Seasonal composition and population density of zooplankton in Lake Timsah, Suez Canal, Egypt

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Abstract

Zooplankton composition and abundance were investigated seasonally at ten sites in Lake Timsah and the adjacent, connected western lagoon in relation to the physico-chemical conditions. A total of 42 taxa (including larval stages) were identified, among them 21 species of copepods, 6 rotifers, 5 cladocerans, 1 chaetognath and 1 urochordate. Copepods represented the predominant component (77.7%

of the total community), followed by rotifers, molluscs, cladocerans and (9.2, 4.7 and 3.9% respectively), while other groups collectively formed about 4.5% of the total zooplankton population. Summer was the most productive season with an average count of 40 864 individuals m^{-3}. The dominant copepod species were *Paracalanus crassirostris* and *Oithona nana* representing 28.3 and 24.3% of the total zooplankton respectively. The total zooplankton count, including copepods, and its dominant species showed significant positive correlations with temperature, pH and total phytoplankton density. However, negative correlations were detected between densities of rotifers, and salinity and dissolved oxygen.

1. Introduction

Zooplankton play an important role in the biological cycling of carbon and other elements in the ocean. Seasonal zooplankton dynamics and the mechanisms driving their variability are highly susceptible to changes of environmental variables, especially in shallow, semi-enclosed bays with heavily populated shores where increased anthropogenic nutrient input severely affects marine communities (Marcus 2004). Many studies have highlighted the significance of the trophic relationship between phytoplankton and zooplankton in estuarine ecosystems (Sautour et al. 1996). An increase in nutrient loading can cause an increase in phytoplankton productivity and standing stocks (Breitburg et al. 1999), especially in the large-sized phytoplankton (Kilham & Kilham 1984). These changes may in turn result in an increase in zooplankton foraging, particularly in copepods (Tan et al. 2004). Several previous studies have indicated that large phytoplankton cells are more likely to be ingested by mesozooplankton communities dominated by copepods (Uye 1986, Bautista & Harris 1992, Nejstgaard et al. 1995, Hansen et al. 2000). In addition, elevated nutrient loadings may cause a change in the ratio of macronutrients, which may alter the species composition, dominance and succession of zooplankton (Breitburg et al. 1999, Park & Marshall 2000).

Studies on the zooplankton communities of Lake Timsah are quite fragmentary when compared to other Egyptian lakes. Most of these studies were based on short-term sampling and considered the lake as one site among many along the Suez Canal (Giesbrecht 1896, Thompson & Scott 1903, Heron-Allen & Earland 1926, Browne 1926, Burfield 1927, Harant 1927, Gurney 1927a,b, MacDonald 1933, Ghazzawi 1938, Kimor 1972, El-Serehy & Shalaby 1994, El-Serehy et al. 2000, El-Serehy et al. 2001). Abou-Zeid (1990) remains the only detailed study, based as it is on monthly collections from many sites representing the lake. Taking into consideration the importance of Lake Timsah with regard to fisheries, tourism and recreational activities, it is important to identify the present status of the lake. Since up-to-date information about zooplankton community dynamics in the lake is desirable, the aim of the present investigation was to study the composition, abundance and species diversity of the zooplankton community in Lake Timsah and to establish its space-time variations in relation to the environmental conditions.

2. Material and methods

2.1. Study area

Lake Timsah lies adjacent to Ismailia City near the middle of the Suez Canal at a point 80 km south of Port Said. It covers about 16 km^2 and is between 3 and 16 m in depth. The lake is considered one of the most productive along the Suez Canal (Fouda 1993, Ahmed 2005, Madkour et al. 2006). On the western side, the lake is connected to a small, shallow lagoon via a narrow passage. The human population of Ismailia is around 1 million. As estimated by ETPS (1995), the western lagoon receives about 833 000 m^3 day^{-1} of domestic and agricultural wastewaters from many drains (the Elmahsama, Abu-Gamouss, Abu-Attwa and Elbahtini drains). On the northern side, the lake receives occasional inputs from the Ismailia freshwater canal (ETPS 1995, Madkour et al. 2006). During the last decade, the efficiency of water treatment plants has improved and the Elbahtini drain has been closed. Despite the diminishing amounts of wastewaters, the lake is still under threat from pollutants (El-Moselhy et al. 2005, Kaiser et al. 2009) as a result of extensive human settlement where domestic agricultural and industrial effluents are continuously discharged. To some extent, this affects the ecological and biological conditions of the lake. Such changes will be manifested in the flourishing or avoidance of some organisms including zooplankton.

2.2. Sample collection

The study area covered Lake Timsah and the western lagoon. Ten sites were sampled seasonally from autumn 2005 to summer 2006. They were chosen to cover different localities representing variable impacts on the lake (Figure 1). Sites 1–3 were located in the northern, middle and southern parts of the Canal's shipping lane respectively. Sites 4–9 were distributed inside the lake, and site 10 lay in the western lagoon. Zooplankton samples were collected at sites 1–9 by vertical hauls (from bottom to the surface) using a plankton net of 150 μm mesh and 40 cm diameter. At site 10, 50 litres of water were collected with a bucket and sieved with the same net. The samples were preserved in 5% neutral formalin solution and their volumes concentrated to 100 ml. Three replicates of 5 ml were transferred to a Bogrove counting tray, and each zooplankter was identified and counted

