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RESEARCH ARTICLE

Effect of chemical input on the temporal and spatial abundance of tintinnid ciliates in Lebanese coastal waters (Eastern Mediterranean)

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Abstract

The tintinnid ciliates community was monitored monthly over two years, from July 2001 to June 2003 at four stations in order to study the temporal and spatial patterns and the response of tintinnid species composition, abundance variation and seasonal succession to environmental variation in a chemical discharge zone in North Lebanon (Eastern Mediterranean). Diversity was estimated as the number of species and the Shannon Index. Tintinnid abundance showed regular marked seasonal changes with bimodal cycle in the stations not affected by the pollution discharge while the other stations showed differences in the timing of maximum abundance depending on the year. Density of tintinnids ranged between 1 and 231 ind. L^{-1} and the annual mean between 24 ± 27 and 37 ± 59 ind. L^{-1}. The highest cell concentrations were observed in November and May of both years of the study in stations not directly affected by discharge and the minimal values were noted in February 2002 for all stations. The number of tintinnid species in samples ranged from 2 to 19 ind. L^{-1}. Shannon Diversity index was between 0.67 and 3.26 bit. Spatially, there was significant difference ($P < 0.05$) among stations (in some seasons) for all the considered environmental variables except temperature, but no difference ($P > 0.05$) was observed among stations in the tintinnid abundance, number of species and diversity indices. The intermittent discharge of effluent and the deteriorated average conditions observed near the shoreline created a clear difference in a qualitative aspect, seasonal succession of populations and the most abundant species. Density and diversity of species were not related to any of environmental parameters ($P > 0.01$).

Keywords: Tintinnid ciliates, chemical input, Lebanon, coastal waters, Eastern Mediterranean.

Introduction

On the Lebanese coastal zone, urbanized areas cover almost half of the coastline and include 10 percent of the large industrial and commercial units that produce chemicals. Industries are, therefore, frequently blamed for much of the environmental problems because they discharged industrial waste water, solid waste and potentially toxic air emissions. Other major sources of these chemicals in marine waters are the agrochemicals that reach the sea through rivers, run-off and/or rainfall, or as by-product wastes from factories and domestic sewers, which currently flow into the coastal areas without any treatment (MoE/ LEDO/ ECODIT 2001).

Batroun Caza (North Lebanon) hosts two major sources of continental inputs. The first is a chemical plant characterized by its heavy production of phosphoric acid, triple superphosphate, simple superphosphate, aluminum sulfate and sulfuric acid and the second is the Al-Jaouz seasonal river. The wastewater produced at the chemical plant interacts with the Al-Jaouz River and discharges water loaded with fertilizers into the marine environment, thus making it possible to study its impact and influence on the chemical composition of marine waters and tintinnid populations. Both types of discharges from the plant and the river add large amounts of phosphorous and nitrogen compounds to the aquatic environment, which may create stressful environment to marine organisms. Most of the arguments used in these conflicts are related to the impact of the chemical plant on the marine ecosystem.

The current study was a part of a comprehensive project aiming to study the impact of inputs and their dispersion from the chemical plants in this part of the Levantine Basin by measuring parameters in pelagic zones and sediments. Fakhri *et al*. (2005) showed that the industry was exerting several impacts on the biochemical processes at the local level. For example, it artificially increases the temperature of the surrounding waters, while the effect of the river is noted by its own natural thermal annual cycle. At this stage, it is not clear if these changes negatively influence tintinnid populations, directly by creating an inhospitable environment or indirectly by affecting their main source of nutrition, i.e. phytoplankton populations.

Tintinnids play a role in carrying matter and energy between the microbial and the metazoan communities and constitute an important link in marine planktonic foodweb (Verity 1985; Laval-Peuto *et al*. 1986; Alder 1999). Although some authors have pointed out that tintinnids can consume particles only about 40-45% of the lorica's oral diameter (Heinbokel 1987), others have observed that larger particles are also taken under food stress conditions (Capriulo *et al*. 1986, 1991; Alder 1999). Tintinnids have been mentioned frequently as being important grazers on detritus, picoplankton, bacterio-plankton, and autotrophic and heterotrophic nannoplankton (Kopylov and Tumantseva 1987; Bernard and Rassoulzadegan 1993). Furthermore, tintinnids can also consume microplanctonic diatoms and dinoflagellates (Verity and Villareal 1986).

The relationship between ciliates and the proximity of polluted coastal areas or the estuaries is less common in the literature (Dolan and Coats 1990; Pierce and Turner 1994; Barria De Cao *et al*. 2003; Bojanic *et al*. 2005, 2006a; Vidjak *et al*. 2006; Elliott and Kaufmann 2007). In the region, most of the studies are still limited to the effect of pollution on primary production because the phytoplankton community usually displays rapid response to environmental changes in both species composition and density (Shams-El-Din and Dorgham 2007; Hussein 2008).

In the Eastern Mediterranean Sea, there are few studies on seasonal variability of abundance and biomass of ciliates. These studies were mostly carried out in eutrophicated bays or near large cities (Üktem and Sesen 1985; Koray 1990; Bizsel and Uslu 2000) like Izmir Bay which is considered as one of the most polluted estuaries in the Mediterranean Sea, being close to the outfall of Athens as well as Alexandria Bay (Mikhail *et al.* 2008).

In the coastal Lebanese waters, the subject of planktonic tintinnids in relation to seasonal and annual variations have been investigated (Abboud-Abi Saab 1989, 2002) but the relation of these organisms with chemical pollution has not been yet studied. This is the first research of its kind in the Lebanese waters and one of very few in the Eastern Mediterranean. The presence of a chemical plant producing several hundred tonnes of orthophosphates in an oligotrophic marine environment could be expected to cause visible effects on mesoscales, by affecting the quality of the marine environment.

This paper aims firstly to study the impact of the multiple discharges on seasonal and spatial variations of the planktonic ciliate tintinnid community abundance and diversity in terms of occurrence and biodiversity and secondly to investigate whether such variations were related to seasonal and spatial trends in the relationships between population dynamics in tintinnids according to physicochemical and biological parameters. The relationship between variations of tintinnids diversity and biomass and the variations of surface temperature, salinity, pH, and chlorophyll a (Chl a) concentration were also explored.

Materials and Methods

Study Area

The study area covered the marine waters located on the northern part of the Lebanese coast, in front of the chemical plant of Selaata, north of the city of Batroun. The area is characterized by shallow waters which are constantly mixed by wind and tidal currents. It is highly turbid environment with scarce light penetration due to a great amount of inorganic suspended materials. In this area, there are two major sources of contamination. The first is the chemical plant that was established in 1957 in Selaata and characterized by its heavy production of phosphoric acid, triple superphosphate, simple superphosphate, aluminum sulfate and sulfuric acid. The by-products like phosphor-gypsum and

sulphuric acid are directly discharged in the coastal waters near the plant (Al-Hajj and Muscat 2000). This plant uses 840 tons of phosphate rock per day (Abboud-Abi Saab and Dargham 1998) and discharges a great amount of phosphate into the sea (Abboud-Abi Saab and Attallah 1996). The plant is classified as a "Class I" (high-risk facility) industry according to the degree of environmental threat. The second source is the Al-Jaouz seasonal river, located also to the north of Batroun (about 400 m to the south of Selaata chemical plant) with a mean annual flow of $2.84 m^3 s^{-1}$ (UNEP 1970). Its watershed is sparsely urbanized, lacks major industries, and the nutrient load it carries originates essentially from agrochemicals. When the water level is low, the river mouth is obstructed by a mass of pebbles (Abboud-Abi Saab *et al.* 2002). Water of the river is used to cool the engines of the Selaata plant.

Four stations were chosen for the sampling of tintinnids. Two of the four stations are affected directly by land chemical discharge (M6 and M9), one coastal station (M1) situated at the north of the plant is affected by the plant discharge only when winds blow from the North, and one offshore station (M13) is affected only during rough weather in winter (Figure 1, Table 1). Sampling was carried out at monthly intervals from July 2001 till June 2003 for M1, M6 and M13 and from November 2001 to June 2003 for M9, using a small fishing boat.

