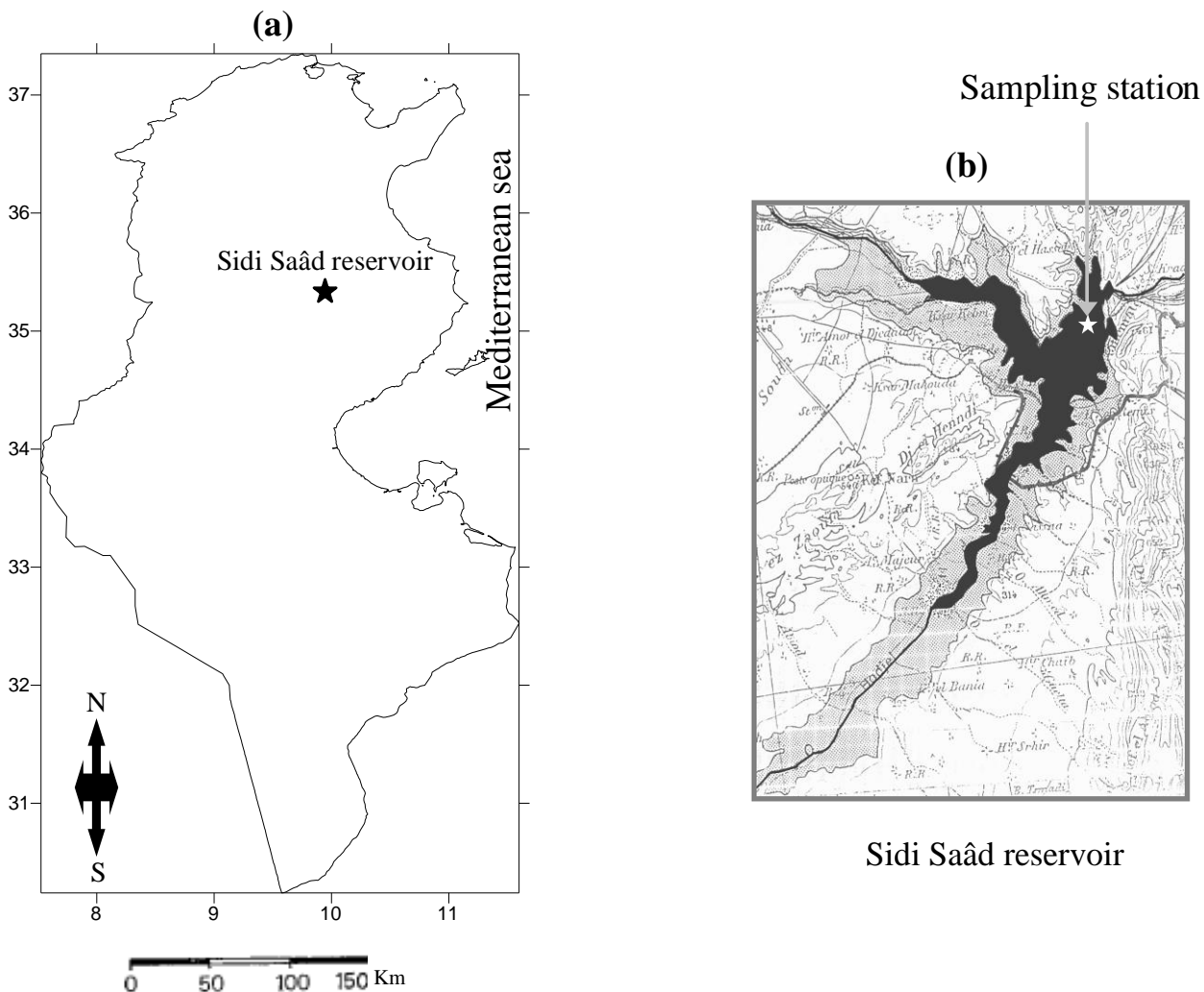
Two trophic state indexes were determined by the classical freshwater TSI of Carlson and Simpson (1996) and Burns and Bryers (2000). TSI was calculated with chlorophyll *a* (Chl *a*) (µg L<sup>-1</sup>), total phosphorus (TP) (µg L<sup>-1</sup>) and Secchi disc (SD) (m), using the following equations:

-Carlson (1977) and Carlson and Simpson (1996)

$$TSI_c (\text{Chl } a) = 9.81 \ln (\text{Chl } a) + 30.6$$

$$TSI_c (\text{TP}) = 14.42 \ln (\text{TP}) + 4.15$$

$$TSI_c (\text{SD}) = 60 - 14.41 \ln (\text{SD})$$



**Figure 1.** Localization of the Sidi Saâd reservoir in Tunisia country. (a) Map of Tunisia and Map showing the sampling station in the reservoir (b).

-Burns and Bryers (2000)

$$TSl_B (\text{Chl } a) = 2.22 + 2.54 \log (\text{Chl } a)$$

$$TSl_B (\text{TP}) = 0.218 + 2.92 \log (\text{TP})$$

$$TSl_B (\text{SD}) = 5.56 + 2.60 \log (1/\text{SD} - 1/40)$$

### Statistical analysis

The data recorded in this study were examined with a normalized principal component analysis (PCA) (Chessel and Dolédec, 1992). Physico-chemical (water temperature, dissolved oxygen, total nitrogen and total phosphorus) and biological parameters (chlorophyll *a*, phytoplankton and zooplankton) were considered. The discrimination between months was assessed by examining the projection of the plots of the extracted factors on a factorial plan consisting of the statistically significant axis of the PCA analysis. Simple  $\log(x + 1)$  transformation was applied to data in order to correctly stabilize the variance (Frontier, 1973). Furthermore, the potential relationships between variables were tested by Pearson's correlation coefficient.  $p < 0.05$  was considered significant in all statistical analyses.