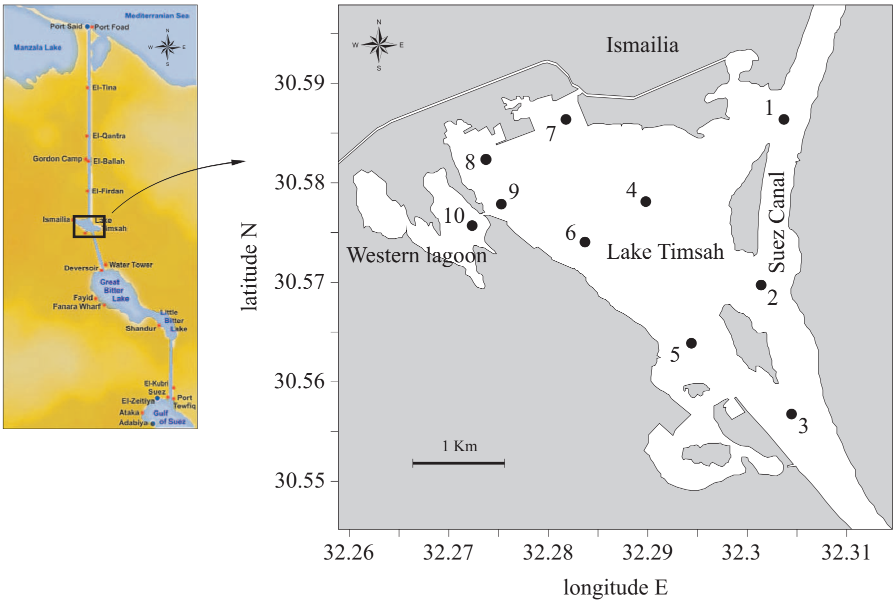

Figure 1. Map of Lake Timsah and location of sampling sites

under a binocular research microscope. The zooplankton organisms were identified according to Giesbrecht (1892), Rose (1933), Tregouboff & Rose (1957) and Edmondson et al. (1959). The standing crop of the total zooplankton community was calculated and expressed in numbers per cubic metre.

2.3. Data analysis

The Pearson correlation coefficient at a confidence limit of 95% was applied using SPSS 13.0 to study the relation between zooplankton distribution and the environmental variables. The species richness, Shannon-Weaver index H' and evenness J' (Pielou 1966) as well as the Bray-Curtis Similarity Index were computed using the software packages PRIMER program V 5.1. These parameters were calculated for each site by pooling data from the sample replicates. Prior to analysis, data were subjected to logarithmic transformation in order to achieve the appropriate parametric analysis requirements (Zar 1984).

Species richness was expressed by considering the number of species D:

$$D = (S - 1)/\ln N, \tag{1}$$

where
D – Margalef's index (richness),
S – number of species,

N – total number of individuals.

Species diversity and homogeneity were determined using the Shannon-Weaver diversity index H' and the evenness index J' (Pielou 1966) from the following equations:

$$H' = -\sum_i P_i(\ln P_i), \tag{2}$$

where P_i – the ratio of the total number of individuals of particular species n to the total number of individuals S, that is $P_i = n_j/S$.

$$J' = H'(\text{observed})/H'_{\text{Max}}, \tag{3}$$

where H'_{Max} – the maximum possible diversity that would be achieved if all species had the same abundance = $(\ln S)$, and S – total number of individuals of particular species.

3. Results

3.1. Environmental parameters

The measured physicochemical parameters were published by Madkour et al. (2006). The average values of these parameters and of the chlorophyll *a* concentration throughout the lake are given in Table 1. Variation in salinity appeared to be the key factor to all changes in the lake's water quality. The lowest surface salinity (average: 1.5 PSU) was recorded in the western lagoon. This salinity increased gradually eastwards, fluctuating between 12 and 37.8 PSU. The lake is considered a low transparent water body: the average Secchi disc reading ranged from 0.38 to 1.91 m at sites 10 and 2 respectively. The concentrations of both nutrient salts and chlorophyll *a* were the highest in the western lagoon and decreased gradually eastwards, coinciding with the increase in salinity, reaching the lowest values in the shipping lane (Table 1). The ranges of the annual nutrient salt averages were 0.7–4.9 μM, 5.1–36.5 μM, 0.1–0.8 μM, 3.4–29.9 μM for phosphate, nitrate, nitrite and silicate respectively.

3.2. Species composition and population density

In total, 34 species were identified (in addition to the larval stages of different groups) from Lake Timsah. Most of them were copepods (21 species), rotifers (6 species) and cladocerans (5 species); urochordates and chaetognaths were represented only by one species each. Other groups (polychaetes, molluscs, decapods, echinoderms and urochordates) were represented by their larval stages. The lowest number of species was recorded in the western lagoon during all seasons (average: 14 taxa including larval stages). On the other hand, the shipping lane sites sustained the highest number of species (29 taxa) at site 1 (Figure 2).