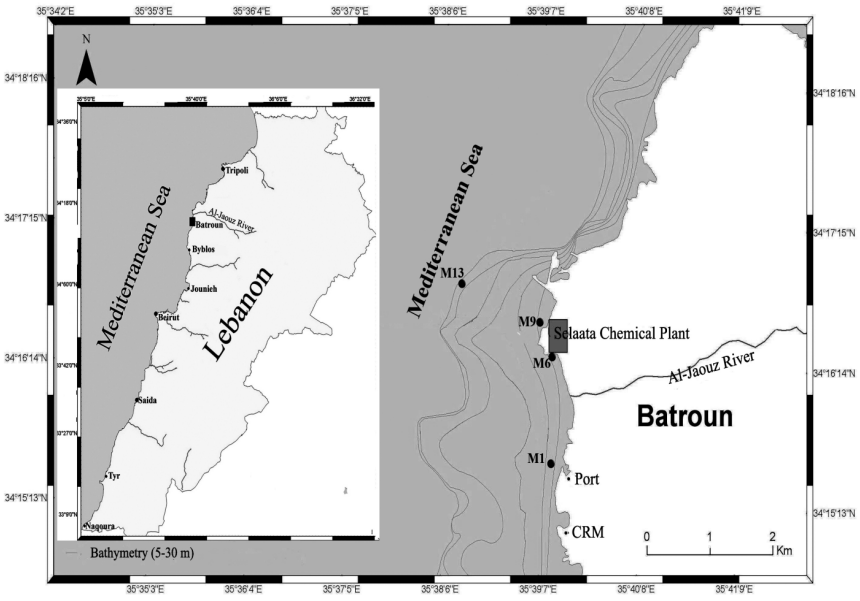

Figure 1. The study area and the location of the four sampling stations in the Lebanese coastal waters

Table 1. Description and coordinates of the four sampling stations in Northern Lebanese coastal waters between July 2001 and June 2003

Stations	Coordinates	Bottom type and Depth (m)	Location
M1	N 34° 15,533' E 35° 39,361'	Rocky with big areas of sand, 10m depth	50 m from the exit of the harbor of Batroun
M6	N 34° 16,317' E 35° 39,280'	Sandy,5m depth	50 m far from the coast and 50 m in front of a small discharge at plant south wall
M9	N 34° 16,579' E 35° 39,132'	Rocky with small areas of sand,5m depth	100 m in front of the principal discharge, north side of the plant
M13	N 34° 16,834' E 35° 38,370'	Rocky with large areas of fine gravel, 24m depth	1200 m offshore from the station M9

Analysis

At each station, hydrological parameters were measured directly in the field using two probes fitted with a multi-parameter type "WTW Multiline P4". The first probe was for water temperature (°C) and salinity measurements (psu). It was calibrated using a salinometer, type Beckman R S7-C model. The second probe was for pH measurement, calibrated with two WTW buffer solutions 4.0 and 7.0 prepared directly before sampling. Water samples for the determination of the concentration of dissolved inorganic nutrients and tintinnids were collected at the surface. Orthophosphate was analyzed by the colorimetric method of Murphy and Riley (1962), nitrites by the method of Bandschneider and Robinson (1952) and nitrates by the method of Strickland and Parsons (1968) with a small modification consisting of utilizing ammonium chloride as an activator (Grasshoff 1961). Samples for measuring total Chlorophyll-a (Chl-*a*) were filtered through a Whatmann GF/C filter at low pressure. Pigments were then extracted in 90% acetone for 24 h in the cold and dark place. The concentration was determined by a spectrophotometer according to the monochromatic method of Lorenzen (1967). For tintinnids, 3 L of water were screened through 20 µm collector and samples were preserved with 4% borate-buffered formaldehyde. In the laboratory, samples were gravimetrically settled to aliquots of 100 ml in combined plate chamber. For tintinnid enumeration of each sample, the entire bottom chamber was examined using a phase contrast inverted microscope Wild M40 following the Utermöhl's method (1958) at 100 X magnifications for most species. A total of 96 samples were analyzed for all parameters and 92 for tintinnnids abundance. All identifications were made on the basis of lorica morphology. Identification and counting were completed to the species level, using standard taxonomic references. The taxonomic results are presented in Table 3. Note that due to the high turbidity in the explored zone it was not possible to increase the volume of sample screened; moreover, due to the selectivity and the high heterogeneity at a small scale, the use of net sample was not quite precise for a quantitative study.

Statistical Analysis

Descriptive statistics (mean, standard deviation (SD), minimum, maximum and standard error of the mean) for environmental factors at the four studied stations and also for biological factors were calculated. Biodiversity was estimated as taxonomic richness (Nsp = number of taxa) and Shannon's diversity index (H' = –Ppilog2 pi, where pi = ni⁄N, ni = number of individuals of one taxon, and N = total number of individuals). One-way ANOVA was performed in order to test statistical differences between four seasons at the four studied stations using Sigma Stat software program (See Tables 1 and 2 for abbreviations). This analysis was performed on hydrological parameters (temperature, salinity and pH) nutrient concentrations (orthophosphates and nitrates), and abundance, diversity and number of species of tintinnids.

Table 2. Descriptive statistics of environmental parameters at the four sampling stations in the Lebanese coastal area between July 2001 and June 2003 (N = 96)

Station →		**M1**	**M6**	**M9**	**M13**
Variable ↓ (abbreviation)		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Temperature °C (T)	**Total**	23.15 ±4.56^{a}	23.1 ± 4.70^{a}	24.06 ± 4.43^{a}	23.37 ± 4.30^{a}
	Winter	18.52±1.21^{a}	18.26±1.46^{a}	19.3±1.48^{a}	18.78±1.3^{a}
	Spring	19.53±2.08^{a}	19.52±2.21^{a}	20.87±1.46^{a}	19.84±2.16^{a}
	Summer	28.22±1.61^{a}	28.33±1.69^{a}	28.47±1.42^{a}	28.12±1.77^{a}
	Fall	26.3±1.8^{a}	26.27 ±1.87^{a}	27.62±2.46^{a}	26.53±1.68^{a}
Salinity (psu) (S)	**Total**	38.98 ± 0.53^{a}	37.58 ± 2.5^{b}	38.87 ± 0.74^{a}	39.0 ± 0.64^{a}
	Winter	38.91 ± 0.26^{a}	37.42 ± 2.38^{a}	38.59 ± 0.91^{ac}	39.01 ± 0.42^{a}
	Spring	38.32 ± 0.53^{a}	35.22 ± 2.6^{b}	38.19 ± 0.58^{a}	38.23 ± 0.73^{a}
	Summer	39.20 ± 0.19^{a}	38.25 ± 2.25^{a}	39.19 ± 0.25^{a}	39.25 ± 0.17^{a}
	Fall	39.48 ± 0.1^{a}	39.45 ± 0.14^{a}	39.5 ± 0.09^{a}	39.54 ± 0.07^{a}
pH	**Total**	8.16 ± 0.09^{a}	7.72 ± 0.74^{b}	7.85 ± 0.31^{b}	8.17± 0.08^{a}
	Winter	8.24 ± 0.04^{a}	8.07 ± 0.25^{a}	7.87 ± 0.23^{b}	8.22 ± 0.1^{a}
	Spring	8.19 ± 0.05^{a}	7.82 ± 0.68^{a}	7.79 ± 0.23^{a}	8.18 ± 0.08^{a}
	Summer	8.06 ± 0.03^{a}	7.45 ± 1.03^{a}	7.78 ± 0.52^{a}	8.11 ± 0.03^{a}
	Fall	8.13± 0.1^{a}	7.54 ± 0.8^{a}	7.96 ± 0.20^{a}	8.16 ± 0.07^{a}
Orthophosphates ($\mu M\ L^{-1}$) (PO_4)	**Total**	0.93 ± 2.41^{a}	4.07 ± 6.34^{a}	24.98 ± 23.9^{b}	0.65 ± 1.20^{a}
	Winter	0.74 ±1.28^{b}	2.72±2.45^{b}	28±9.59^{a}	0.175±0.25^{b}
	Spring	0.155±0.12^{b}	1.9±2^{b}	27.9±16.5^{a}	1.05±2^{b}
	Summer	0.61±0.12^{a}	1.81±1.6^{a}	28.4±45	0.44±0.66^{a}
	Fall	2.21±3.9^{b}	9.84±10.87^{a}	15.61±8.49^{a}	0.94±1.10^{a}
Nitrates ($\mu M\ L^{-1}$) (NO_3)	**Total**	1.23 ± 1.21^{a}	4.48± 4.99^{b}	0.93± 1.18^{a}	0.54± 0.6^{a}
	Winter	2.06±1.31^{a}	5.86±6.78^{a}	1.93±2.04^{a}	0.6±0.55^{a}
	Spring	1.52±1.76^{b}	5.78±3.98^{a}	0.89±0.59^{b}	0.82±1.08^{b}
	Summer	0.84±0.43^{a}	1.92±3.09^{a}	0.46±0.27^{a}	0.48±0.26^{a}
	Fall	0.40±0.15^{a}	0.47±0.24^{a}	0.31±0.16^{a}	0.24±0.16^{a}

