Protozoa in a stressed area of the Egyptian Mediterranean coast of Damietta, Egypt

doi:10.5697/oc.55-3.733
OCEANOLOGIA, 55 (3), 2013.
pp. 733–750.

KEYWORDS
Environmental conditions
Pollution indicators
Coastal protozoa
Tintinnids
Non-tintinnid ciliates

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Received 5 July 2012, revised 21 March 2013, accepted 16 April 2013.

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

Abstract

The Damietta coast is part of the Egyptian Mediterranean coast off the Nile Delta and has recently been polluted as a result of intensive human activities. The environmental parameters and protozoan community in the area were studied biweekly from January to December 2007. The results of the environmental parameters indicated low salinity, oxic and anoxic conditions, high nutrient levels and intensive phytoplankton growth. A total of 69 protozoan species were identified, belonging to Amoebozoa (8 species), Foraminifera (12 species), non-tintinnid ciliates (22 species) and tintinnids (27 species). The numerical density of protozoans was high over the whole area, with annual averages between 8.2×10^3 cells m^{-3} and 51.4×10^3 cells m^{-3}. Spring was the most productive season for protozoans, but several distinct peaks were observed during the year at the sampling sites. The protozoan groups showed clearly different spatial patterns in both composition and abundance: whereas amoebozoans and non-tintinnid ciliates were dominant in the more polluted areas (sites IV and V), tintinnids dominated in the less polluted areas (sites, I, II and III). Several pollution indicators were recorded: amoebozoans – *Centropyxis aculeata*, *Centropyxis* sp., *Cochliopodium* sp., *Difflugia* sp.; non-tintinnids – *Bursaridium* sp., *Frontonia atra*, *Holophrya* sp., *Paramecium* sp., *Paramecium bursaria*, *Vasicola ciliata*, *Vorticella* sp., *Strombidium* sp.; tintinnids – *Favella ehrenbergii*, *Helicostomella subulata*, *Leprotintinnus nordgvisti*, *Tintinnopsis beroidea*, *Stenosemella ventricosa*, *Tintinnopsis campanula*, *T. cylindrica*, *T. lobiancoi*, *Eutintinnus lusus-undae*.

1. Introduction

Protozoans are an important biotic component in the aquatic ecosystem, particularly ciliates, which act as predators of bacteria, provide nutrition for organisms at higher trophic levels (Kneitel & Chase 2004, Dopheide et al. 2009), increase mineralization and make nutrients more available to other organisms (Vickerman 1992). They also play a crucial role in food chains as biomonitors and/or indicators of water quality (Charubhun & Charubhun 2000).

During the last two decades the Damietta coast has been exposed to severe environmental stress resulting from intensive human activities, such as industrial, agricultural and fishing activities, as well as the discharge of untreated domestic wastes. Unfortunately, there are no reliable indicators for assessing the degree of pollution.

Although some data on protozoa are available in several zooplankton studies along the Egyptian Mediterranean Coast (Dorgham 1987, Abdel-Aziz 2001, 2002, 2004, Abdel-Aziz & Aboul-Ezz 2003, Anon. 2007), only two studies have been conducted on the Damietta coast. El-Ghobashy (2009) carried out a study on zooplankton at one site outside the Damietta Harbour, including data on protozoa, and Dorgham et al. (2009) conducted the first comprehensive study of foraminiferans and tintinnids in the

Damietta Harbour over a period of one year. However, no information is available on the freshwater protozoans in the coastal waters of Damietta, particularly those exposed to terrestrial discharges.

The present study is the first comprehensive study of protozoa in fish fry aggregations along the Damietta coast under the prevailing environmental conditions, particularly in stressed coastal spots, in order to define the protozoan species that could be used as indicators of water quality.

2. Material and methods

2.1. Study area and sampling methods

The Damietta coast lies in the eastern part of the Nile Delta on the south-eastern Mediterranean Coast, between 31°10′–32°05′E and 31°20′–31°35′N. Five sites characterized by fish fry aggregations and pollution were selected for the present study, representing different environmental entities (Figure 1).