Table 1. Average values of different physicochemical parameters and chlorophyll *a* in Lake Timsah during the study period

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
temperature [°]	22.1	22.1	22.1	22.4	22.6	22.8	22.6	22.9	22.4	22.5
transparency [m]	1.6	1.9	1.5	1.0	1.1	0.9	1.1	1.2	0.6	0.4
salinity [PSU]	37.8	37.8	36.3	28.5	33.3	31.3	26.0	21.8	12.0	1.5
pH	8.1	8.1	8.1	8.0	8.0	8.1	8.0	8.0	7.9	7.9
oxygen [mg l^{-1}]	7.2	7.1	7.3	7.5	6.8	6.9	7.2	7.3	7.7	5.2
phosphate [μM]	1.2	0.7	0.7	2.2	0.8	1.6	2.3	3.4	3.8	4.9
nitrate [μM]	7.9	5.5	5.1	14.7	8.2	14.5	16.4	20.4	24.1	36.5
nitrite [μM]	0.1	0.1	0.1	0.2	0.1	0.2	0.3	0.3	0.4	0.8
silicate [μM]	4.2	3.8	3.4	9.6	6.0	9.1	10.1	12.2	17.3	29.9
chlorophyll *a* [μg l^{-1}]	16.2	13.4	11.0	12.6	10.8	19.4	20.7	17.4	20.2	22.7
depth [m]	15	16	16	15	8	7	7	6	4	0.5

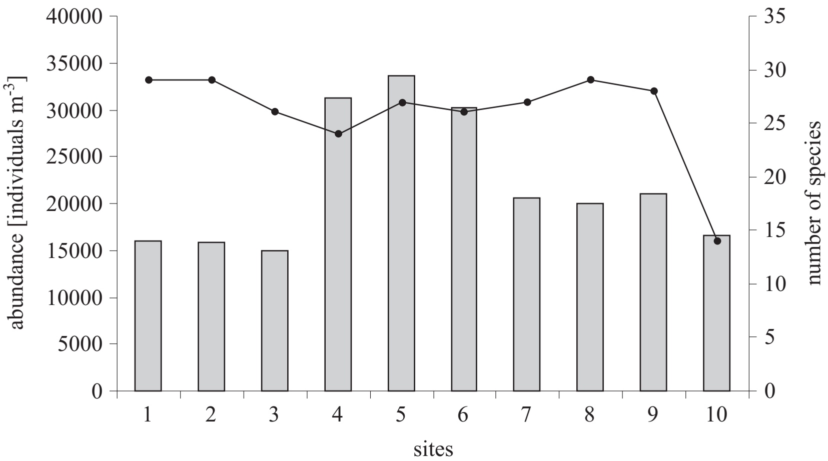

Figure 2. Spatial distribution of total zooplankton (individuals m^{-3}) and number of species recorded in Lake Timsah during the period of study

Zooplankton was represented mainly by holoplanktonic groups with an average of 20 098 individuals m^{-3}, forming 91.2% of the total zooplankton. The remaining 8.8% consisted of meroplanktonic groups (molluscs, polychaetes, cirripedes, decapods and echinoderms) (Table 2). Copepods were the predominant component of the holoplankton in Lake Timsah during all seasons in terms of species diversity and numerical abundance. Numerically, copepods made up 77.7% of the total zooplankton population, with an annual average of 17 119 individuals m^{-3} (Figure 3). Their larval stages (nauplii and copepodites) respectively made up 23.2 and 18% of the total copepods and total zooplankton, with an average of 3978 individuals m^{-3}. On the other hand, adult copepods were more abundant than larval stages, with an average of 13 242 individuals m^{-3}, forming 76.8 and 59.7% of the total copepods and total zooplankton respectively. Among the most dominant copepod species were *Paracalanus crassirostris* and *Oithona nana* (36.5, 28.3 and 31.3, 24.3% of the total copepods and total zooplankton respectively). Rotifers formed the second most important group, comprising about 9.2% of the total zooplankton count with an annual average of 2036 individuals m^{-3} (Figure 3). Rotifers were mostly represented by *Brachionus calyciflorus* and *B. plicatilis* (forming 65, 6% and 2.8, 30.8% of the total rotifers and total zooplankton respectively). Although cladocerans were represented by 5 species, collectively they formed only about 3.9% of the total zooplankton density in the lake, with relatively higher densities at the western and central sites of the lake (4–9). Molluscs and polychaetes were represented only by their larval stages, which made up about 4.7 and 2.7% of the total zooplankton count with respective annual averages of 1029 and 592 individuals m^{-3} (Figure 3). Lamellibranch and gastropod veligers constituted 55.1 and 44.9% of the total mollusc count respectively. Cirripede larvae accounted for 1% of the total zooplankton count, with an annual average of 211 individuals m^{-3}. Chaetognaths was represented only by *Sagitta enflata*, which appeared infrequently and did not exceed 0.01% of the total zooplankton community. Decapod and echinoderm larvae were rare at some sites during spring and summer.

3.3. Spatial distribution of the zooplankton standing crop

The annual average zooplankton standing crop throughout the study area was 22 026 individuals m^{-3}. As illustrated in Figure 2, the highest density (annual average: 33 645 individuals m^{-3}) was recorded at site 5, followed by sites 4 and 6 (annual averages: 31 198 and 30 211 individuals m^{-3} respectively). Sites 1, 2, 3 harboured the lowest standing crop with a minimum density of 14 985 at site 3. Based on numerical abundance, copepods were the most dominant zooplankton group, making up the bulk

Table 2. Seasonal distribution of the recorded zooplankton groups [indiv. $m^{-3} \pm SD$] and their percentage frequency in Lake Timsah during the period of study