^{ab} The differences in the mean values in each row between stations with different superscripts are statistically significant ($p < 0.05$)

To determine the dominance of each parameter, Principal Components Analysis (PCA) was conducted by using SPSS statistics program for Windows for the multivariate hydrological, hydrobiological and some quantitative aspects of the tintinnid assemblages (abundance, species richness, Shannon diversity index) dataset. Data on phytoplankton populations and chlorophyll *a* (chl*a*) published by Abboud-Abi Saab *et al.* (2006) were also included in this analysis. In addition, the relationships between the different environmental factors and the log-transformed abundance of tintinnid abundance were assigned by computing the bivariate Bravais–Person correlation coefficients (r) using the SPSS program.

Similitude index of Jaccard (1902) j= 2c/a+b x 100 (a= number of taxon in station I, b= number of taxa in station 2 and c= number of common taxa between I and II was also applied.

Table 3. Descriptive statistics of tintinnids at the four sampling stations in the Lebanese coastal area between July 2001 and June 2003

Station → Variable ↓ (abbreviation)		**M1** Mean ± SD	**M6** Mean ± SD	**M9** Mean ± SD	**M13** Mean ± SD
Tintinnid abundance (Ind. L^{-1}) (Tint)	**Total**	37 ±59 [a]	24 ± 27 [a]	24. ± 31 [a]	30 ± 35 [a]
	Winter	14 ±19[a]	19±20 [a]	19 ±28 [a]	13 ±7 [a]
	Spring	52 ±74 [a]	26 ±28 [a]	35 ±43 [a]	43 ±53 [a]
	Summer	10 ±4 [a]	13 ±7 [a]	8±7 [a]	22 ±23 [a]
	Fall	71 ±84 [a]	37 ±42 [a]	22 ±25 [a]	40 ±36 [a]
Number of species (Nsp)	**Total**	7.2± 3.9 [a]	7 ± 3.4 [a]	6.3 ± 2.9[a]	8.5 ± 4.1[a]
	Winter	6.5± 1.87 [a]	7± 3.2 [a]	6± 4.5 [a]	8± 3.7 [a]
	Spring	8± 00 [a]	6± 00 [a]	5± 00 [a]	7± [a]
	Summer	7± 1.8 [a]	6± 3.2 [a]	6± 2.9 [a]	9± 2 [a]
	Fall	8± 4.3 [a]	8± 4.5 [a]	8± 4 [a]	10± 5 [a]
Species diversity index H'_{log2} (bit) (Index)	**Total**	2.04 ± 0.72 [a]	2.17 ± 0.61 [a]	2.04 ± 0.66 [a]	2.3 ± 0.77 [a]
	Winter	1.9 ± 0.84 [a]	2.25 ± 0.66 [a]	2. ± 0.6 [a]	2.55 ± 0.56 [a]
	Spring	1.61 ± 0.66 [a]	1.93 ± 0.64 [a]	1.92 ± 0.75 [a]	1.8 ± 1 [a]
	Summer	2.48 ± 0.52 [a]	2.26 ± 0.47 [a]	1.88 ± 0.8 [a]	2.55 ± 0.52 [a]
	Fall	2.15 ± 0. 7 [a]	2.23 ± 0.74 [a]	1.87 ± 0.70 [a]	2.45 ± 0.86 [a]

The differences in the mean values in each row between stations with different superscripts are statistically significant ($p < 0.05$)

Results

Environmental Factors

The descriptive statistics of environmental parameters are shown in Table 2. During the study, surface seawater temperature ranged from 16.3 °C (February 02, M6) to 32 °C (November 01, M9), with a maximum annual mean value at M9 (24.06 ± 4.43 °C) (0.91 and 0.69 °C warmer than the other stations) but

without significant differences among stations. Conversely, surface salinity was more variable ranging from 32.19 psu (May 02, M6) to 39.61 psu (November 02, M13). The highest variability and the lowest mean value were recorded at station M6 affected by river input (mean value =37.58 ± 2.5 psu) whereas the other stations showed higher ($P < 0.05$) averages. The pH values fluctuated between 5.67 (July 02, M6) and 8.3 (January 02, M13) showing differences ($P < 0.05$) between affected and less affected stations. Concentration of orthophosphates varied between 0.01 (July 02, M13) and 116.6 μML^{-1}(June 03, M9) while nitrates ranged between 0.02 (March 02, M13) and 14.66 μML^{-1} (February 02, M6). The highest variability and mean value were recorded at station M9 for orthophosphates (24.98 ± 23.9 μML^{-1}) affected directly by the chemical plant and at M6 for nitrates (4.48 ± 4.99 μML^{-1}) affected by river input.

Composition, Diversity Abundance and Distribution of the Tintinnids

The list of tintinnids taxa found is presented in Table 3. Over the whole period, the community of tintinnids was comprised of 75 species belonging to 28 genera. *Eutintinnus* was the most numerous genus in terms of number of species with 11 species of the total recorded in this study, followed by *Tintinnopsis* with 9 species and *Salpingella* with 7 species. These 3 genera represented 36% of the total recorded species. The total number of species recorded at each station was 55, 46, 36 and 64 species at M1, M6, M9 and M13, respectively. From a qualitative aspect, some species of genera were absent at M9, such as *Amphorides* and *Rhabdonella*, but it seems that *Tintinnopsis* species were less affected, such as *Tintinnopsis beroidea.*

Seasonal Succession of Tintinnid Species

The most abundant species, with their monthly density and their percentage to the total number of tintinnids, at each station are listed in Table 4. The percentage of the 14 dominant species reached 94 % (May 02 at M13) in the case of *Tintinnopsis beroidea* which is the most frequent dominant species followed by *Eutintinnus lusus-undae* (79 % in May 02 at M1).

Many species succeeded each other during the one year cycle without any clear pattern at different stations. Only during the months of April, May and October 2002, the dominant species were the same in all stations, but with different percentages. As for the remaining months, dominant species changed both among stations and years. Additionally, 7 species were observed to reach a density of more than 10 ind. L^{-1} (*Tintinnopsis beroidea, T. cylindrica, Eutintinnus lusus-undae, Codonellopsis schabi, Amphorella tetragona, Stenosemella nivalis* and *Favella campanula*) whereas the rest registered a density between 2 and 9 ind. L^{-1}. Furthermore, frequent absence of dominance at station M9 was noticed whereas it was present at the other stations. M1 and M13 were more similar with each other than with other stations. In the affected

stations only the most abundant species were present but the rare species had disappeared.