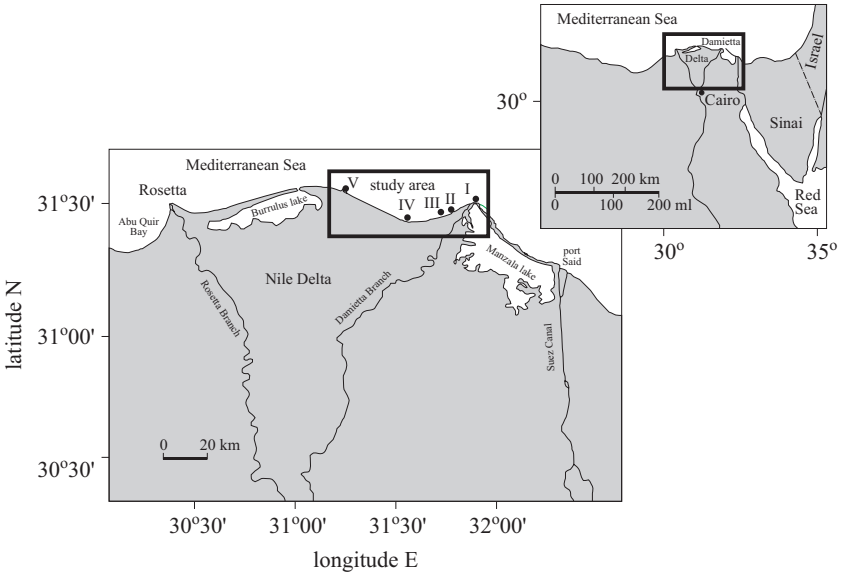

Figure 1. The Damietta coast and the locations of the sampling sites

Site I lies at Ezbet El-Burg Algadeeda, at the connection of the Manzalah Lagoon to the Mediterranean Sea. This area is affected by fresh water from the Damietta Branch of the River Nile, domestic wastes from surrounding villages, industrial wastes from a sardine factory, wastes from fish ponds, and from numerous fishing boats.

Site II is located at the connection between the Damietta Harbour and the Mediterranean Sea. It is exposed indirectly to fresh water from the River Nile, direct discharges of sewage and agricultural wastes from the surrounding area, not to mention wastes from a chemical fertilizer factory, a methanol production factory and a natural gas liquefaction facility.

Site III lies west of the River Nile Branch at Ezbet Setta and receives large amounts (6×10^6 m^{-3} day^{-1}) of untreated agricultural and industrial wastes in addition to sewage from the City of New Damietta.

Site IV is located at the mouth of Gamasa Drain, west of the River Nile branch. It receives about 13.1×10^6 m^{-3} day^{-1} of untreated domestic and agricultural wastes.

Site V lies at the mouth of El-Kassara Drain, west of the River Nile Branch, receiving approximately 8.6×10^6 m^{-3} day^{-1} of industrial, agricultural and sewage wastes, as well as waters from adjacent fish ponds.

This study was carried out on a biweekly sampling basis from January to December 2007. Hydrographic parameters (temperature, salinity, turbidity, dissolved oxygen and pH), nutrients (total phosphorus, NO_3, NO_2, NH_4 and SiO_3) and chlorophyll *a* were measured. The surface water temperature was measured directly with a thermometer graduated to 0.1°C, water turbidity with a nephelometric turbidity unit (NTU) and pH with a digital pH meter. Dissolved oxygen was determined according to Winkler's method, the surface salinity argentometrically (Strickland & Parsons 1972). For nutrient determination water samples were collected at 50 cm beneath the water surface using a Nansen water sampler and kept cold in an ice box until the return to the laboratory. 500 ml of each water sample were passed through a membrane filter (diameter = 47 mm, pore size = 0.45 μm) and frozen at −20°C for later analysis. Nutrients and phytoplankton biomass (chlorophyll *a*) were determined according to the methods described by Strickland & Parsons (1972).

Protozoan samples were collected by filtering 100 litres of seawater through a phytoplankton net. The collected samples were transferred to 250 ml polyethylene bottles and the phytoplankton net was washed carefully to remove any protozoan organisms attached to the net material; this water was added to the collected samples and preserved in 5% neutralized formalin solution. The protozoan species were identified under a research microscope and their standing crop determined from the average count of three 5 ml aliquots from each sample. The protozoan species were identified following Tregouboff & Rose (1957), Newell & Newell (1963, 1979), Marshall (1969), Cosper (1972) and Corliss (1979).