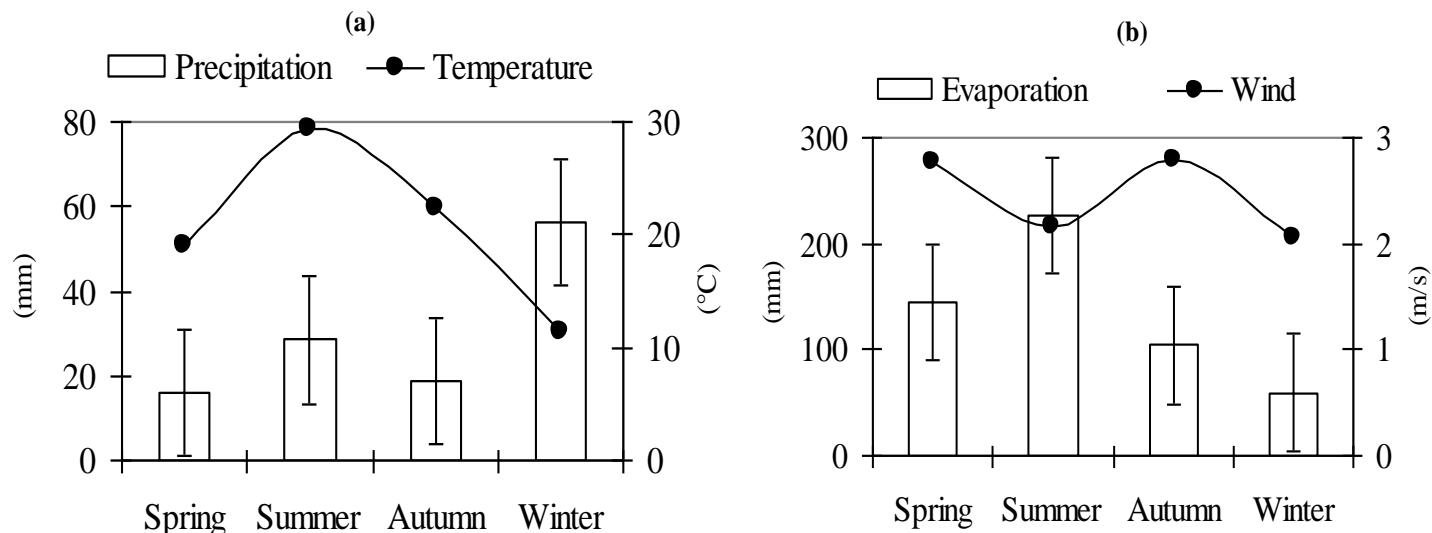
## RESULTS

### Environmental parameters

Meteorological data are shown in Figure 2. The water temperature varied from 6.5°C in winter at a depth of 15 m to 28.1°C in summer at surface (mean  $\pm$  s.d. = 18.6  $\pm$  7.8 °C) (Figure 3a).

Average pH value was between 7.9 in winter at a depth of 15 m and 8.6 in spring at a depth of 5 m (mean  $\pm$  s.d. = 8.2  $\pm$  0.2 °C) (Figure 3b). Dissolved oxygen concentrations ranged from 3.5 mg L<sup>-1</sup> in autumn at a depth of 15 m to 8.2 mg L<sup>-1</sup> in winter at surface (mean  $\pm$  s.d. = 5.6  $\pm$  1.8 mg L<sup>-1</sup>) (Figure 3c).

Concentrations in suspended matter fluctuated from 16.2 mg L<sup>-1</sup> in spring at a depth of 5 m to 36.1 mg L<sup>-1</sup> in winter at a depth of 10 m (mean  $\pm$  s.d. = 26  $\pm$  5.8 mg L<sup>-1</sup>) (Figure 3d). The total nitrogen concentrations varied from



**Figure 2.** Meteorological data (mean values) (a) precipitation (mm) and air temperature (°C); (b) evaporation (mm) and wind speed (m.s<sup>-1</sup>).

0.2 mg L<sup>-1</sup> in spring at surface to 1.5 mg L<sup>-1</sup> in winter at surface (mean  $\pm$  s.d. = 0.4  $\pm$  0.3 mg L<sup>-1</sup>) (Figure 3e). The total phosphorus concentrations oscillated from 0.02 mg L<sup>-1</sup> in autumn at a depth of 15 m to 0.07 mg L<sup>-1</sup> in spring at a depth of 5 m (mean  $\pm$  s.d. = 0.1  $\pm$  0.01 mg L<sup>-1</sup>) (Figure 3f).

### Trophic state indexes

The trophic state indexes of Carlson and Simpson (1996) and Burns and Bryers (2000) varied between 42.1 (Chl a), 15.5 (TP), 45.9 (SD) and 5.5 (Chl a) and 1.8 (TP), 7.7 (SD) respectively. Our study indicated an oligo-mesotrophic status (Carlson, 1977; Carlson and Simpson, 1996) toward tendency to eutrophic status (Burns and Bryers, 2000) (Table 1).

### Phytoplankton and zooplankton species diversity

The phytoplankton community of the Sidi Saâd reservoir consisted of cyanobacteria (7 species), dinophyceae (5 species), bacillariophyceae (6 species), chlorophyceae (3 species) and conjugatophyceae (1 species) (Table 2) which contributed 61, 33, 4, 3 and 1% of the total phytoplankton abundance respectively.