Table 4. List of tintinnid species encountered at the four sampling stations in the Lebanese coastal area between July 2001 and June 2003

Name of species	M1	M6	M9	M13
Amphorellopsis tetragona (Kofoid and Campbell) Kofoid and Campbell	X			
Amphorides amphora (Claparède and laachmann) Strand	X	X	X	X
A. minor (Jörgensen) Strand				X
A. quadrilineata (Claparède and laachmann) Strand	X	X		X
Ascampbelliella armilla (Kofoid and Campbell) Corliss	X	X		X
Codonella apicata Kofoid and Campbell				X
C. aspera Kofoid and Campbell		X	X	X
C. galea Haeckel	X	X		X
Codonellopsis schabi (Brandt) Kofoid and Campbell	X	X	X	X
C. laciniosa (Brandt) Brandt	X	X	X	X
Coxliella sp.	X			X
Cyttarocylis sp.				X
Dadayiella ganymedes (Entz, Sr.) Kofoid and Campbell	X	X	X	X
Dictyocysta elegans var. *elegans* Ehrenberg	X	X		X
D. mitra Haeckel			X	X
Epiplocylis blanda Kofoid and Campbell	X	X		X
E. constricta Kofoid and Campbell	X			
Epiplocyloides acuta (Kofoid and Campbell)	X	X	X	X
E. brandti (Kofoid and Campbell) Hada	X	X		X
Eutintinnus apertus Kofoid and Campbell	X	X	X	X
E. elegans (Jörgensen) Kofoid and Campbell	X	X	X	X
E. fraknoi (Daday) Kofoid and Campbell	X	X	X	X
E. lusus-undae (Entz) Kofoid and Campbell	X	X	X	X
E. macilentus (Jörgensen) Kofoid and Campbell	X	X	X	X
E. medius Kofoid and Campbell		X	X	
E. pinguis (Kofoid and Campbell) Kofoid and Campbell	X	X	X	X
E. perminutus (Kofoid and Campbell) Kofoid and Campbell	X	X		X
E. stramentus (Kofoid and Campbell) Kofoid and Campbell	X		X	X
E. tubulosus (Ostenfeld) Kofoid and Campbell	X	X	X	X
E. turgescens (Kofoid and Campbell) Kofoid and Campbell	X	X		X
Favella adriatica (Inhof) Jörgensen	X			
F. azorica (Cleve) Jörgensen	X			X
F. campanulla (Schmidt) Jörgensen	X		X	X
F. ehrenbergii (Claparède and Lachmann) Jörgensen	X	X		X
Favella sp.				X
Helicostomella subulata (Ehrenberg) Jörgensen				X
Metacylis jorgensenii (Cleve) Kofoid and Campbell	X	X	X	X
Parundella lohmanni Jörgensen	X			
Proplectella angustior (Jörgensen) Kofoid and Campbell	X	X		X
P. claparedei (Entz Sr.) Kofoid and Campbell	X	X	X	X
P. parva Kofoid and Campbell				X
P. pentagona Jörgensen	X			
Protorhabdonella curta (Cleve) Jörgensen	X	X	X	X
P. simplex (Cleve) Kofoid and Campbell	X	X		
Rahbdonella amor (Cleve) Kofoid and Campbell	X			X
R. brandti Kofoid and Campbell				X
R. elegans Jörgensen	X	X	X	X
R. spiralis (Fol) Brandt	X	X	X	X

Table 4. Continued

Name of species	M1	M6	M9	M13
Rahbdonella sp.				X
Salpingella acuminata (Claparède and Lachmann)Jörgensen	X	X		X
S. cuneolata Kofoid and Campbell				X
S. attenuata Jörgensen				X
S. decurtata Jörgensen	X	X	X	X
S. glockentgeri (Brandt) Kofoid and Campbell	X			
S. gracilis Kofoid and Campbell		X		
Salpingella sp.				X
Salpingacantha sp.				X
Steenstrupiella steenstrupii (Claparède and Lachmann) Kofoid and Campbell	X	X	X	X
Steenstrupiella sp.				X
Stenosemella nivalis (Meunier) Kofoid and Campbell	X	X	X	X
S. ventricosa (Claparède and Lachmann) Jörgensen	X	X	X	X
Tintinnopsis beroidea Stein	X	X	X	X
T. brandti (Nordqvist)			X	X
T. campanula (Ehrenberg) Daday	X	X	X	X
T. campanula var. bütschlii (Daday)		X	X	
T. compressa (Daday) Laackmann	X	X	X	X
T. cylindrica Daday	X	X	X	X
T. nana Lohmann	X	X	X	X
T. radix (Inhof) Brandt	X	X	X	X
Tintinnopsis sp.	X			X
Tintinnus inquilinus (O.F.Müller) Schrank	X			X
Undella clevei Jörgensen	X	X	X	X
U. hyalina Daday	X	X		
Xystonella longicauda (Brandt) Laackmann	X	X	X	X
X. lohmanni (Brandt) Kofoid and Campbell				X
Total	55	46	36	64

Abundance

Tintinnid abundances ranged from 2 (February 02) to 231 ind. L^{-1} (November 01) at station M1, from 2 (February 02) to 117 ind. L^{-1}(November 01) at M6, from 1 (February 02) to 109 ind. L^{-1}(March 03) at M9 and from 2 (February 02) to 135ind. L^{-1} (May 02) at M13. The annual mean values showed the following results: 37 ± 59 ind. L^{-1} at M1, 24 ± 27 ind. L^{-1} at M6, 24 ±30 ind. L^{-1} at M9 and 30 ±35 at M13 (Table 4).

Tintinnid abundance generally showed marked seasonal trends with bimodal cycles. The highest cell concentrations were observed in November and May of both years in M1 and in M13 (Figure 2) and depending on the year, at M6 and M9 other maxima were noted in October 2001 and February 2003 at M6, and in December 2001 and March 2003 at M9. The minima were noted in February 2002 for all stations.

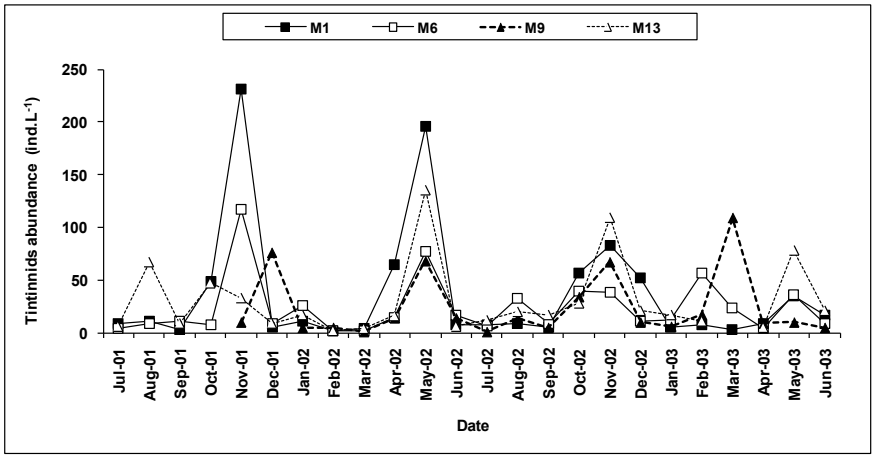

Figure 2. Seasonal variations of tintinnids abundance in the four sampling stations in the Lebanese coastal waters between July 2001 and June 2003

The number of tintinnid species in the samples ranged from 2 (December 01, February, March 02), to 15 (May 02), 2 (February, March 02) to14 (October 02), 2 (April, July 02) to 14 (November 02), and 2(February, March, April 02) to 19 (November 02) successively at M1, M6, M9 and M13. The mean values ranged from 6.3 ± 2.9 at M9 to 8.5 ±4.1 at M13 (Table 2). The seasonal distribution showed a clear cycle with a maximum in May –June and another one in Nov-Dec. These seasonal trends, however, were less consistent at M6 and almost absent at M9 (Figure 3).