Shannon's (H') index (Shannon & Weaver 1949) and Odum's (D_O) index (Odum et al. 1960) were calculated. The correlation coefficients

were calculated between the environmental parameters and the counts of the total protozoans and the dominant species. Canonical correspondence analysis (CCA) was performed to identify the relations between protozoan abundance and the environmental variables. The analysis was performed with version 4.5 of the CANOCO program (Lepš & Šmilauer 2003). Monte Carlo tests were performed with 999 unrestricted permutations, using the eigenvalues of the axes as test of statistics (Ter Braak & Prentice 1988, Sousa et al. 2008). All analyses were performed by SPSS 18.

3. Results

3.1. Environmental conditions

The values of the environmental parameters in the Damietta coastal waters are listed in Table 1. There were negligible spatial differences in

Table 1. Minimum, maximum and mean values of different environmental parameters at the sampling sites along the Damietta coast (January–December 2007)

	I	II	III	IV	V
temperature [°C]	12.5–31.0	15.0–31.0	14.0–31.0	14.0–31.0	13.0–31.0
turbidity (NTU)	1.1–91.0 18.6	0.2–13.4 3.9	3.6–117.0 44.8	13.4–57.0 34.7	10.9–50.0 32.3
salinity [‰]	9.3–38.1 25.0	1.6–27.7 16.4	3.1–32.9 18.6	0.3–9.4 1.4	2.5–6.3 4.0
pH	7.4–8.4 7.9	7.6–8.55 7.97	7.4–8.3 7.73	7.3–8.1 7.59	7.25–8.05 7.74
DO [mg l^{-1}]	2.7–9.5 6.4	3.2–10.8 7.4	1.7–9.0 5.6	0.5–7.5 2.6	0.5–9.2 4.4
SiO_3 [μM]	0.04–255.16 52.28	1.41–97.72 39.66	13.14–412.6 106.3	48.86–287.74 149.26	156.36–443.01 255.84
NO_3 [μM]	0.05–1.58 0.42	0.1–2.81 0.83	0.15–3.29 1.08	1.93–27.12 9.71	0.58–12.3 3.42
NO_2 [μM]	0.01–1.23 0.24	0.07–2.86 0.57	0.17–2.55 0.76	0.52–24.04 7.46	0.33–8.91 2.63
NH_4 [μM]	0–1.2 0.27	0–3.71 1.07	0–10.63 4.27	2.12–91.25 31.14	0–12.18 4.05
total P [μM]	0–60.74 11.72	0–71.37 14.45	0–86.95 16.71	0–82.95 14.96	0.53–73.48 16.72
Chl *a* [μg l^{-1}]	0.4–49.0 7.0	2.4–34.0 12.6	0.6–26.5 8.1	1.7–17.1 8.8	7.6–197.4 80.6

surface water temperature, but distinct temporal variations between the winter minimum of 14°C and the summer maximum of 30.5–31°C. The surface salinity was always low over the whole area, with the annual average varying between 1.4‰ at site IV and 25‰ at site I. In accordance with the salinity gradient the sampling sites could be ranked as follows: site I > site II > site III > site V > site IV.

The study area was characterized by high turbidity over the year (0.2–117 NTU), with the lowest value at site II and the highest one at site III. The concentrations of dissolved oxygen reflected oxic and anoxic conditions, whereas relatively high concentrations (4.4–10.8 mg l^{-1}) occurred in the less stressed area (sites I, II) and distinctly low concentrations (0.5–3.3 mg l^{-1}) in the more stressed area (sites IV, V). The pH displayed little variation, with the annual average between 7.73 and 7.97 at the sampling sites.

Nutrient concentrations were high for most of the year: total phosphorus (an undetectable level – 86.95 μM), ammonium (an undetectable level – 91.25 μM), nitrite (0.01–24.04 μM), nitrate (0.05–27.12 μM) and silicate (0.4–287.74 μM). The high nutrient levels promoted the intensive growth of phytoplankton, so that chlorophyll *a* was always > 2 μg l^{-1}; the maximum was 197.4 μg l^{-1} (Table 1).

3.2. Protozoan community

The protozoan community in the Damietta coastal waters comprised 69 species: amoebozoans (8 species), foraminiferans (12 species), non-tintinnid ciliates (22 species) and tintinnids (27 species). The number of species varied from 27 at site V to 44 at site III. Of the total number, 7 tintinnids were persistent at sites I–III and 4 non-tintinnid ciliates and 3 amoebozoans persisted at sites IV and V (Table 2). All the other species were found either intermittently or rarely.