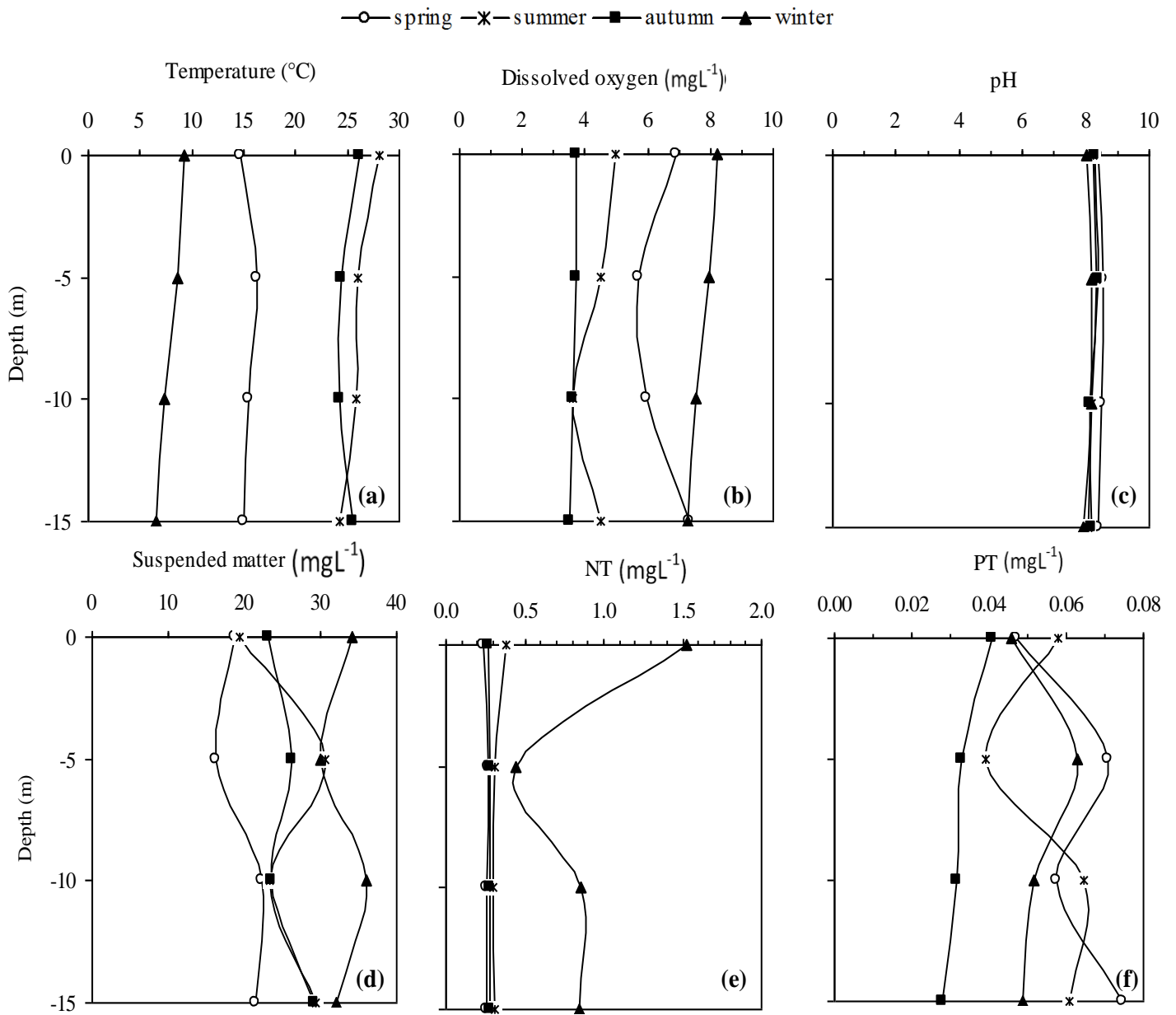
Moreover, during the studied period a total of 6 species of zooplankton was recorded, consisting of 5 species of rotifers (*Brachionus urceolaris*, *Hexarthra mira*, *Keratella quadrata*, *Keratella cochlearis* and *Asplanchna* sp.), 2 species of copepods (*Acanthocyclops viridis* and *Acanthocyclops robustus*) and one species of cladocerans (*Diaphanosoma brachyurum*) (Table 2). The copepods (56% of the total zooplankton abundance) and cladocera (42% of the total zooplankton abundance)

were most frequent. The dominant species was *A. viridis* followed by *D. brachyurum*.

### Spatial and temporal abundance variation of phytoplankton, bacterioplankton and zooplankton

Total phytoplankton abundance varied from 1.7  $\times 10^3$  in winter at a depth of 15 m to 7.2  $\times 10^6$  cells L<sup>-1</sup> in spring at a depth of 5 m (mean  $\pm$  s.d = 5.2  $\times 10^5 \pm 1.7 \times 10^6$  cells L<sup>-1</sup>). The cyanobacteria (*Microcystis aeruginosa*, 73% of the total phytoplankton abundance) and dinophyceae (*Peridinium africanum*, 20% of the total phytoplankton abundance) were responsible for this exceptional peak, accounting for 63 and 33% of the total phytoplankton abundance respectively (Figure 4a and b). Total bacterioplankton abundance ranged between 5.2  $\times 10^2$  cells L<sup>-1</sup> in autumn at a depth of 15 m and 2.1  $\times 10^3$  cells L<sup>-1</sup> in autumn at the surface (mean  $\pm$  s.d = 1.1  $\times 10^3 \pm 4.2 \times 10^2$  cells L<sup>-1</sup>).

The total zooplankton abundance ranged from 0.7 ind L<sup>-1</sup> in spring at surface to 92.2 ind L<sup>-1</sup> in summer at a depth of 10 m (mean  $\pm$  s.d. = 25.8  $\pm 32.2$  ind L<sup>-1</sup>), and the biomass varied from 1.7  $\mu$ g l<sup>-1</sup> in spring at surface and 0.43  $\times 10^3 \mu$ g l<sup>-1</sup> in summer at a depth of 10 m (mean  $\pm$  s.d. = 1.1  $\times 10^3 \pm 1.4 \times 10^3 \mu$ g l<sup>-1</sup>). There were two peaks in autumn (86.9 ind L<sup>-1</sup>, 0.23  $\times 10^3 \mu$ g L<sup>-1</sup>) and especially in summer (92.2 ind L<sup>-1</sup>, 0.43  $\times 10^3 \mu$ g L<sup>-1</sup>) at a depth of 10 m. These peaks of abundance and biomass were associated with the development of the copepods and cladocera (Figure 5a to d). The species *A. viridis* and *D. brachyurum* were responsible for the exceptional peak the abundance that occurred in summer, accounting respectively for 57% and 38% of the total zooplankton abundance. The peak of biomass was related to the proliferation of the copepods (the species *A. viridis* accounted for 83% of the total biomass).



**Figure 3.** Vertical profiles of water temperature (a), dissolved oxygen (b), and pH (c), suspended matter (d), total nitrogen (e) and total phosphorus (f) along the water column in the Sidi Saâd reservoir.