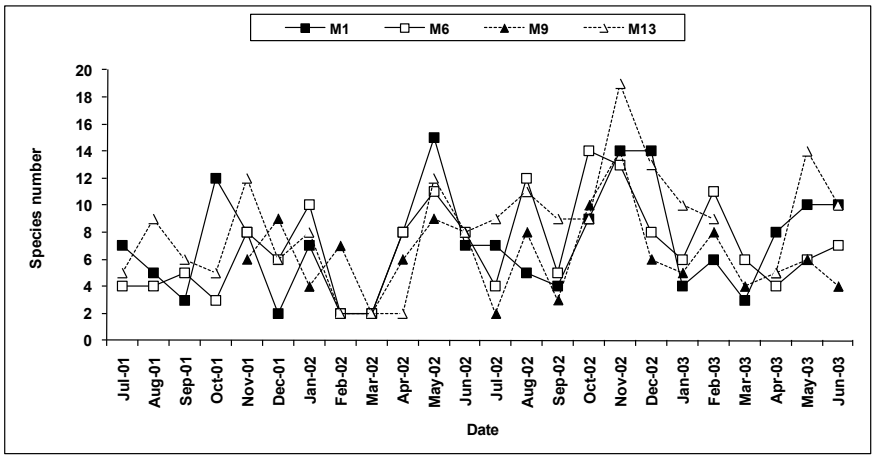

Figure 3. Seasonal variations of the number of tintinnids species in the four sampling stations of the Lebanese coastal waters between July 2001 and June 2003

The species diversity index of tintinnids was between 0.7 and 3.3 bit (3.2 - 0.8, 3.2 - 1, 3.1-1 and 3.3-0.07 bit, respectively at M1, M6, M9 and M13) and the annual mean values were globally constant in all stations (2.1±07, 2.2±0.6, 2±0.7 and 2.3±0.8 bit, respectively at M1, M6, M9 and M13) (Table 4). The species diversity index showed no seasonal trend except for M13 which exhibited a minimum in March 02 followed by a gradual increase. This trend was not detected in the second cycle (Figure 4).

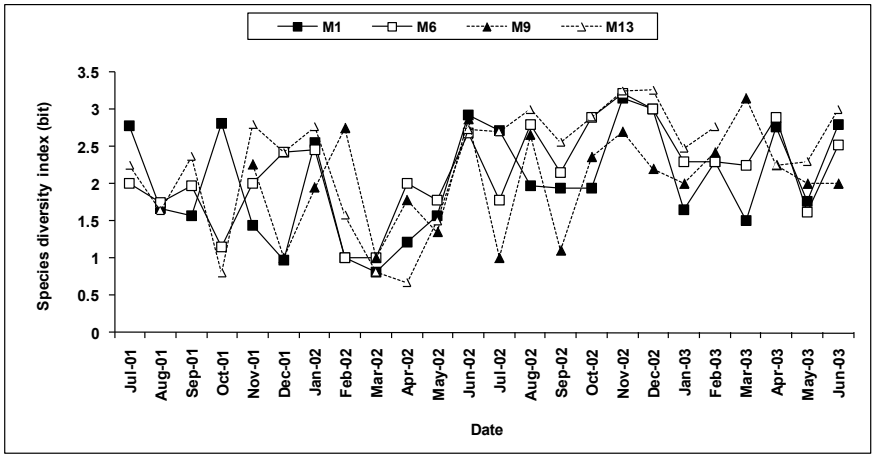

Figure 4. Seasonal variations of diversity index of tintinnids at four sampling stations in the Lebanese coastal waters between July 2001 and June 2003

The comparison between stations based on the Jaccard's Index of similitude (Table 7) showed that the highest resemblance was observed between M1 and M6 (0.85%) due to their coastal and geographic position; while the lowest value (0.64%) was noted between M9 and M1 followed by 0.68% between M9 and M13. These results suggest that M9 was the most affected qualitatively due to the impact of thermal and chemical stress and the high turbidity.

Statistical Result

The outcome of the ANOVA carried out for testing the null hypothesis of equality among stations by seasons is reported in Table 2 and Table 3. Significant differences ($P < 0.05$) for the total annual means among stations were observed for all the considered environmental variables except for temperature but no significant differences occurred by season among all stations (Table 3); significant differences ($P < 0.05$) were noted in winter and spring for salinity, in winter for pH, in Winter, Spring and Fall for orthophosphates and in Spring for nitrates. Seasons did not have an effect ($P > 0.05$) among stations for tintinnid abundance, number of species and diversity indices.

The multivariate analysis showed the distribution of variables in Principal Factors (PF). The first two factors (F1 and F2) together explained 53.5%, 53.4%, 52%, and 48.7% of the total variance at M1, M6, M9 and M13 stations, respectively (Figure 5).

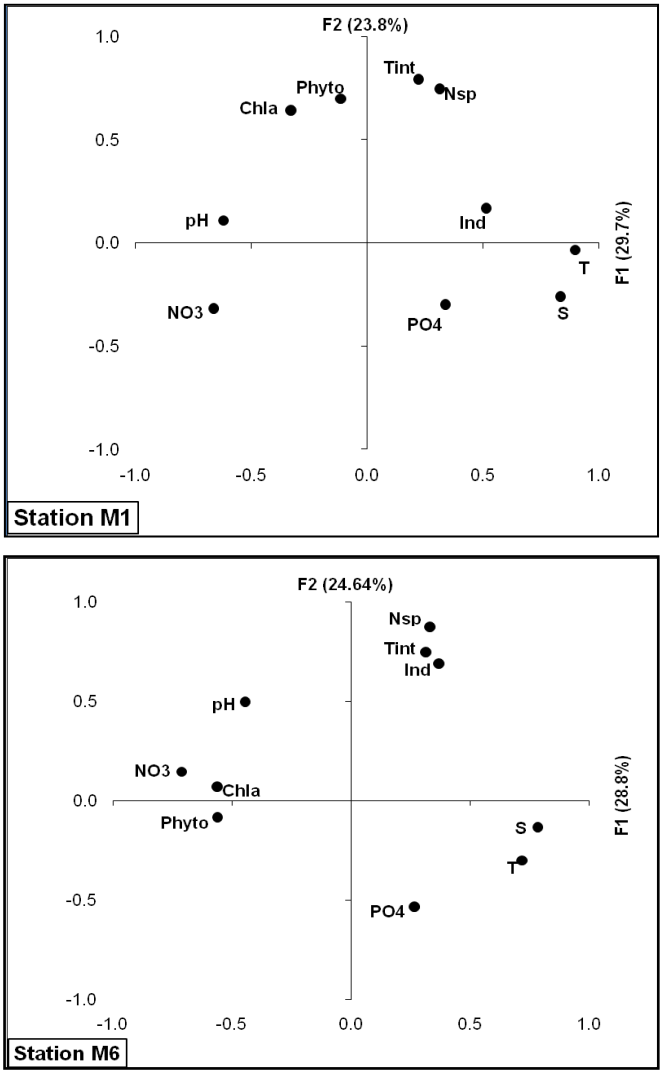

Figure 5. Principal Component Analysis applied to the environmental and biological dataset. The projection of the variable on the factor-plane described by the first and second principal factors and the percentage variance for each factor are indicated. (See Table 1 and 2 for abbreviations.)