There was little difference between the Shannon indices at the various sampling sites (annual average: 1.34–1.79), but it did exhibit a wide biweekly variation at each site (Table 3). In contrast, Odum's index showed marked variations (annual average: 0.2 and 2.4) across the study area (Table 3).

A distinct spatial difference was reported in the distribution of protozoan groups along the Damietta coast. Tintinnids were more diversified and dominant at sites I, II and III and non-tintinnid ciliates dominated at sites IV and V, while amoebozoans were co-dominant at site IV (Figure 2).

Numbers of protozoans were very high in the study area. Site I sustained the lowest number (annual average: 8.2×10^3 cells m^{-3}), sites II and IV harboured roughly the same numbers (21.9×10^3 cells m^{-3} and 20.5×10^3 cells m^{-3} respectively), while sites III and V were inhabited by the

Table 2. Persistent protozoan species at the sampling sites

Less stressed area	More stressed area
Tintinnids	**Amoebozoans**
Favella ehrenbergii	*Arcella* sp.
Helicostomella subulata	*Centropyxis aculeata*
Leprotintinnus nordgvisti	*Centropyxis* sp.
Tintinnopsis beroidea	
Tintinnopsis campanula	**Non-tintinnids**
Tintinnopsis cylindrica	*Bursaridium* sp.
Tintinnopsis lobiancoi	*Paramecium* sp.
	Vasicola ciliata
	Vorticella sp.

Table 3. Variations of species number (S), abundance (N), Shannon's index (H') and Odum's index (D_O) at the sampling sites

Stations	S	$N \times 10^3$ cells m^{-3}	H'	D_O
I	1–19	0.4–8.17	0.90–2.31	0.30–7.89
II	6–20	1.7–196.6	0.81–2.38	0.10–3.53
III	4–18	2.4–178.4	0.30–2.16	0.06–1.90
IV	3–16	1.0–45.2	0.68–2.32	0.13–2.97
V	3–13	3.3–125.3	0.69–1.99	0.04–0.92

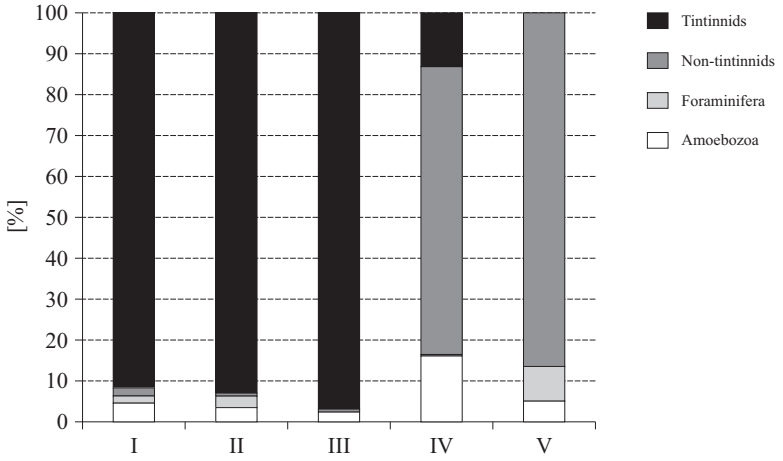

Figure 2. Relative abundance of different protozoan groups along the Damietta coast

highest numbers (51.3×10^3 cells m^{-3} and 45.5×10^3 cells m^{-3} respectively). The peaks of abundance were reached at different times of the year at the sampling sites, except one common peak in late April at most of the sites (Figure 3).