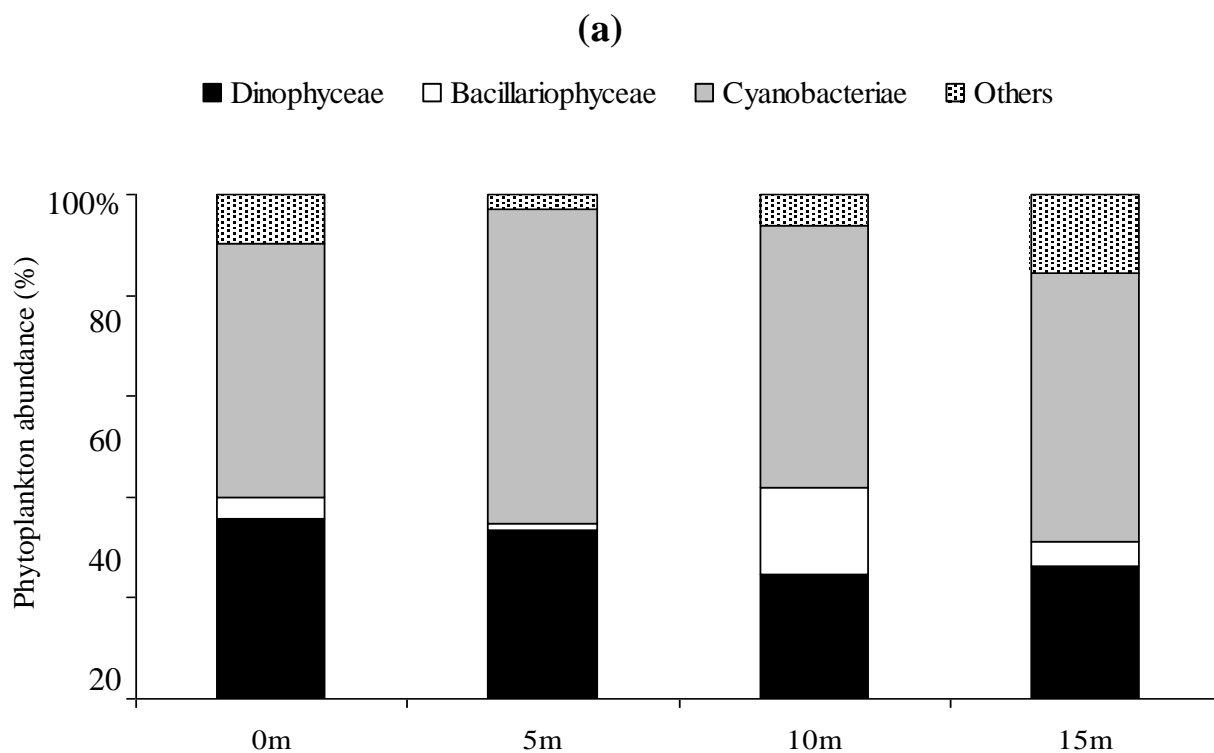
**Table 1.** Values of trophic index

TSI <sub>C</sub>	TSI <sub>C</sub> Sidi Saâd	Trophic status	TL <sub>B</sub>	TSI <sub>B</sub> Sidi Saâd	Trophic status
<30		Oligotrophic	0.0 - 1.0		Ultra-microtrophic
30-40	34.5	Oligo-mesotrophic	1.0 - 2.0		Microtrophic
40-50		Mesotrophic	2.0 - 3.0		Oligotrophic
50-60		Eutrophic	3.0 - 4.0		Mesotrophic
60-70		Eutrophic- hypereutrophic	4.0 - 5.0	5	Eutrophic
>70		Hypereutrophic	5.0 - 6.0		Supertrophic
			6.0 - 7.0		Hypertrophic

TSI<sub>C</sub>, Carlson and Simpson index; TSI<sub>B</sub>, Burns and Bryers index.

**Table 2** . Plankton taxa found in Sidi Saâd reservoir.

Phytoplankton		Zooplankton
<b>Cyanophyceae</b>	<b>Dinophyceae</b>	<b>Copepoda</b>
<i>Anabaena</i> sp.	<i>Gonyaulax</i> sp.	<i>Acanthocyclops robustus</i> <i>Acanthocyclops viridis</i>
<i>Chroococcus</i> sp.	<i>Gonyaulax spinifera</i>	
<i>Gleothoece</i> sp.	<i>Peridinium africanum</i>	<b>Cladocera</b>
<i>Microcystis aeruginosa</i>	<i>Peridinium</i> sp.	<i>Diaphanosoma brachyurum</i>
<i>Microcystis</i> sp.	<i>Proto-peridinium</i> sp.	
<i>Planktolyngbya subtilis</i>		<b>Rotifera</b>
<i>Pseudoanabena</i> sp.	<b>Chlorophyceae</b>	<i>Brachionus urceolaris</i>
	<i>Scenedesmus</i> sp.	<i>Hexarthra mira</i>
<b>Bacillariophyceae</b>	<i>Closterium</i> sp.	<i>Keratella quadrata</i>
<i>Amphiprora</i> sp.	<i>Tetraedron</i> sp.	<i>Keratella cochlearis</i>
<i>Cylindrotheca closterium</i>		<i>Asplanchna</i> sp.
<i>Navicula</i> sp.1	<b>Conjugatophyceae</b>	
<i>Navicula</i> sp.2	<i>Cosmarium</i> sp.	
<i>Nitzschia</i> sp.		
<i>Pinnularia</i> sp.		

**Figure 4.** Spatial and temporal variation of phytoplankton abundance groups' (a and b) and chlorophyll a concentrations(c) in the Sidi Saâd reservoir.