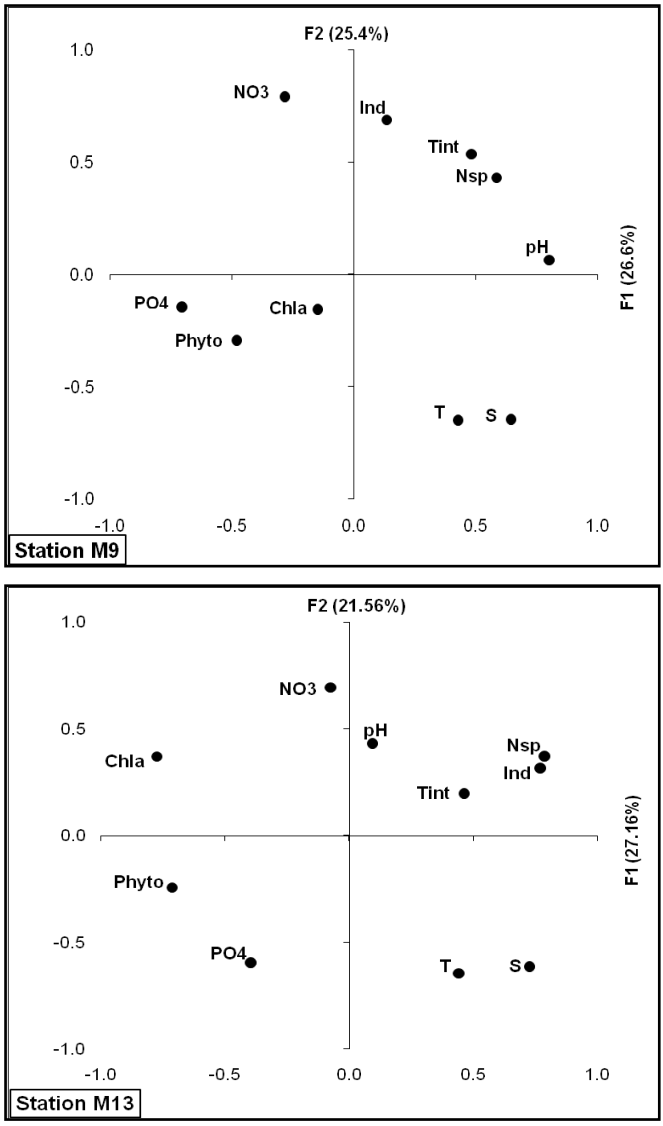

Figure 5. Continued

The projection of the variables on the factor plane described by F1 and F2 (Figure 5) highlighted different grouping of variables on F1 and F2. In M1, F1 was found to be positively related to T, S, and the Shannon diversity index and negatively with pH and NO_3. This axis could be called seasonal environmental axis. The F2 was positively related to Tint density, Nsp, phyto and chl*a*; it represents the seasonal biological factor. Both components showed a similar weak relation with PO_4 but were positive on F1 and negative on F2. In M6, F1 was highly positively related to S and T and negatively to NO_3, (Phyto and Chl*a*); this was considered to represent the axis of the river. F2 was positively highly related to Tint, Nsp and ind. Both components showed approximately similar relation with pH but were negative on F1 and positive on F2. In M9, F1was highly positively related to pH and negatively to PO4; it could be called the axis of the chemical plant whereas the F2 was positively related to NO3 and the Diversity index. In M13, F1was highly positively related to Nsp and ind. and negatively to chl*a* and phyto, whereas F2 was positively related to NO_3 and negatively to PO_4 and temperature. In contrast to other stations, F1 was considered a biological axis and F2 as an environmental axis; the position of the parameters of temperature, salinity and NO_3 were similar in the last 2 stations (M9 and M13) while tintinnid and Nsp and the Diversity index were grouped differently.

Bravais –Person correlation matrix was applied at each station between tintinnid abundance, number of species and index on one side and the environmental parameters and the first producers (chl*a* and phyto) on the other side (Table 6). Abundance did not show any significant correlation ($p > 0.05$) with any of these parameters in the four studied stations except with salinity in M6 ($r= 0.05$, $p < 0.05$) and with the diversity index ($r= 0.4$, $p < 0.05$). Number of species showed a highly positive significant correlation with abundance of tintinnids ($r= 0.83$, 0.8, 0.71, 0.73, $p < 0.001$, respectively, at four stations), with the diversity index ($r= 0.59$, $p < 0.01$, 0.68, $p < 0.001$ and 0.67, $p < 0.001$) respectively, at M1, M6 and M13 and negatively with PO_4 ($r = -0.48$, $p < 0.05$) at M13). The diversity index showed a negative significant correlation with orthophosphates ($r= -0.52$, $p < 0.01$) and with chl*a* ($r= -0.45$, $p < 0.05$) at M13.

Discussion

According to the results (Table 2), M9 station had the highest temperature and this was most likely due to the effect of water cooling of the plant of Selaata and was most affected by the thermal and chemical (phosphates) discharge. However, Station M6 was the most influenced by the river discharge that enters the area as it registered the highest levels of nitrates and low salinity. Salinity was at the lowest ($P < 0.05$) at station M6 as compared to the other three stations which may have been the result of heavy rain and the river run-off.

At the local scale, the buffering capacity of the seawater did not prevent the increase in seawater acidity to abnormally high levels (Table 2). The acid

discharge from the factory to its immediate proximity has apparently created a local and destructive factor to the ecosystem as was observed at the primary production level where chlorophyll-a concentrations and phytoplankton populations were decreased (Abboud-Abi Saab *et al.* 2006). In fact, large differences ($P < 0.05$) were recorded among the mean values of pH and PO_4 at the different stations.

The high variability of nutrients among stations reflects the consequence of the land input (Table 2). These nutrients were generally low in other sampling sites of the Lebanese coast but expressed higher values in coastal stations rather than the offshore ones (Abboud-Abi Saab *et al*. 2008).

Many factors, such as the hydrodynamic and geomorphologic position of each station, the flow rate and concentrations of the different continental discharges, were interfering in the level of contamination. In our case, the limit of expansion of the water masses discharged by the Al-Jaouz River and the chemical plant was conditioned by the interactions of two main factors, namely, the dominant wind (direction and speed) and the intensity of the river flow (Fakhri *et al*. 2006). These preliminary findings justified the choice of these sampling stations for the study of phytoplankton populations (Abboud-Abi Saab *et al*. 2006) and at the present study of the tintinnids as M6 and M9 were directly affected by land discharge waters versus M1 and M13 stations, which represent the characteristics of Lebanese coastal waters slightly influenced by these two land sources.

It is important to mention the prevailing factors to mitigate the effect of continental input despite the presence of high level of nutrients: the Lebanese coast is an open sea environment; the continental shelf is very narrow, edging deep waters; there are no closed bays and no barrier and water is being continuously mixed helping the dispersion of nutrients and pollutants. As a result, the dispersion of nutrient becomes relatively easy and prevents conditions of accumulation and negative effect. Therefore, widespread offshore heavy pollution cannot be expected (Abboud-Abi Saab 1996).

In order to highlight the polluting impact of the chemical factory on Batroun marine environment, a preliminary study was made on the benthic ecosystem by analyzing the stress of two biological components, the chlorophyll-*a* and the meiofauna populations. Results showed that the variability in the concentrations of chlorophyll-*a* and in the meiofauna densities were not affected by the sediments composition but mainly by the nature and toxicity of particulate matters discharged through the plant's outflows such as the phosphogypsum (Fakhri *et al*. 2008). Indeed, the permanent discharges in the proximity of the factory did great damage to the whole water column in general and to the benthic populations in particular but the later harmful effect was limited in space and did not cover a great area. Seasonal fluctuations of phytoplankton in this area were also detailed by Abboud-Abi Saab *et al*. (2006). Results showed that the nutrients contributions, represented by phosphates and nitrates, did not

compensate the effect of high turbidity and the decreasing in pH caused by the chemical discharged; at the affected stations, the cells, especially the centric diatoms, were fragile and some were deformed. On the level of the water column, the seasonal variation, which is a natural phenomenon, was more marked than the local anthropogenic one.

At a local space scale, the buffer capacity of seawater did not prevent the increase in seawater acidity to abnormally high levels and the acid discharge from the factory to its immediate proximity has created a local and destructive factor for ecology that was marked out at primary production level represented by chlorophyll-*a* concentrations and phytoplankton populations (Abboud-Abi Saab *et al*. 2006). In fact, statistically significant differences were noted among the annual mean values of pH and PO_4 at the different stations (Table 2). For pH, significant differences were noted between M6 and M9 on one side and M1 and M13 on the other.

The data obtained for nutrients (Table 2) showed main differences in orthophosphate and nitrate values, which were always higher at M9 for the former and at M6 for the latter. The large amount of nitrate reaching the seawater near the river and the great inflow of phosphate from the plant into the seawater did not provide the expected favorable conditions for phytoplankton development like in other oligotrophic places without such nutrient supplies (Abboud-Abi Saab *et al*. 2006). Furthermore, they often lead to a dystrophic situation where N/P ratio is frequently unbalanced (Fakhri *et al*. 2005). This inhospitable environment was also not favorable for the tintinnid population in matter of abundance and species; it showed a decrease in abundance and number of species at stations M6 and particularly M9, even if there was no statistically significant difference in the mean values among the treatment stations.