Groups	Season									
	Autumn		Winter		Spring		Summer		Average	
	No.	[%]	No.	[%]	No.	[%]	No.	[%]	No.	[%]
Rotifera	2078 ± 4410	7.7	1124 ± 2568	13.1	2638 ± 6678	22.4	2305 ± 4421	5.6	2036 ± 4457	9.2
Polychaeta	1055 ± 572	3.9	237 ± 179	2.8	86 ± 65	0.7	990 ± 1025	2.4	592 ± 384	2.7
Cladocera	22 ± 62	0.1	2076 ± 1391	24.2	492 ± 269	4.2	818 ± 508	2.0	852 ± 475	3.9
Copepoda	$22\,263 \pm 10\,806$	82.8	4893 ± 2185	57.0	7841 ± 3610	66.6	$33\,479 \pm 16\,847$	81.9	$17\,119 \pm 7775$	77.7
Cirripedia	10 ± 10	0.0	69 ± 62	0.8	358 ± 228	3.0	407 ± 354	1.0	211 ± 128	1.0
Lamellibranchia	90 ± 101	0.3	36 ± 32	0.4	336 ± 253	2.9	1804 ± 1466	4.4	567 ± 370	2.6
Gastropoda	1070 ± 1893	4.0	100 ± 85	1.2	14 ± 24	0.1	668 ± 630	1.6	463 ± 632	2.1
Decapoda	0	0.0	0	0.0	7 ± 8	0.1	377 ± 412	0.9	96 ± 102	0.4
Urochordata	304 ± 303	1.1	43 ± 77	0.5	4 ± 8	0.0	1 ± 4	0.0	88 ± 82	0.4
others	0	0.0	1 ± 3	0.0	0	0.0	8 ± 5	0.0	2 ± 3	0.0
Total	$\mathbf{26891 \pm 9262}$	**100**	$\mathbf{8580 \pm 1967}$	**100**	$\mathbf{11\,776 \pm 6200}$	**100**	$\mathbf{40\,857 \pm 17\,380}$	**100**	$\mathbf{22\,026 \pm 7035}$	**100**

of the zooplankton population in most of the studied sites (Figure 4). The highest copepod densities were observed in the middle of the lake (sites 4–6), decreasing gradually towards the western side of the lake (sites 7–9) and the shipping lane sites (1–3); its average values ranged between 1896 at site 10 (11.4% of the total count) and 28 479 individuals m^{-3} at site 5

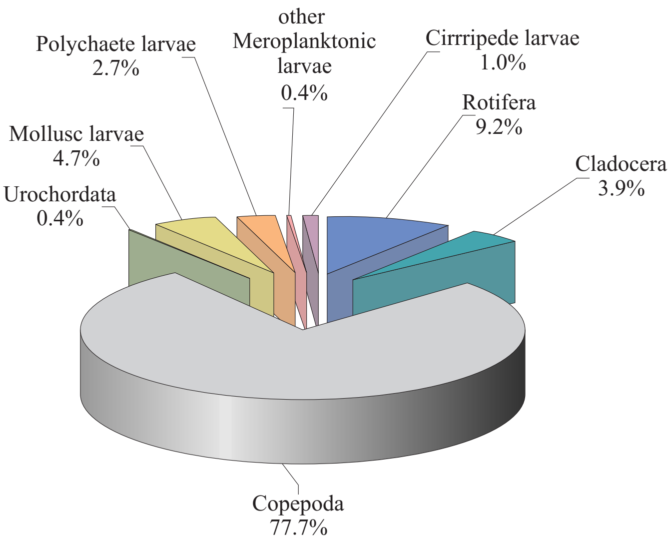

Figure 3. Percentage of occurrence of the recorded zooplankton groups in Lake Timsah during the period of study

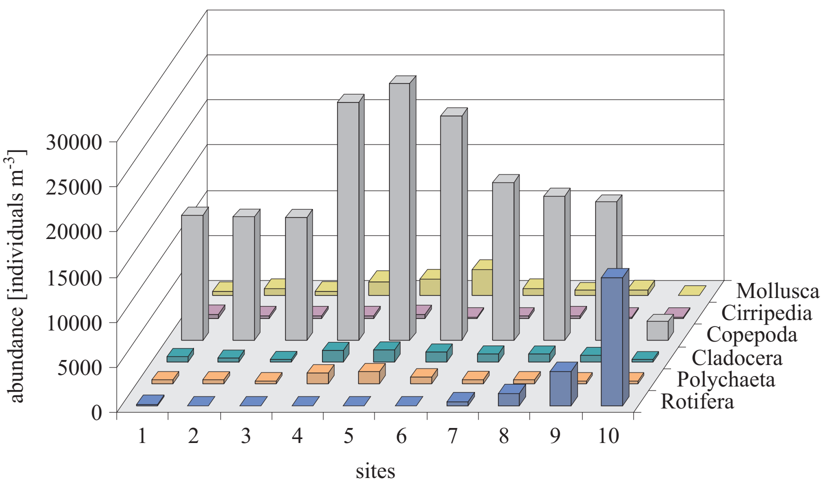

Figure 4. Spatial distribution of the dominant zooplankton groups in Lake Timsah during the period of study

(84.6%). Both copepod larval stages as well as dominant adult species (*P. crassirostris*, *O. nana*, *Centropages kroyeri*, *Euterpina acutifrons* and *Paracalanus parvus*) showed nearly the same pattern of total zooplankton, the highest densities being in the middle of the lake and values decreasing on the western side and at the shipping lane sites. The abundance was lowest at site 10. The freshwater copepod *Mesocyclops leuckarti* was recorded only at sites 9 and 10 with respective averages of 24 and 614 individuals m^{-3}.

Rotifers were the most dominant group in the western lagoon (site 10), making up 85.4% of the total zooplankton population at this site. Their abundance decreased gradually: densities were minimal on the western side of the lake (sites 7–9) and nearly zero in the middle of the lake (Figure 4). Other zooplankton groups (cladocerans, molluscs, polychaetes and urochordates) showed nearly the same distributional pattern as the total zooplankton. Their densities were the highest in the middle of the lake (sites 4–6) and decreased gradually towards the western sites and the shipping lane sites (Figure 4). On the other hand, the abundance was the lowest at site 10. The highest count of cirripedes was in the shipping lane (sites 1–3) with a maximum average of 403 individuals m^{-3} at site 1, and decreased in the lake; cirripedes were not present in the western lagoon.