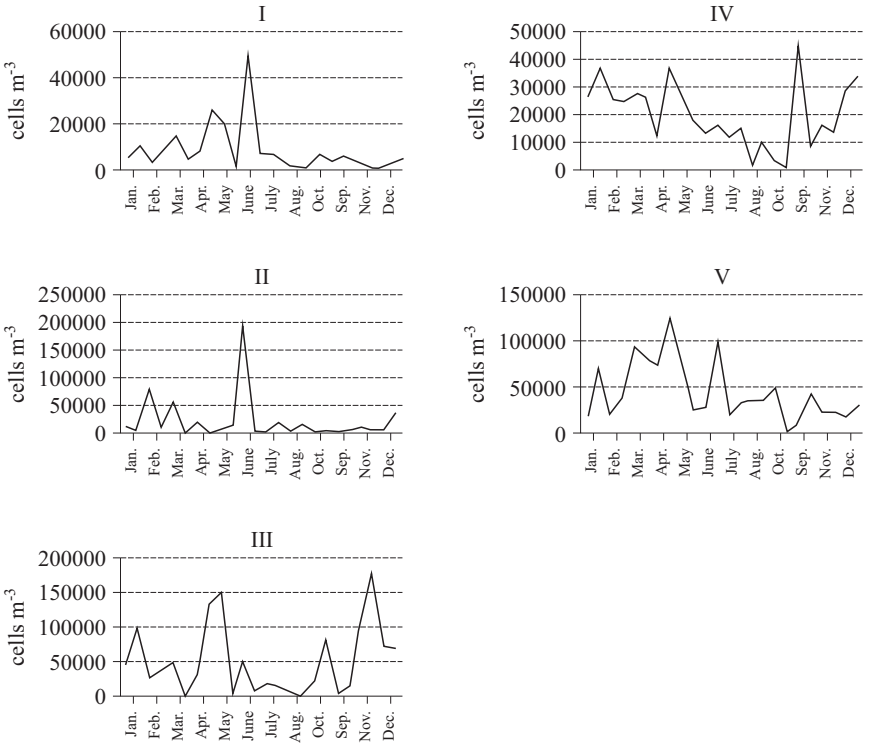

Figure 3. Biweekly abundance of total protozoans at the sampling sites

Several species accounted for the bulk of the protozoan numbers. The tintinnids *Leprotintinnus nordgvisti*, *Tintinnopsis beroidea*, *Tintinnopsis buetschlii*, *Tintinnopsis cylindrica* and *Tintinnopsis lobiancoi* constituted collectively ca 74.2% of the total protozoans at site I. The tintinnid *Helicostomella subulata* alone made up ca 50.1% at site II, while other tintinnids like *Amphorellopsis acuta*, *Favella serrata*, *Tintinnopsis campanula* and *T. beroidea* together made up a further 25.1%. At site III, *T. beroidea*, *T. cylindrica* and *T. lobiancoi* contributed a total of 61.7%, while the proportions of the tintinnids *Stenosemella ventricosa*, *L. nordgvisti*, *Eutintinnus lusus-undae* and *H. subulata* were between 5.4 and 7.7% each. In contrast, site IV was dominated by the non-tintinnids *Paramecium* sp. (17.7%), *Vasicola ciliata* (14.5%), *Bursaridium* sp. (11.9%), *Frontonia atra* (10.8%), and to a lesser extent by the amoebozoans *Centropyxis aculeata*

(5.3%) and *Centropyxis* sp. (4.7%). The former three non-tintinnid ciliates that dominated at site IV were also dominant at site V, jointly making up 71.2% of the protozoan total. Other species appeared in conspicuously large numbers once or twice a year at the various stations. At site V, *Paramecium bursaria* contributed 15% of the total protozoans early May, *Bursaria* sp. made up 27% in late April and *Plagiophyla* sp. 25.1% in late January, while at site IV *Arcella* sp. contributed 9.7% in late December.

4. Discussion

Human activities along the Damietta coast have caused drastic changes in the environment, expressed by a salinity decrease, frequent anoxic conditions, high nutrient levels and intensive phytoplankton growth. These changes are reflected in the structure and abundance of the protozoan community in the study area.

The nutrient concentration ranges reported as criteria of eutrophication in coastal waters were: 1.15–2 μM for NH_4, 0.53–4 μM for NO_3 (Vucak & Stirn 1982, Ignatiades et al. 1992), >0.15–0.34 μM for PO_4 (Marchetti 1984, Ignatiades et al. 1992) and 1.99 μg l^{-1} for chlorophyll *a* (UNEP/UNSECO/FAO 1988). According to these values, sites III, IV and V in our study could be classified as eutrophic, while sites I and II fluctuated between mesotrophic and eutrophic. These conditions demonstrated an evident impact on the protozoan community along the Damietta coast, as indicated by the significant correlations between the protozoan count and the number of species on the one hand, and the environmental parameters on the other (Table 4). However, these correlations appeared to vary at the sampling sites depending on the