In temperate coastal waters like Lebanese ones, the microzooplankton community of tintinnids shows marked seasonal variations in abundance. The bimodal annual cycle of tintinnids was comparable to those observed in similar Mediterranean localities (Vitiello 1964; Travers and Travers 1971; Rassoulzadegan 1979; Paulmier 1997). Concerning abundance and due to the differences of methodology, it is not easy to compare results of abundance. For species composition and according to a previous study (Abboud-Abi Saab *et al.* 2002), thermal affinity data showed that most of the species present in our waters were found in tropical or inter-tropical waters.

Under oligotrophic conditions, most open areas in the Mediterranean accommodate relatively high loads of domestic inputs. In our study, the discharges of nitrates from freshwater of the river and orthophosphates from the chemical plant could be beneficial to the primary production, first producers, and second to the tintinnids, first consumers. This is especially true for station M13 because when the wind blows, it can transport the layer of fresh water coming from the river rich in nitrates far from the source and the water from the wastewater of chemical plant rich in orthophosphates without the direct effect of

acidic discharge; this was proven by the range of salinity and the parameters cited above compared to other stations (Abboud-Abi Saab *et al.* 2008). Whereas, when the wind is calm, the situation would be different and the stability of water could be in favor of the normal development of species.

Environmental variability plays a major role in determining spatial and temporal patterns of plankton distribution in shallow-water ecosystems (Bojanic *et al.* 2006b). In the central Mediterranean, abundance and diversity of tintinnids are strongly influenced by the hydrological characteristics of the site (Sitran *et al.* 2007). In general, the abundance of ciliates is associated with changes in standing stocks of phytoplankton as well as with local hydrographic variables (Park and Marshall 2000; Kamiyama *et al.* 2003; Stelfox-Widdicombe *et al.* 2004). The structure of the zooplankton community reflects trophic states within an ecosystem (Park and Marshall 2000). The structure and composition of zooplankton assemblages are significantly altered by eutrophication (Schiewer 1998; Gismervik *et al.* 2002; Bojanic *et al.* 2006a, b).

The excess of nutrients did not favor the development of bloom for some species noted in eutrophied environment either for phytoplankton (Abboud-Abi Saab *et al.* 2006) or for the tintinnids.

Tintinnids are an important link in marine planktonic food webs (Stoecker 1984; Laval-Peuto *et al.* 1986; Alder 1999; Dolan *et al.* 2002; Bojanic *et al.* 2006a) and can also consume microplanktonic diatoms and dinoflagellates (Verity and Villareal 1986). Reports on coastal environments show daily consumption of the standing stock of chlorophyll-*a* to 41% (Capriulo and Carpenter 1983) and an annual consumption up to 62% of the total 5-10 µm chlorophyll-*a* production (Verity 1986). In any of our sampling stations we did not observe any significant correlation with total phytoplankton nor with chlorophyll-*a* (Table 6); it seems that under these stress conditions (intermittent input of acidic water, cooling and heating water, instability, turbidity) even if food is available, the animals are stressed, thus the feeding may also be disturbed. The relationship between chlorophyll *a* and tintinnids concentrations is expected to be fairly complex (Modigh *et al.* 2003) and the lack of correlation between tintinnids abundance and phytoplankton biomass in the oligotrophic regions might be explained by the fact that most of tintinnids preys are in fact autotrophic planktons and feed also on heterotrophic pico- and nano-planktons (Verity 1991).

The fact that the number of species is correlated with abundance (Table 6) supports the idea that when the condition is not favorable, it affects not only abundance but also species composition. In warmer months, these factors combined could be worse and the whole food web will be altered. It is interesting to note that while temperature did not appear to directly correlate with total tintinnid abundance, there was a monthly succession of dominant species; the rest of species were very rare and restricted to certain times of the year. In this case temperature may not be important in controlling total

abundance; it has a major influence on species composition. Tintinnids diversity appeared to be negatively linked to chlorophyll ($r= -0.45$, $p < 0.05$) at M13. Our findings are coherent with those of Sitran *et al.* (2007) in the central Mediterranean.

Concerning the population density of tintinnids and comparing to a previous study (Abboud-Abi Saab and Kassab 1990) done in the area of the central Lebanese coastal water not affected directly by the land input, during two successive years also using the sedimented method, showed a density between 2 and 1388 ind. L^{-1} (mean = 215) in a coastal station and between 8 and 960 ind. L^{-1} (mean 145) in another station situated offshore; in conclusion the mean and the maximum were much higher. In another study carried out in northern Lebanon using net sampling (52 µm), the density varied between 1 and 390 ind. L^{-1} (mean = 109) (Abboud-Abi Saab 2002). The density and the maximum values were found to be much higher.

The number of species recorded in this study (Table 4) represent 36, 30, 24 and 42 %, respectively, at M1, M6, M9 and M13.The total number recorded in Lebanese coastal water was 150 taxa (117 species, 2 varieties and 31 unidentified species) recently (Abboud-Abi Saab *et al.* 2008). We notice that the relatively offshore station was the most diverse station and present almost about twice as much diversity as M9, the most affected station.

Due to the lack of information on the effect of chemical input on the Lebanese waters, the comparison between the present work and others will be unfeasible.

Generally the total richness showed that marked seasonal changes followed the pattern as total tintinnid abundance and reached a maximum at the same period of the abundance in M1 and M13 (less affected stations). Other maxima (December 01 and August 02) were also noted in the stations affected directly by the land input but the values stayed inferior to the richness observed in non affected stations.

In the Lebanese waters the annual cycle of tintinnids is bimodal with a peak in spring and another one in autumn like other results observed in similar Mediterranean sites (Travers and Travers 1971; Rassoulzadegan 1979; Paulmier 1997; Pitta and Giannakourou 2000; Daly Yahia *et al*. 2005; Bojanic 2007; Sitran *et al*. 2007) but the appearance of peaks and their height were irregular depending on stations and years. In North Lebanon, a major peak was noted in May and another one in October-December while minimum values were recorded in August-September (Abboud-Abi Saab 2002). In the central Lebanese coast the maxima were noted in April, May or June and in October-November depending of the year or the station (Abboud-Abi Saab 1989).

In this study, the bimodal annual cycle of tintinnids was comparable to the results found in previous studies with a principal peak in spring and another one in autumn for the stations not directly affected but with a small drift for the affected stations. In fact, we notice an early peak at station M9 which may be

due to the rising of temperature water (about 1°C between M9 and the other stations) knowing that no significant correlations are established between temperature and abundance of tintinnids in this work in contrast to prevous work in the Lebanese waters (Abboud-Abi Saab *et al*. 2002). Temperature and light can affect directly the growth of these protistae and consequently their abundance (Stoecker and Guillard 1982).

In conclusion, the contamination impact of Selaata's high level industrial activity and Al-Jaouz River seasonal activity remains at a critical level. On the other hand, the contamination can be considered local and not as widespread as expected in the pelagic ecosystem.

At the local level, the effect of the intermittent discharge of effluent into the sea near the shoreline and the deteriorated average conditions can be observed at the surface layer near the affected stations. Generally, our results confirm the high variability previously found for environmental parameters.

Although, no substantial differences were observed among the four stations considered for tintinnids populations, the results still indicate a negative effect on the density; the differences were more apparent in qualitative aspect by the seasonal succession of populations and also in the dominance of species (Tables 4 and 5).

Under these special conditions occurring within short-term scale where the changes are frequent and are not easily recognized through seasonal or monthly observations, it was difficult to control the factors affecting the development and the distribution of tintinnids especially when the importance of tintinnids lies in their short generation times, high abundance and fast reproduction rates. Therefore, in order to understand the immediate reaction of these organisms to sudden changes, it is recommended that samplings must be done more frequently.