3.4. Seasonal distribution of the zooplankton standing crop

The seasonal average of the total zooplankton standing stock throughout the study area showed that the lake was productive all the year round. Abundance was at its lowest (average: 8580 individuals m^{-3}) during winter. Obviously, the most frequently sampled sites showed a more or less similar

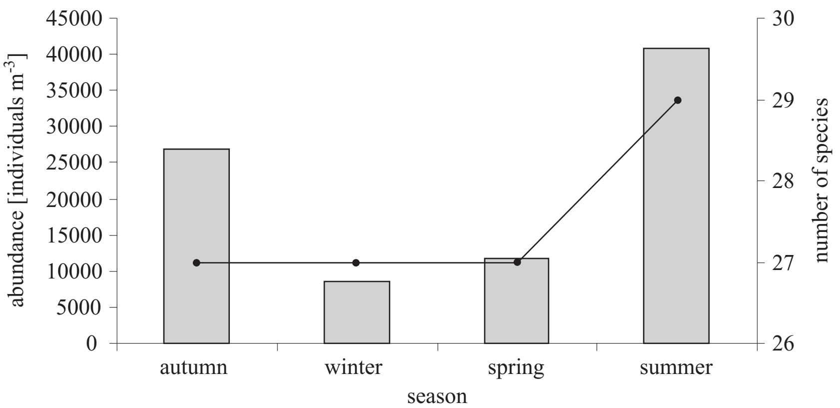

Figure 5. Seasonal distribution of total zooplankton (individuals m^{-3}) and number of species recorded in Lake Timsah during the period of study

seasonal variation. The zooplankton standing crop increased gradually during the subsequent seasons (spring), showing a distinct peak (average: 40 857 individuals m^{-3}) in summer and another smaller one in autumn with an average of 26 891 individuals m^{-3} (Figure 5).

In summer, copepods dominated the zooplankton community (average: 33 479 individuals m^{-3}), constituting 81.9% of the total zooplankton (Figure 6). They were represented by 12 species: *P. crassirostris*, *O. nana*, *E. acutifrons*, *C. kroyeri*, *C. furcatus*, *P. parvus*, *M. leuckarti*, *Acartia negligens*, *Acrocalanus gibber*, *A. latisetosa*, *Microsetella norvigica* and *Harpacticus* sp. Of these, *P. crassirostris* and *O. nana* were the dominant species at all sites (except site 10) with averages of 17 517 and 10 013 individuals m^{-3} (42.9 and 24.5% of the total zooplankton) respectively. Mollusc larvae were the second most abundant group with an average of 2472 individuals m^{-3}, making up 6% of the total zooplankton count (Figure 6). They were dominated by lamellibranch veligers (1804 individuals m^{-3}) representing 4.4% of the total zooplankton. Rotifers constituted 5.6% of the total zooplankton (average: 2306 individuals m^{-3}) with *Brachionus calyciflorus* dominant at sites 9 and 10 with an average of 1701 individuals m^{-3} (73.8 and 4.2% of the total rotifers and total zooplankton) respectively.

During autumn, the zooplankton showed a smaller peak than in summer, but practically the same groups and species were dominant, although they

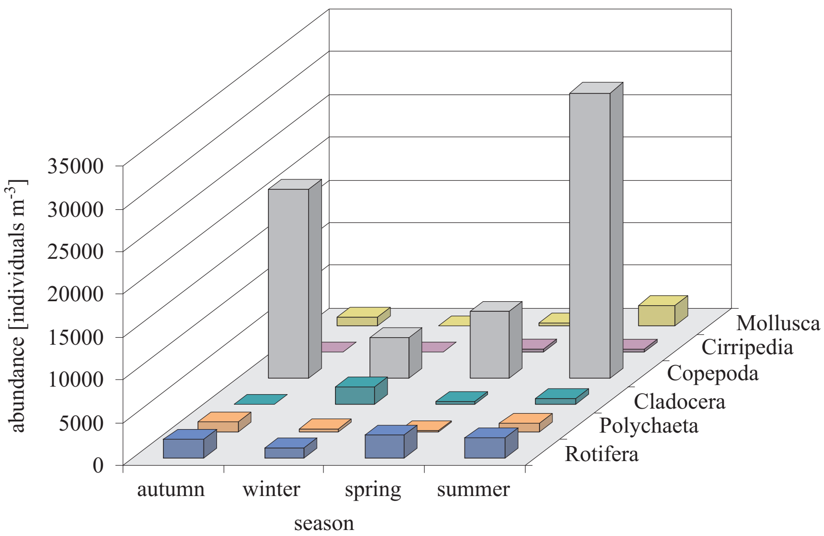

Figure 6. Seasonal distribution of the dominant zooplankton groups in Lake Timsah during the period of study

were present in smaller numbers (Figure 6). The zooplankton community was dominated by copepods (average: 22 263 individuals m^{-3}, representing 82.8% of the total zooplankton), rotifers (2078 individuals m^{-3}, 7.7%) and molluscs (1160 individuals m^{-3}, 4.3%). The leading species were the copepod *O. nana* (9017 individuals m^{-3} – 33.5% of the total zooplankton), *P. crassirostris* (6164 individuals m^{-3}, 22.9%) and *C. kroyeri* (1195 individuals m^{-3}, 4.4%) as well as the rotifer *B. calyciflorus* (1413 individuals m^{-3}, 5.3%) and gastropod veligers (1070 individuals m^{-3}, 4%).