Table 4. Significant correlations between the total protozoan count and environmental parameters ($r = 0.344$–0.403 significant at $p = 0.1$, $r \geq 0.403$ significant at $p = 0.05$); values in bold indicate a negative correlation

	Total abundance	Sp. No.
temperature	**0.5656**	**0.5338**
turbidity	**0.4206**	**0.4740**
salinity	0.4575	
pH	0.3970	
DO		0.4513
total P	0.3680	0.3582
NO_3	0.6254	0.4919
NO_2	0.7514	0.5064

differences in their environmental characteristics. The significant negative correlation of salinity with amoebozoans and non-tintinnid ciliates (Table 5) explains the high abundance of both groups in the low salinity areas (sites IV and V), while the positive significant correlation of salinity with tintinnids explains their abundance in the high salinity area (sites I, II and III). It seems that each protozoan group demonstrated a different response to the environmental parameters at the sampling sites. The non-tintinnid ciliates showed a significant negative or positive correlation with temperature, dissolved oxygen, turbidity, silicate and ammonium at one or more sites, while tintinnids were significantly correlated with nitrate, nitrite and ammonium (Table 5). Although silicate is not essential for amoebozoans and non-tintinnid ciliates, its significant negative correlation with the amoebozoans presumes a negligible food relationship between this group and phytoplankton, whereas the positive correlation with non-tintinnid ciliates indicates a definite food relationship between phytoplankton and this group. However, the significant correlations between the protozoan groups and

Table 5. Significant correlations between the protozoan groups and environmental parameters at the sampling sites ($r = 0.344$–0.403 significant at $p = 0.1$, $r \geq 403$ significant at $p = 0.05$); values in bold indicate a negative correlation

	Site I		Site II		Site III		
Parameter	Non-tin	Tintin	Non-tin	Tintin	Amoeboz	Non-tin	Tintin
temperature	**0.5593**		0.37974				**0.3719**
pH				0.39334			
salinity [‰]					**0.3575**	**0.6692**	
DO [mg l^{-1}]						**0.4648**	
NO_3 [μM]		0.61135		0.48519			
NO_2 [μM]		0.74584		0.42301			
NH_4 [μM]						0.57781	
total P. [μM]		0.38970					
SiO_3 [μM]			0.60952				

	Site IV			Site V		
Parameter	Amoeboz	Non-tin	Tintin	Amoeboz	Non-tin	Tintin
temperature		**0.4563**				
turbidity [NTU]		**0.4213**			**0.4139**	
salinity [‰]			0.91202			0.41062
NO_3 [μM]						0.43433
NH_4 [μM]				0.37072		
SiO_3 [μM]	**0.4153**					

nutrients are attributed to the role of tintinnids in the recycling of nutrients in the aquatic habitat (Bloem et al. 1989, Vickerman 1992).

The diversity index is a suitable criterion for water quality (Balloch et al. 1976) and Odum's index is efficient in assessing eutrophic levels