The species *D. brachyurum* (78% of the total abundance) and *A. viridis* were responsible for the peak that occurred in autumn (17% of the total zooplankton abundance, and 48% of the total zooplankton biomass). The relationship between phytoplankton and zoo-

plankton was evidenced by a comparison of further changes in density of both communities. Consequently, the decrease in the density of phytoplankton was associated by an increase in zooplankton density (Figure 6a). More also, the biomass of fish varied between 4.33 Kg

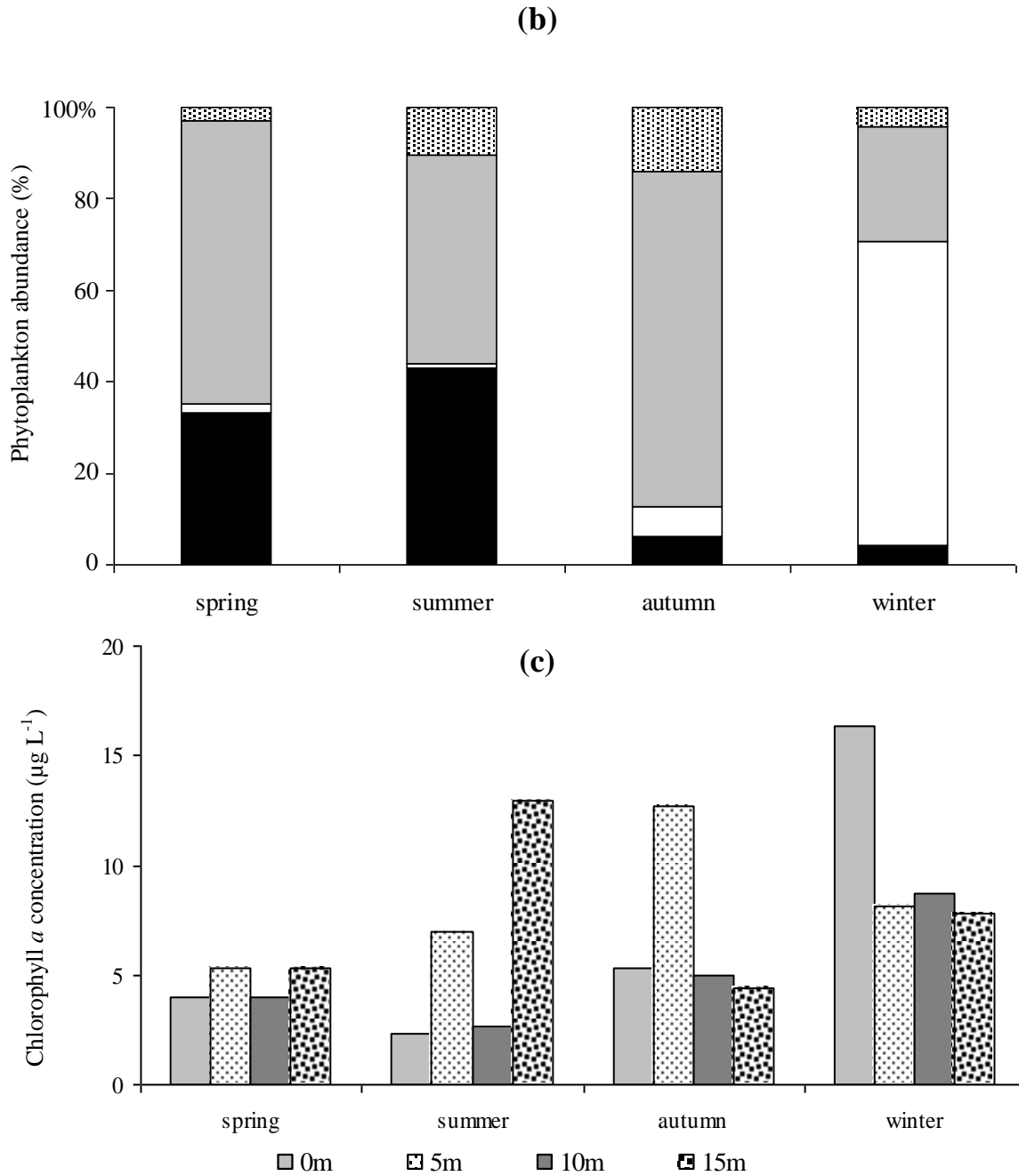


Figure 4. Continue.

per hectare in summer and 11 Kg per hectare in winter (Figure 6b).

**Species diversity**

The diversity index of phytoplankton ( $H'$ ) varied between the seasons. The higher values were observed in autumn (2.93 bits cells<sup>-1</sup>, 18 species). However, the lowest are observed in spring (1.46 bits cells<sup>-1</sup>, 14 species). The

diversity index of zooplankton ( $H'$ ) varied between 0.80 bits ind L<sup>-1</sup> in winter and 1.38 bits ind L<sup>-1</sup> in spring.

**Community analysis**

The zooplankton abundance was positively correlated with the temperature ( $r = 0.53$ ,  $p = 0.027$ ,  $n = 16$ ) and negatively correlated with the dissolved oxygen ( $r = -0.59$ ,  $p = 0.03$ ,  $n = 16$ ). A principal component analysis (PCA)