The zooplankton standing crop was the smallest during winter (average: 8582 individuals m^{-3}). The contribution of copepods to the total zooplankton decreased during winter, representing only 57% of the total zooplankton with an increase of their larval stages (forming 26.9 of the total zooplankton). Moreover, the dominant adult species were *P. crassirostris* (944 individuals m^{-3}, 11% of the total zooplankton) and *O. nana* (767 individuals m^{-3}, 8.9%). During this season, cladocerans were more numerous, forming the second most dominant group with an average density of 2076 individuals m^{-3} (24.2% of the total zooplankton) (Figure 6). *Podon polyphemoides*, *Moina micrura* and *Alona bukobensis* represented the cladoceran population in the lake during winter, *P. polyphemoides* being dominant (average: 2072 individuals m^{-3}, 24.1% of total zooplankton). Rotifers were prevalent during this season (1124 individuals m^{-3}, 13.1% of the total community). The most common rotifer species was *Brachionus plicatilis* (11.2%).

In spring, the zooplankton standing crop was larger than in winter (average: 11 776 individuals m^{-3}). Copepods represented 66.6% of the total zooplankton with an increase of their larval stage densities, making up 44.5% of the total zooplankton (average: 5242 individuals m^{-3}). They were represented by 11 species with the dominance of *O. nana* (average: 1617 individuals m^{-3}, 13.7% of the total zooplankton). *Paracalanus crassirostris*, *C. kroyeri* and *E. acutifrons* were frequent species. Rotifers were the second dominant group with an average density of 2638 individuals m^{-3}, accounting for 22.4% of the total count. This percentage was relatively high in comparison with the other seasons. Regarding species composition, rotifers were more diversified (6 species). *B. calyciflorus* (78.8% of the total rotifers) and *B. plicatilis* (18%) were the dominant ones. Cladocerans (average: 492 individuals m^{-3}) contributed about 4.2% to the total community. The most common cladoceran species was *Podon polyphemoides*, accounting for 3.9% of the total zooplankton with an average of 465 individuals m^{-3}. Cirripedes were represented by nauplii, which contributed 3% of the total count (average: 358 individuals m^{-3}); their abundance reached a maximum at the shipping lane sites (Figure 6).

3.5. Species diversity

The diversity indices were designed to measure species richness, the number of species in a community, and the degree of evenness or equitability of the species' relative abundances. However, spatial and seasonal variations in the number of species and individuals were reflected by the species diversity (Shannon-Weaver index). Lake Timsah showed a relatively low species richness with a minimum of 1.04 at site 10 in autumn and a maximum of 2.11 at site 3 in spring. The lowest average species richness (1.34) was recorded at site 10, while the highest average of 2.93 was at site 8 (Figure 7). The maximum species diversity values generally coincided with maximum evenness and richness and vice versa (Figure 7).

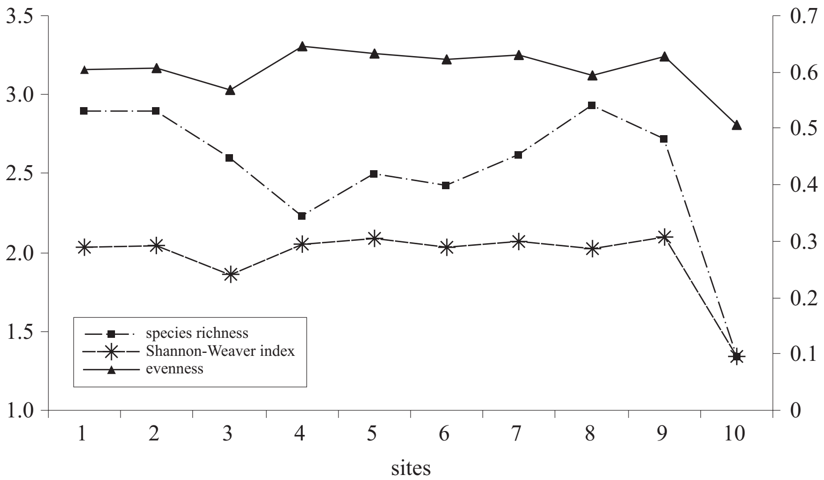

Figure 7. Diversity indices of total zooplankton recorded at different sites in Lake Timsah during the period of study

3.6. Zooplankton structure and environmental conditions

The correlation coefficient of the total zooplankton density and its main groups in terms of abundance and diversity (copepods, rotifers, molluscs, cladocerans and polychaetes) with some physicochemical parameters and phytoplankton biomass (as chlorophyll *a* and total count) are given in Table 3. Temperature and pH showed an approximately similar pattern of correlations with each of total count of zooplankton, copepods and molluscs as well as the two dominant copepods *O. nana* and *P. crassirostris*. This pattern was different from that of rotifers and polychaetes, which showed no significant correlations. For rotifers and their dominant species, significant negative correlations were recorded with salinity, chlorophyll *a* and dissolved oxygen (Table 3).