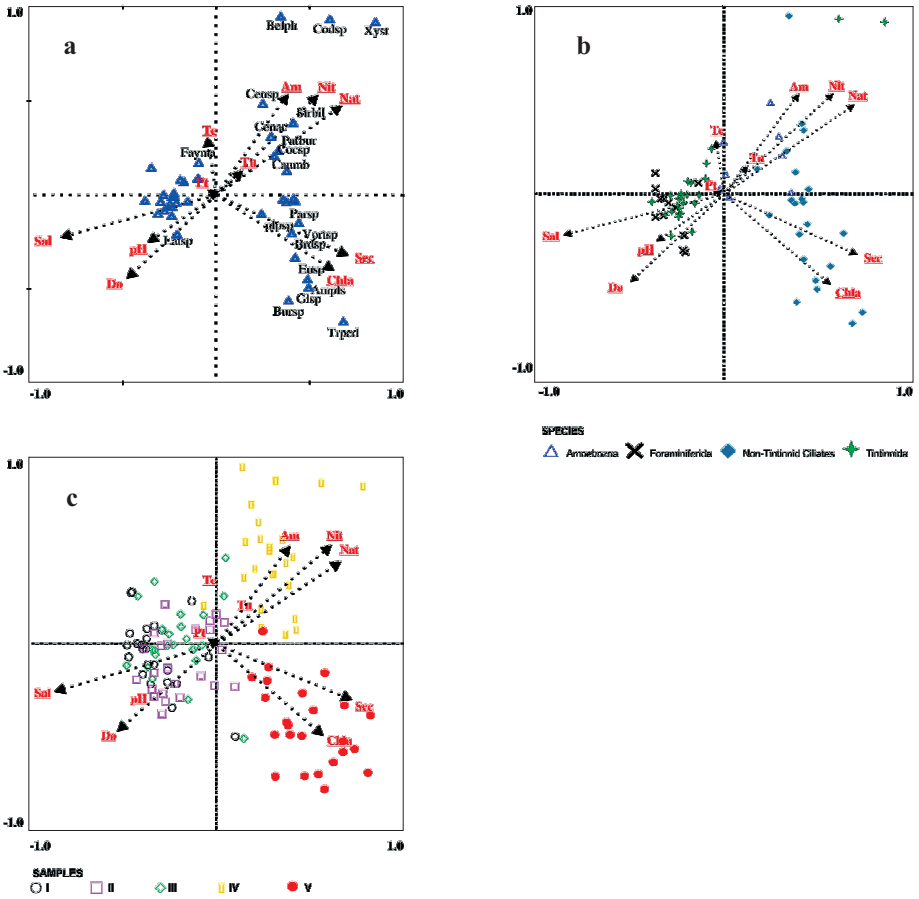

Figure 4. a) Ordination diagram by CCA analysis of protozoan species (5% of species fit range to the first two axes) as a function of environmental variables. Cluster I in the left-hand half of Figure 4a includes (*Difflugia* sp., *V. ciliata*, *F. atra*, *Holophrya* sp.), cluster II in the right-hand half of the figure includes (*F. ehrenbergii*, *M. mediterranean*, *T. lobiancoi*, *L. nordgvisti*, *T. cylindrica*, *T. tocantinensis*, *T. tubulosa*, *B. inflata*, *Quinqueloculina* sp., *S. ventricosa*, *T. campanula*, *F. serrata*, *H. subulata*, *A. acuta*, *S. nivalis*, *T. bütschlii*). b) Systematic classification of species as a function of environmental variables. c) Spatial classification of species samples as a function of environmental variables. Te (temperature), Tu (turbidity), Sal (salinity), Am (NH_4), Nit (NO_2), Nat (NO_3), Pt (total phosphorus), Sec(SiO_3) and Chla (chlorophyll *a*)

(Tsirtsis & Karydis 1998). The Shannon indices in our area (0.3–2.16) were close to those (1–2.5) recorded in actively growing coastal populations and eutrophic lakes (Margalef 1978) and in polluted areas of the Egyptian Mediterranean Coast (Ismael & Dorgham 2003, Dorgham et al. 2009). Similarly, the low values of Odum's index at the more polluted sites during the present study support the observations of Ibrahim & Abdullahi (2008) in Challawa River, Kano State, Nigeria. Boyle et al. (1990) presumed a low diversity with increasing pollution load owing to the elimination of great numbers of sensitive species. This is in agreement with our results, which recorded the lowest protozoan diversity at the more polluted and eutrophic sites.

The CCA ordination diagram (Figure 4) shows that the vectors of the environmental variables collectively explain 68.6% of the variance in the distribution of the species (Table 6). Around 68% of non-tintinnid ciliate species were found in the more eutrophic habitats, particularly at site V (Figures 4a and b). Therefore, *Bursaridium* sp., *Frontonia atra*, *Holophrya* sp., *Paramecium* sp., *Vasicola ciliata*, and *Vorticella* sp., the most frequent non-tintinnid ciliates, can be considered indicators of eutrophication. *Vorticella* sp. stands out for its tolerance to a highly polluted environment (Salvado et al. 1995, El-Bassat & Taylor 2007), and *V. ciliata* was recorded in a stressed area west of Alexandria coast (Abdel-Aziz 2005). On the other hand, the vectors representing gradient concentrations of nitrate and ammonium indicate that the amoebozoan *Centropyxis aculeata*, *Centropyxis* sp., *Cochliopodium* sp. and the non-tintinnid ciliates *Campanella umbellaria* were predominately found in highly nitrogenous habitats, specifically at station IV. The tintinnid and foraminiferan species were associated with the highest salinities but lower concentrations of nutrients and chlorophyll *a*, mainly at stations I and II. But some tintinnid species, like *Favella ehrenbergii*, *Helicostomella subulata*, *Leprotintinnus nordgvisti*, *Tintinnopsis beroidea*, *Stenosemella ventricosa*, *Tintinnopsis campanula*, *T. cylindrica*, *T. lobiancoi* and *Eutintinnus lusus-undae*, attained high numbers at the stressed site (III), indicating their tolerance of environmental