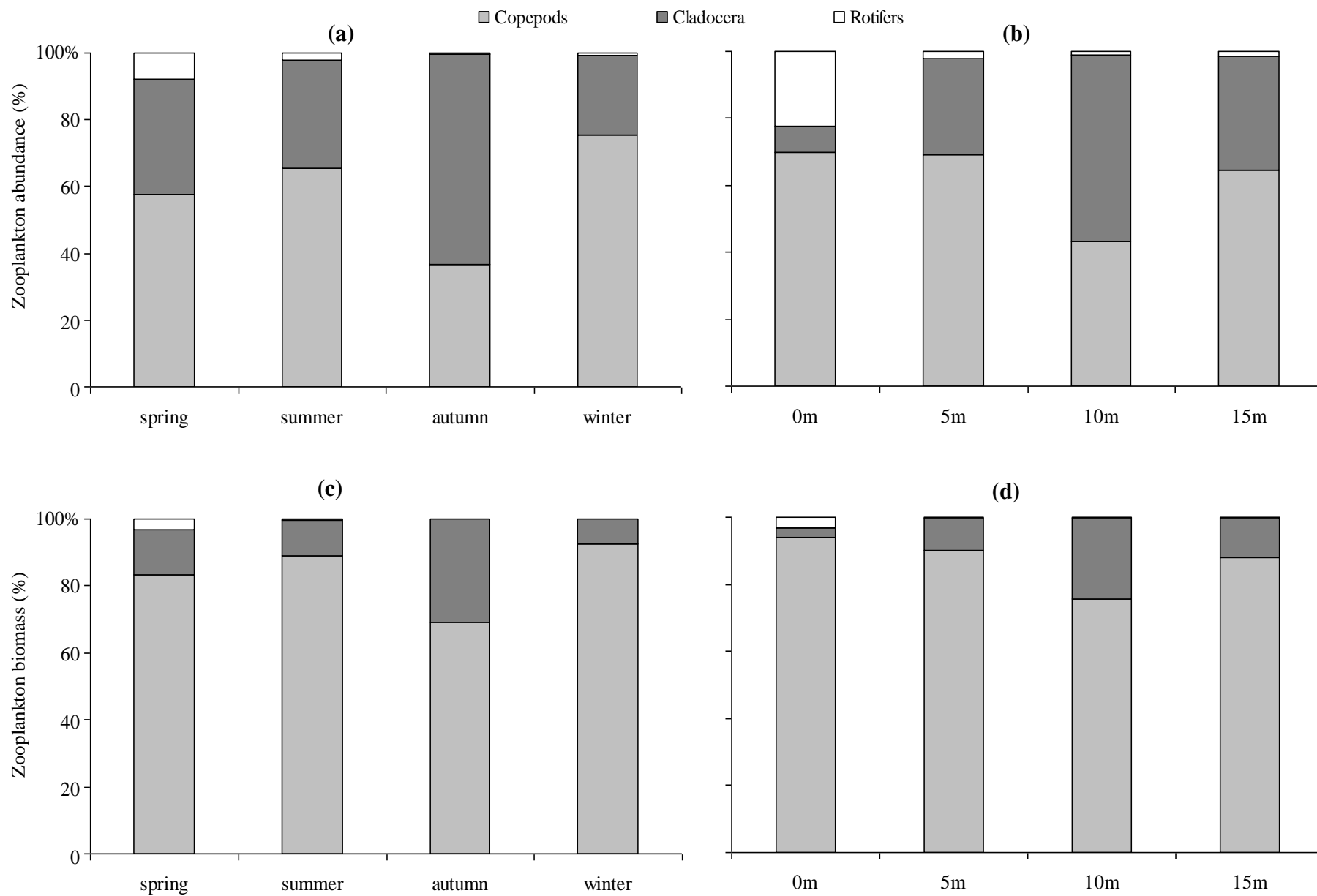
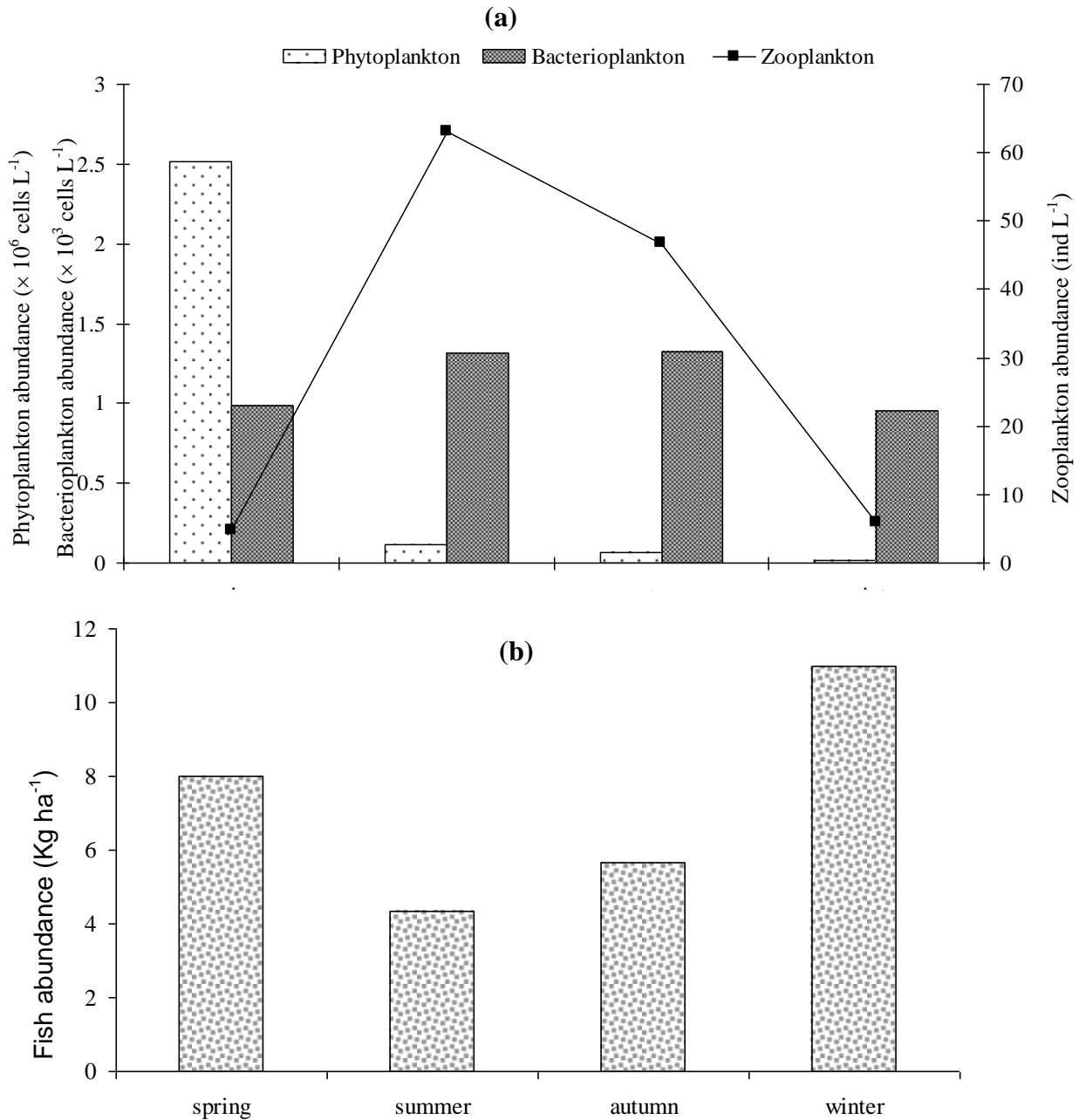


Figure 5. Spatial and temporal variation of zooplankton groups' abundance (a and b) and biomass (c and d) in the Sidi Saâd reservoir.





**Figure 6.** Spatial and temporal variation of total phytoplankton, bacterioplankton and total zooplankton abundances (a), and biomass of fish (b) in the Sidi Saâd reservoir.