Table 3. Significant correlation coefficients of the total zooplankton and its dominant groups with different physicochemical parameters, chlorophyll *a* and the total phytoplankton count in Lake Timsah during the period of study

Group	Temperature [°C]	Salinity [PSU]	pH	Dissolved oxygen [mg l^{-1}]	Chlorophyll *a* [μg l^{-1}]	Total phytoplankton
total zooplankton	0.664**		0.494**		0.314*	0.408**
Copepoda	0.617**		0.541**			
Oithona nana	0.443**		0.499**			0.314*
Paracalanus crassirostris	0.717**		0.583**			0.496**
Rotifera		−0.773**		−0.606**	0.324*	
Mollusca	0.502**	0.398*				

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

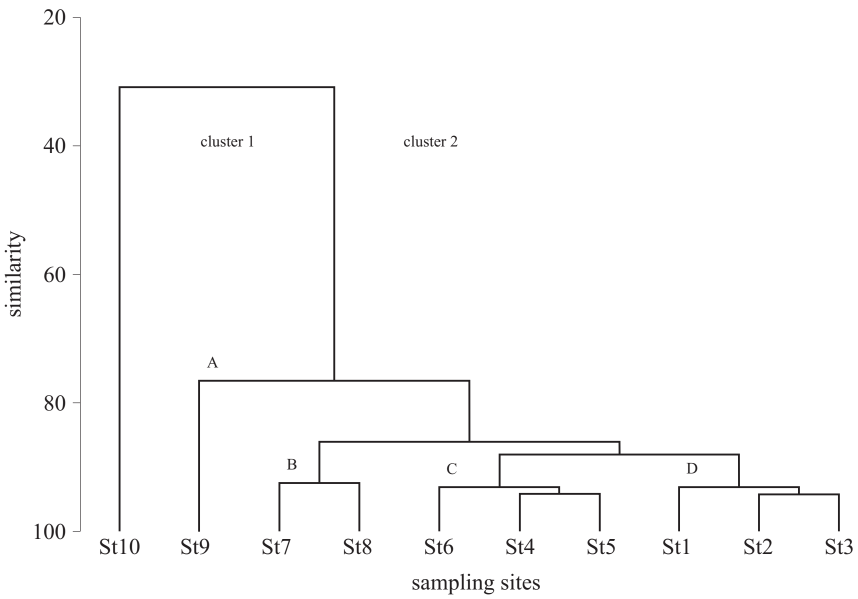

Figure 8. Dendrogram showing similarity of sampling sites on the basis of their zooplankton composition in Lake Timsah during the period of study

3.7. Cluster analysis

In order to reveal the similarities and differences among the investigated sites, cluster analysis was performed based on the total abundance of the zooplankton community (Figure 8). The results showed the presence of two main clusters with a 32.9% similarity. The first cluster contains only site 10, which is located in the western lagoon, where rotifers are dominant. The second cluster consists of the other sites (1–9). This latter cluster can be divided into 4 sub-clusters: sub-cluster A contains site 9 which is located in front of the western lagoon; sub-cluster B includes the sites adjacent to site 9 (i.e. 7 and 8); sub-cluster C comprises the central lake sites (4–6), distinguished by high zooplankton densities and lower salinity; sub-cluster D includes the shipping lane sites, located in the canal itself (1–3), and which are characterized by a relatively low abundance and high salinity.

4. Discussion

The present study showed that the diversity of the zooplankton community in Lake Timsah was low (34 species), with only 7 persistent taxa, and that the remainder of the species were recorded at low densities or rarely encountered. The temperature variations did not affect the diversity of zooplankton: their distinctly large standing stock in summer at 31.5°C contained 29 species, while the extremely low stock in winter at 16°C had nearly the same number of species (27). The poor diversity of the zooplankton community and of copepods appears to be a characteristic feature of several small basins on the Egyptian Mediterranean coast, particularly those receiving land-based effluents (e.g. Abdel-Aziz & Dorgham 2002, Abdel-Aziz 2004). The number of zooplankton species recorded during the present study (42 taxa including larval stages) is slightly higher than that recorded (37 taxa) by Abou-Zeid (1990) and El-Serehy et al. (2001). This may be because their studies did not take into account the western lagoon connected with the lake, or the continuous dredging activities in the main lake and shipping lane, which renew the lake's water masses.

In general, the low number of species recorded in the lake can be attributed to the continuous discharge of wastewater, which leads to increasing nutrient concentrations and hence the dominance of just a few species. This was confirmed by Ludsin et al. (2001) and Prepas & Charette (2003), who concluded that the biodiversity of most aquatic systems decreases with increasing nutrient load as a result of increasing eutrophication.

During the study period, the zooplankton standing crop in Lake Timsah showed an annual average zooplankton of 22 026 individuals m^{-3}. This average is comparable with the study of Abou-Zeid (1990) in the lake (23 419 individuals m^{-3}), even though his vertical samples did not cover the whole lake. Also, this value indicated that the lake is less productive than Lake Buroullus (183 000 individuals m^{-3}) during 1987 (Aboul-Ezz 1995), Lake Maryout with approximately 117 000 individuals m^{-3} during 1996–1997 (Abdel-Aziz & Aboul-Ezz 2004), Lake Idku with 326 000 individuals m^{-3} during 2000 (Aboul-Ezz & Soliman 2000) and Lake Manzalah with 5×106 individuals m^{-3} (El-Sherif et al. 1994). The seasonal pattern of the zooplankton standing crop was characterized by conspicuously high numbers in summer and a lower peak in autumn, with minimum densities being recorded in winter. Copepods were by far the most important group of zooplankton in the study area, comprising 77.7% of the total population, and the seasonal variation in the total zooplankton population was governed mostly by variations in this group. This dominance of copepods was documented previously in the same area (Abou-Zeid 1990, Ghobasy et al. 1992), in the Suez Canal area (El-Serehy et al. 2001), in the eastern Mediterranean (e.g. Nour El-Din 1987, Dowidar 1988) and at other coastal sites of the Arabian Gulf (Yamazi 1974, Michel et al. 1986, Dorgham & Hussein 1997). The Pearson correlation revealed that temperature and pH were the common factors controlling copepod abundance in the Lake Timsah ($r = 0.617$ and 0.541 respectively). This is in agreement with Goldman & Horne (1983) and Rodriguez et al. (1995), who found that temperature was the main factor affecting zooplankton production. In terms of salinity tolerance, and despite the absence of a correlation between salinity and total zooplankton densities, the whole study area, especially the middle part of the lake, may be optimal (21.8–33.3 PSU) for most zooplankton groups and species.