Table 5. Monthly dominant species, their density (ind.L^{-1}) and percentage to the total tintinnid at the four sampling stations in the Lebanese coastal area between July 2001 and June 2003

Month	Year	M1			M6			M9			M13		
		Sp	Density	%	Sp	Density	%	Sp	Density	%	Sp	Density	%
Jan.	2002	*T. radix*	4	36	*T. cylindrica* *E. fraknoi*	11 9	41 33	Absence of dominance			*D. ganymedes*	5	30
	2003	*D. ganymedes*	3	60	*D. ganymedes*	5	42	*T. beroidea*	2	33	*D. ganymedes*	9	53
Feb.	2002	Absence of dominance			Absence of dominance						Absence of dominance		
	2003	Absence of dominance			*C. shabi* *S. nivalis*	25 15	45 28	*E. ubulosus*	7	41	*E. lusus-undae*	3	27
Mar.	2002	*T. beroidea*	3	75	Absence of dominance			Absence of dominance			Absence of dominance		
	2003	*E. tubulosus*	2	67	*C. shabi* *T. beroidea*	6 6	26 26	*T. beroidea*	104	95	Absence of sample		
Apr.	2002	*T. beroidea*	51	80	*T. beroidea*	8	57	*T. beroidea*	9	64	*T. beroidea*	15	94
	2003	*S. steenstrupii*	3	33	Absence of dominance			*T. compressus*	3	33	Absence of dominance		
May	2002	*E. lusus-undae*	150	79	*E. lusus-undae*	55	71	*E. lusus-undae*	53	78	*E. lusus-undae*	104	77
	2003	*E. lusus-undae*	23	67	*E. lusus-undae*	24	67	*F. campanula*	4	40	*F. campanula* *E. lusus-undae*	23 37	29 47
June	2002	Absence of dominance			*E. tubulosus*	5	31	*P. curta*	3	21	*Metacylis sp*	2	33
	2003	*E. fraknoi*	5	31	*E. fraknoi*	3	37	Absence of dominance			*E. fraknoi*	4	19

Table 5. Continued

Month	Year	M1			M6			M9			M13		
		Sp	Density	%	Sp	Density	%	Sp	Density	%	Sp	Density	%
July	2001	*T. beroidea*	3	37	Absence of dominance			Absence of sample			Absence of dominance		
	2002				*C. shabi*	3	50				*E. lusus*	5	42
Aug.	2001	*T. beroidea*	7	64	*T. beroides*	4	44	Absence of sample			*T. beroides*	47	70
	2002	*T. beroidea*	5	55	*T. beroides*	14	45	*E. tubulosus*	4		*E. macilentus*	5	25
Sep.	2001	Absence of dominance			*T. beroides*	5	45				Absence of dominance		
	2002	*T. beroidea*			*T. beroidea*	3	37	*T. beroidea*	4	25	*S. decurtata*	7	43
Oct.	2001	*A. tetragona* *A. quadrilineata*	16 9	33 27	*T. beroidea*	*5*	71	Absence of sample			*T. beroidea*	41	87
	2002	*T. beroidea*	37	65	*T. beroidea*	*15*	38	*T. beroidea*	17	51	*T. beroidea*	6	21
Nov.	2001	*E. acuta* *T. beroidea* *C. shabi*	153 36 34	66 16 15	*T. beroidea* *E. acuta* *C. shabi*	38 41 28	32 35 24	*T. beroidea*	3	30	*D. ganymedes*	15	45
	2002	*X. longicauda*	29	35	*T. beroidea*	12	32	*T. beroidea* *E. acuta*	31 11	46 16	*E. acuta* *T. beroidea*	26 25	24 23
Dec.	2001	*T. beroidea*	3	60				*S. nivalis*	64	84	*T. beroidea*	3	33
	2002	*T. radix*	15	29	Absence of dominance			*T. beroidea*	4	40	*T. radix*	6	28

Table 6. Bravais –Person correlation matrix showing relationships between species abundance, number and species diversity of loricate ciliates and environmental parameters for the stations M1, M6, M9 and M13

*p<0.05, **p<0.01, ***p<0.001
k=n-2=22, r=0.41, r=0.52, r=0.63

T	S	pH	PO_4	NO_3	Chl*a*	Index	Tin	Nsp	Phyto	
1.00	**0.65*****	**-0.82*****	0.22	**-0.50***	-0.17	0.33	0.12	0.14	-0.04	**T**
	1.00	-0.32	0.20	**-0.56****	**-0.52****	0.28	0.11	0.09	**-0.41***	**S**
		1.00	-0.37	0.34	-0.14	-0.06	0.17	0.18	-0.20	**pH**
			1.00	-0.16	-0.12	0.05	-0.21	-0.17	0.01	**PO4**
				1.00	-0.04	-0.13	-0.24	-0.21	**-0.42***	**NO3**
M1					1.00	-0.24	0.23	0.07	**0.74*****	**Chl*a***
						1.00	0.20	**0.59****	-0.22	**Index**
							1.00	**0.83*****	0.23	**Tin**
								1.00	0.16	**Nsp**
									1.00	**Phyto**

T	S	pH	PO_4	NO_3	Chl*a*	Index	Tin	Nsp	Phyto	
1.00	**0.52****	**-0.45***	0.26	**-0.60****	-0.30	0.05	0.03	0.04	-0.06	**T**
	1.00	-0.12	0.19	**-0.85*****	-0.23	0.12	0.05	0.14	-0.28	**S**
		1.00	-0.37	0.20	0.30	0.11	0.09	0.24	0.28	**pH**
			1.00	-0.08	-0.15	-0.21	-0.16	-0.25	-0.13	**PO4**
				1.00	0.01	-0.16	-0.03	-0.10	0.04	**NO3**
M6					1.00	-0.11	-0.08	-0.06	**0.71*****	**Chl*a***
						1.00	0.39	**0.68*****	-0.26	**Index**
							1.00	**0.80*****	-0.24	**Tin**
								1.00	-0.10	**Nsp**
									1.00	**Phyto**

Table 6. Continued

T	S	pH	PO_4	NO_3	Chl*a*	Index	Tin	Nsp	Phyto	
1.00	**0.69*****	0.072	-0.12	**-0.53****	0.03	-0.21	-0.12	0.11	-0.01	**T**
	1.00	0.34	-0.15	**-0.72*****	-0.10	-0.25	-0.02	0.14	-0.29	**S**
		1.00	**-0.89*****	-0.11	-0.06	-0.02	0.25	0.21	-0.34	**pH**
			1.00	-0.06	0.01	-0.06	-0.18	-0.24	0.17	**PO4**
				1.00	-0.11	0.36	0.07	0.08	-0.25	**NO3**
M9					1.00	-0.13	-0.01	-0.04	0.26	**Chl*a***
						1.00	**0.41***	0.38	-0.23	**Index**
							1.00	**0.71*****	-0.17	**Tin**
								1.00	-0.23	**Nsp**
									1.00	**Phyto**
T	**S**	**pH**	**PO_4**	**NO_3**	**Chl*a***	**Index**	**Tin**	**Nsp**	**Phyto**	
1.00	**0.59****	**-0.57****	0.00	-0.32	**-0.42***	0.15	0.26	0.17	0.02	**T**
	1.00	-0.02	0.10	**-0.55****	**-0.84*****	0.35	0.13	0.28	**-0.43***	**S**
		1.00	-0.14	-0.02	-0.10	0.15	-0.03	0.12	-0.21	**pH**
			1.00	-0.22	-0.08	**-0.52****	-0.31	**-0.48***	0.25	**PO4**
				1.00	0.17	0.14	0.04	0.13	-0.25	**NO3**
M13					1.00	**-0.45***	-0.09	-0.35	**0.62****	**Chl*a***
						1.00	0.10	**0.67*****	**-0.59****	**Index**
							1.00	**0.73*****	-0.10	**Tin**
								1.00	**-0.46***	**Nsp**
									1.00	**Phyto**

Table 7. Index of similitude between the four sampling stations

Station	M1	M6	M9	M13
M1	-	0.85	0.64	0.72
M6		-	0.78	0.74
M9			-	0.68
M13				-

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