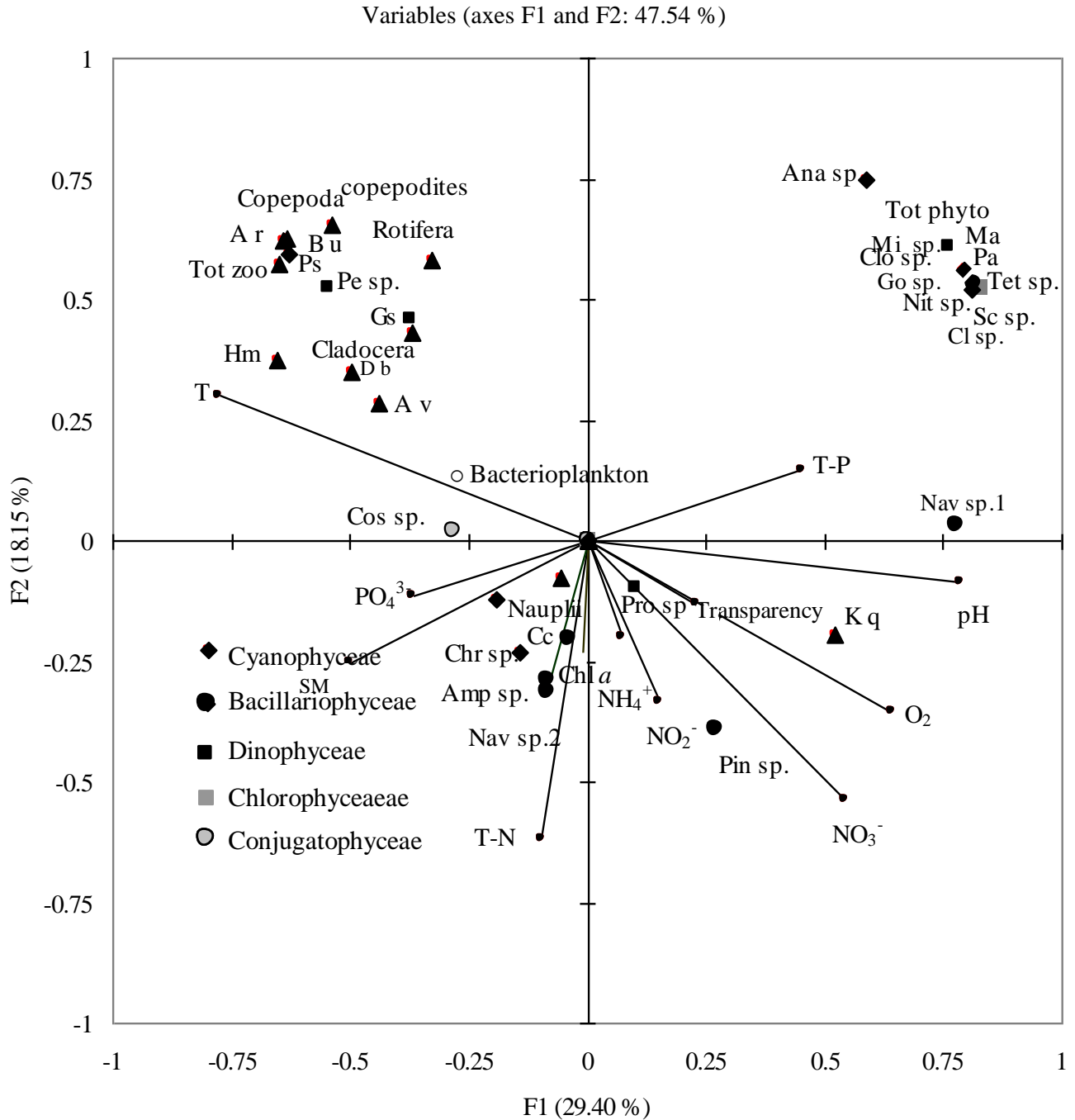
was applied to environmental factors (zooplankton and phytoplankton communities, chlorophyll *a* and physico-chemical variables) as shown in Figure 7.

**DISCUSSION**

The trophic level is a critical indicator of water quality as it provides a measure of the nutrient status of a body of water. For lakes and reservoirs, four (Chlorophyll *a*,

Secchi depth, total phosphorus and total nitrogen) commonly measured key variables are good indicators of the trophic level. Detecting a small degree of deterioration in a reservoir enables remedial action to be taken before the reservoir undergoes extensive degradation.

Our study indicated an oligo-mesotrophic status (Carlson, 1977; Carlson and Simpson, 1996) toward tendency to eutrophic status (Burns and Bryers, 2000). The seasonal patterns of zooplankton abundance and distribution are results from interactions of various factors



**Figure 7.** Principal component analysis (PCA) (axes 1 and 2) on mean values of environmental and biological variables in the Sidi Saâd reservoir. T, Water temperature; O<sub>2</sub>, dissolved oxygen; SM, suspended matter; NO<sub>2</sub><sup>-</sup>, nitrite; NO<sub>3</sub><sup>-</sup>, nitrate; NH<sub>4</sub><sup>+</sup>, ammonium; T-N, total nitrogen; PO<sub>4</sub><sup>3-</sup>, orthophosphate; T-P, total phosphorus; T zoo, total zooplankton; T phyto, total phytoplankton; Ana sp., *Anabena* sp.; Chr sp., *Chroococcus* sp.; Clo sp., *Gloeotheca* sp.; Ma, *Microcystis aeruginosa*; Mi sp., *Microcystis* sp.; Ps, *Planktolyngbya subtilis*; Ps sp., *Pseudoanabena* sp.; Amp sp., *Amphiprora* sp.; Cc, *Cylindrotheca closterium*; Nav sp.1, *Navicula* sp.1; Nav sp.2, *Navicula* sp.2; Nit sp., *Nitzschia* sp.; Pin sp., *Pinnularia* sp.; Go sp., *Gonyaulax* sp.; G,s *Gonyaulax spinifera*; Pa, *Peridinium africanum*; Pe sp., *Peridinium* sp.; Pro sp., *Protoperidinium* sp.; Sc sp., *Scenedesmus* sp.; Cl sp., *Closterium* sp.; Tet sp., *Tetraedron* sp.; Cos sp., *Cosmarinum* sp.; Chl a, chlorophyll a; A r, *Acanthocyclops robustus*; A v, *Acanthocyclops viridis*; D b, *Diaphanosoma brachyurum*; H m, *Hexarthra mira*; B u, *Brachionus urceolaris*; K q, *Keratella quadrata*.