Only 2 of the 21 copepod species recorded in the study area (*Paracalanus crassirostris* and *Oithona nana*) formed the main bulk of the copepods, in addition to 3 other species (*Centropages kroyeri*, *Euterpina acutifrons* and *Paracalanus parvus*) that were frequently captured. These species are the major constituents of the zooplankton population along the Egyptian Mediterranean coast (Abdel-Aziz & Dorgham 2002, Abdel-Aziz 2004). *Paracalanus crassirostris* was the most dominant copepod in Lake Timsah (6241 individuals m^{-3}; 36.4 and 28.3% of the total copepod and total zooplankton population respectively). Its densities peaked in summer, and there was an increase in autumn. This finding is in agreement with that reported by Abou-Zeid (1990) in Lake Timsah, by El-Serehy et al. (2001) in the Suez Canal area and by Michel et al. (1986) in the Arabian Gulf. Also, this small paracalanid copepod is a major constituent of plankton communities in the tropics (McKinnon & Thorrold 1993, McKinnon & Klumpp 1998).

Widely distributed in estuaries, neritic and oceanic waters, *O. nana*, the second most abundant species, is cosmopolitan; it seems to prefer deeper shelf and coastal waters (Paffenhöfer 1993, Bradford-Grieve et al. 1999, Vieira et al. 2003, Abdel-Aziz et al. 2007). It is also a eurytopic species, tolerating a wide range of temperature and salinity (Dowidar 1965); it was abundant in the eastern Mediterranean (Hussein 1977). Maximum standing crops of this species were recorded in summer in the Egyptian Mediterranean (Dowidar & El-Maghraby 1970, Hussein & Abdel-Aziz 1997), Lake Timsah (Abou-Zeid 1990) and the Gulf of Suez (Abdel-Rahman 1993). *Oithona nana* was the most important species in Doha Harbour (Arabian Gulf), comprising 34% of the total copepods, with the highest density in summer (Dorgham & Hussein 1997). It is distributed in the tropical and subtropical waters of the Pacific and Indian Oceans, with a high density in tropical waters (Nishida 1985). It has frequently been recorded in the tropical and subtropical Atlantic (Grice 1960, Gonzalez & Bowman 1965). Temperature, pH and total phytoplankton count were the most important and significant factors controlling the densities of these species ($r = 0.717$, 0.583, 0.469 and 0.443, 0.499, 0.314 respectively).

Rotifers are known to be excellent indicators of organic pollution as they thrive better in organically rich environments (Karabin 1985, Paleolog et al. 1997). A comparative investigation of Egyptian lagoons showed that cleaner environments have smaller standing crops and are not so species-rich, whereas eutrophic areas sustain the greatest number of both individuals and species, though only up to a certain level (Guerguess 1992). Rotifers constituted the second most important group, representing 9.2% of the total zooplankton community. They were found in high densities at sites of low salinity ($\mathrm{PSU} = 8$–10), which receive polluted water from agricultural drainage as well as domestic sewage (ETPS 1995), but were practically absent in the middle of the lake. The relatively low numbers appearing at site 1 may be attributed to the presence of freshwater runoff at this site from the adjacent club buildings as well as from the Suez Canal Authority hospital. This distribution is confirmed by its negative correlation with the salinity and dissolved oxygen ($r = -0.773$ and -0.606 respectively) and at the same time was positively correlated with the chlorophyll *a* content ($r = 0.324$) (Table 3).

The high densities of mollusc and polychaete larvae reflect their great contribution and the dominance of these groups in the lake (Ghobashy et al. 1992, Kandeel 1992). The seasonal abundance of these groups showed that summer is the reproductive season. This is in agreement with

Kandeel (1992), Ghobashy & El-Komi (1980), Ghobashy et al. (1992) and Emara & Belal (2004), who recorded that summer is the main reproductive and settlement season for molluscs and polychaetes. Cirripede nauplii constituted only 1% of the total population with an average of 211 individuals m^{-3}. They attained their highest densities at sites 1–3 during spring and summer. This may be explained by the presence of hard substrates along these sites, which are characterized by the presence of large numbers of adult forms. The presence of high densities in these seasons may also be due to the breeding season of this species. This is comparable with the studies of Abou-Zeid (1990) in the same area and Hanafy et al. (1998) in the mangrove area in the Gulf of Aqaba.

The flourishing of dominant zooplankton groups (copepods and molluscs) at high temperatures producing a distinct peak in summer explains the positive correlations with temperature. On the other hand, the great variation in the salinity did not affect the abundance of copepods because the lake contains species characteristic of different habitats (brackish and marine sea water) – hence the dominance of different species of copepods at the different salinities in the lake.

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