Table 6. Results of CCA analysis

	Axis 1	Axis 2	Axis 3	Axis 4
eigenvalues	0.551	0.104	0.073	0.059
cumulative percentage variance of species data	15.300	18.200	20.200	21.800
species-environment correlations	0.894	0.781	0.713	0.690
cumulative percentage variance of species environment relation	57.700	68.600	76.300	82.600

Table 7. Significant correlations between the dominant protozoan species and environmental parameters ($r = 0.344$–0.403 significant at $p = 0.1$, $r \geq 403$ significant at $p = 0.05$); values in bold indicate a negative correlation

	Temperature	pH	Turbidity	Salinity	DO	NO_3	NO_2	NH_4	Total P	SiO_3	Chl *a*
Arcella sp.	**0.497**				0.356			0.405			
Centropyxis sp.										**0.564**	
C. aculeata			**0.434**								
Difflugia sp.	0.347		**0.509**			0.564	0.376		0.587		
Plagiopyxis sp.	0.509			**0.419**						0.631	
Tintinnids											
Bursaria sp.			**0.435**								
Campanella umbellaria	**0.556**							0.580		0.701	**0.539**
Frontonia atra	**0.644**									0.472	
Holophrya sp.	**0.355**		**0.396**							0.507	
Paramecium sp.	**0.606**								0.522	0.571	
Plagiophyla sp.			**0.493**		0.394						0.373
Vorticella sp.	**0.516**	0.529			0.380						
Tintinnids											
A. acuta						0.412	0.363		0.447		
F. ehrenbergii	0.529				**0.477**						
H. subulata		**0.396**				0.660	0.817		0.495	0.670	0.357
L. nordgvisti				0.849		0.445	0.531				
Metacylis mediterranean	0.673				**0.362**				0.564	0.458	

Table 7. (*continued*)

	Temperature	pH	Turbidity	Salinity	DO	NO_3	NO_2	NH_4	Total P	SiO_3	Chl *a*
S. ventricosa					0.442	0.583	0.523				
T. beroidea					0.373						0.4875
T. bütschlii						0.676	0.884		0.511		
T. campanula						0.507	0.465				
T. cylindrica	**0.542**	0.483		0.926	0.375			0.378			
T. lobiancoi	0.468		**0.390**			0.657		**0.384**	0.621		0.585
T. tocantinensis				0.359			0.377	**0.418**			
T. tubulosa						0.651	0.849		0.580		

stress. In contrast, Curds (1982) reported that tintinnids are highly sensitive to waste water discharges.

The present study revealed that the protozoan species exhibited different responses to the environmental conditions with regard to their requirements and physiological status. This statement is endorsed by the significant correlations between the dominant species and the environmental parameters (Table 7).

Compared to earlier studies, the present protozoan counts along the Damietta coast (annual average: 8.2×10^3–51.3×10^3 cells m^{-3}) were close to that (23.78×10^3 cells m^{-3}) found outside the Damietta Harbour (El-Ghobashy 2009), that (21.6×10^3 m^{-3}) inside it (Dorgham et al. 2009) and that (8.7×10^3 m^{-3}) in the Western Harbour of Alexandria (Abdel-Aziz 2002). But lower counts have been observed in other stressed Egyptian coastal areas, for example, the 4.7×10^3 cells m^{-3} in Maadya, east of Alexandria (Abdel-Aziz & Dorgham 2004) and the 1.3×10^3 cells m^{-3} in the Naubaria Canal west of Alexandria (Abdel-Aziz 2005).

5. Conclusions

The present study shows that the Damietta coastal waters are characterized by low salinity, frequent anoxic conditions and a high level of eutrophication. These characteristics are reflected in the moderately diverse protozoan community, comprising amoebozoans, foraminiferans, non-tintinnid ciliates and tintinnids. The spatial distributions of the protozoan groups differ markedly in both species composition and numerical abundance with respect to the salinity gradient and pollution stress. Several pollution and eutrophication indicator species have been recorded.

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