such as water temperature, food quality, competition and selective feeding of fish. The highest density of zooplankton was recorded in summer and autumn; which can be related to temperature (averaged 25°C). A positive correlation was observed between zooplankton abundance and temperature ( $r = 0.53$ ,  $p = 0.027$ ,  $n = 16$ ). This is in accordance with the study of Primo et al. (2009) concluding that water temperature was the main factor influencing the spatial and temporal patterns of zooplankton distributions. Furthermore, not much variation in pH values was observed. Water pH is known to affect crustacean plankton community composition (DeSellas et al., 2008; Tavernini et al., 2009) with crustaceans being more sensitive than rotifers to extreme pH levels (Berzins and Bertilsson, 1990). The dissolved oxygen values were decreased in summer and autumn. This depletion was associated with the development of zooplankton. A negative correlation was observed between zooplankton abundance and dissolved oxygen ( $r = -0.59$ ,  $p = 0.03$ ,  $n = 16$ ). Our findings appear to agree with what is known about the influence of dissolved oxygen on zooplankton densities (Whitman et al., 2004). Probably, the high abundance of phytoplankton caused high content of dissolved oxygen, thus negative correlation.

In the present study, the zooplankton abundance was dominated by cyclopoid copepods and cladocerans; comparable results have been found in floodplain reservoir (Fisher and Parsley, 1979). Among the copepods, juveniles (copepodites) dominated. Food availability and quality are important factors determining the abundance and composition of zooplankton communities in this reservoir. And similar results were found by Agasild et al. (2007). During the study period, the dominance of inedible cyanobacteria provokes a very low species diversity of zooplankton; only one species of cladocera, *D. brachyurum* was found. An ecosystem generally becomes poor at high trophic levels (Leoni and Garibaldi, 2009) with few species and a low structural complexity.

The absence of *Daphnia* was probably explained by the quality of food.

The absence of daphnids as also caused by presence of planktivorous fish. In lakes, planktivorous fish have significant impacts on zooplankton (Persson et al., 2004) imposing top-down control on the food web. In Missisquoi Bay, introduced planktivorous fish had impact plankton communities through a reduction in *Daphnia* density (Couture and Watzin, 2008). Thus, good predictors for the observed variability of daphnid growth in reservoirs were found among a variety of algal quality and quantity (Scheuerell et al., 2002). The rotifers are not susceptible to a toxic influence of blue-green algae (Kirk and Gilbert, 1992). Thus, the low density of rotifer observed during this study was probably caused by other factors such as invertebrate predation. The importance of invertebrate predation on rotifer populations was confirmed by Yan et al. (1991).

The warm temperatures in spring, typical of semi arid area, that enables a faster growth of cyanobacteria, possibly allied with cladoceran grazing pressure (top-down control) in small edible phytoplankton, promote their dominance and the appearance of blooms in Sidi Saâd. Many studies (Weithoff et al., 2000) show that zooplankton grazing can interfere in phytoplankton dynamics and have an impact on phytoplankton diversity. The development of cyanobacteria can explain the unobserved spring peak of zooplankton in this reservoir. Similar results were found by Abrantes et al. (2006). The peak of zooplankton, especially the cladocera, occurs in autumn as a consequence of the nutrient replenishment (bottom-up control) and the subsequent development of cyanobacteria.

Therefore, smaller cladocerans are less affected by cyanobacteria (Pinel-Alloul, 1993). In contrast, cyclopoids can be expected to be more sensitive to food quantity and quality (Anneville et al., 2007).

In winter, the reduction of light energy results in phytoplankton density decrease to the minimum, which is associated to cool winter temperatures and restricts zooplankton production rates and, for some species, stimulates diapause (Sommer et al., 1986). In addition, the lower temperature (< 10°C) is also an important factor that can explain their lower winter densities. Furthermore, the results showed that the zooplankton community structure is significantly influenced by precipitation, with maximum values of 56 mm in winter. The same results were found by Guevara et al. (2009) showing that a negative association was observed between zooplankton density and rainfall intensity. In the same way copepods (cyclopoids) became abundant when rainfall was lower (Sánchez-Carrillo and Cobelas, 2001).

The variation in chlorophyll *a* values was also reflected in zooplankton densities. An inverse zooplankton-chlorophyll *a* relationship was observed. These results are in agreement with study by Forrest and Arnott (2007). In addition, the highest zooplankton density was found in the upper water layer (0 to 10 m). This vertical distribution was probably related to the food accessibility. This finding supports the field observations of several studies (Cherbi et al., 2008). The zooplankton community of Sidi Saâd reservoir (mainly cyclopoids copepods and *D. brachyurum*) probably had a lesser impact on bacteria because of their specific feeding modes (Sanders and Wickham, 1993). Cyclopoid copepods are mainly carnivores, feeding on relatively large prey, while smaller prey like bacteria are not efficiently ingested (Sanders and Wickham, 1993). We did not observe a significant correlation between zooplankton and bacterioplankton abundances. Moreover, fish predation is another factor affecting the zooplankton community. The decline of zooplankton density in spring and winter was probably attributable to the top-down control from planktivorous fishes (Figure 6b). These results are in agreement with many studies (Abrantes et al., 2006; Medley and Havel,

2007).

## Conclusion

Environmental parameters especially the water temperature and dissolved oxygen play an important role in determining the zooplankton species abundance and diversity in the Sidi Saâd reservoir. Moreover, the present work demonstrated that phytoplankton is an important factor responsible for the succession of zooplankton community, which is well related to changes in algae composition and density, the cyanobacteria being the group with major impact. Furthermore, fish predation is another factor affecting the zooplankton seasonal dynamics. In addition, the occurrence of a massive Cyanobacteria bloom during this study and the dominance of cyclopoids copepods in this reservoir indicated high trophic levels.

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