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Surface Microplankton Composition at a Hyper Saline Oligotrophic Environment of Bitter Lake on the Suez Canal, Egypt

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Abstract

The Bitter Lake is the central and most important water body of the Suez Canal as it contains 85% of the water of the canal system. This study reports the microplankton found occurring in the surface water of the Bitter Lake at monthly intervals from November 2008 until November 2009. A total of 130 taxa were identified, among which 67 taxa were of Bacillariophyceae, 15 Dinophyceae, 11 Chlorophyceae, 11 Cyanophyceae, 1 Euglenophyceae, 18 Tintinnidae, 4 Foraminiferidae, as well as 3 of Rotifera. Species diversity, numerical abundances and dynamics were analyzed for each taxon at three sites inside the Bitter Lake. At each of these sites Bacillariophyceae were predominant in the standing crop forming 67.2% of the total microplankton community with an average of 11,594 ind. L^{-1}. The Dinophyceae occupied the second rank constituting about 16.5% of the total microplankton. Increase of microplankton abundance started in spring with maximum values being attained in late summer and early autumn (August), with an average of 37,498 ind. L^{-1}, while January was characterized by the lowest density (9,251 ind. L^{-1}). Relatively higher diversity values were recorded at the northern part of the lake and a progressive decline in diversity was observed southward. Nutrient concentrations in the lake waters were very low, with silicate varying between 0.52-1.34 µM, phosphate between 0.14 and 0.55 µM and nitrate between 0.82-3.16 µmol L^{-1}. Moreover, chlorophyll *a* fluctuated between 0.4 and 0.89 µg L^{-1}. Data from microplankton analyses, nutrient (P) and chlorophyll *a* concentrations and transparency measurements were used to assess the ecosystem health of the Bitter Lake according to OECD, Canadian, and Quebec classification criteria, and it is concluded that the Bitter Lake be classified as an ultraoligotrophic lake.

Keywords: Limnology, marine lakes, phytoplankton, protozooplankton, eutrophication, Bitter Lake, Suez Canal.

Introduction

The Suez Canal is a transitional zone that links two fundamentally different basins: the Indo-Pacific Red Sea basin and the Atlanto-Mediterranean basin, and in so doing, reconnects two biogeographical provinces, the Mediterranean and the Red Sea, that had been partially separated since the early Miocene (ca 20 Ma) and completely separated since the late Miocene (Messinian), ca 5 Ma ago (Robba, 1987). This, in its turn, has influenced the fauna and flora of the canal.

The canal crosses three different lakes: Lake Menzalah, Lake Timsah and the Bitter Lake, on its route from Port Said on the Mediterranean Sea to Port Suez on the Red Sea. The original length of the canal was 162.4 km, of which only 70 km were cut from dry land. In the early years after its opening the canal had a navigational depth of 8 m and a surface width of 59-98 m, but successive projects to widen and deepen the canal have brought its depth to 28 m and its width to 350 m. There are no locks on the main canal; although for most of the year the main sea level at Suez is slightly above that at Port Said (Lisitzin, 1974) and a north-bound current flows through the central parts of the canal, while south-bound currents occur from July-September when the Mediterranean at Port Said is a little higher than the Red Sea at Suez (Morcos and Gerges, 1974). When the Suez Canal was opened, the differing faunas and floras of the tropical Red Sea and the subtropical Eastern Mediterranean were connected. It was therefore, reasonable to expect that the canal might bring about an exchange of species between the two areas, a phenomenon that has indeed been observed by a number of biologists (e.g. Steinitz, 1929; Por, 1978, 1990; Galil, 1994; El-Serehy and Al-Rasheid, 2011).

The Bitter Lake is the central and most important water body of the Suez Canal. It contains about 85% of the water of the Suez Canal System, but

only 24% of the canal length. The Bitter Lake has a total length of 39 km with a narrowing straight at "Kabrit" which separates the basin into a narrow southern part, the "Little Bitter Lake", with a total length of 15 km, and a much wider northern part, the "Great Bitter Lake", with a total length of 24 km. The undredged depth of the Bitter Lakes is about 6 m, but they are dredged to a depth of 28 m where the canal crosses the lake in a curving path from the north-east to the south-east corners. Water movements in the lake are probably mainly due to tidal influence from the Suez Gulf (Por, 1978). When the canal was opened in 1869 the lake exhibited some most unusual hydrographic conditions (Thorson, 1971). At that time, a 13.4 m thick salt layer of about 97 million tons covered the bottom of the Great Bitter Lake. This layer was gradually dissolved by the overlying water which thus acquired a very high salinity, initially measuring 50-52 PSU at the surface and 68-80 PSU at the bottom. Today the salt layer has almost disappeared and this has reduced the surface and bottom salinity to 43-44 PSU and 45-46 PSU, respectively. Most of the floor of the lake is covered by gypsum and mixed mud (Fox, 1926; Gruvel, 1936). In some of the deeper areas this mud is black and apparently anaerobic (Por, 1978), while in shallower areas gray aerobic mud is found. The shores, shallow water and some dredged areas are sandier with occasional rock outcrops. The sandy bottoms of the lake are inhibited by blue green algal communities. Moreover, the rocky and other hard substrates are densely covered with filamentous and thalloid algae (Lipkin, 1972).

Previous works on the Bitter Lake of the Suez Canal have concentrated on specific areas rather than on overall ecosystem health and/or trophic conditions, for example (Holthuis, 1956; Miller and Munns, 1974; Heimdal *et al*., 1977; El-Serehy, 1993).

The study of the flora and fauna of the Bitter Lake is valuable, not only for its own sake, to understand their composition for the purposes of exploitation and conservation, but also because (a) the Suez Canal is held to be a route of migration for marine organisms from the Red Sea to the Mediterranean, and possibly *vice versa* (Por, 1978), and (b) it is important to know the composition of the biosphere at this way-station near the south of the canal. Indeed, it is appropriate to quote Por (1978), who wrote in his book, "Lessepsian Migration: The influx" of the Red Sea biota into the Mediterranean by way of the Suez Canal, "However, the lack of information, especially concerning Bitter Lake, is very regrettable". Taking into consideration the importance of Bitter Lake with regard to fisheries, tourism, navigation in Suez Canal and recreational activities, it is important to identify the present status of the lake. Since up-to-date information about microplankton community dynamics in the lake is desirable, the aim of the present investigation was to study the composition, abundance and species diversity of microplankton community in Bitter Lake and to establish water quality status.

Materials and Methods

Three sampling sites were chosen in the lake to represent different regions (Figure 1). Station 1 is at the south of the lake, near the Suez entrance, in a region where the water ranges between 4-7 m deep, with greater pollution from industry and domestic sources, including oil and some sewage; at this site the water is stagnant, the floor of the lake being formed of a concrete platform covered with mud which is inhabited by polychaete worms and is without macroscopic plants. Station 3 is at the north of the lake, in a region where the water ranges between 6-13 m deep, is clear and unpolluted, and where the floor of the lake is generally sandy with a diverse animal community but few seaweeds. Station 2 is in between the two previously mentioned stations (1 and 3), where the clear waters are 10-13 m deep and support rich growths of brown and blue green algae upon stones among sand on the bed of the lake. Each station was visited monthly for 13 months from November 2008 until November 2009, and on each visit various measurements were made and samples collected for analysis by methods described below; all three stations were visited on the same day and in the same sequence between $11.^{00}$ and $14.^{00}$ h. The salinity of the near-surface water (50-75 cm) was measured with a portable electronic salinometer (MC Salinity/ Temperature Bridge). The water temperature was measured at the same depth with a mercury-in-glass thermometer and with the salinometer thermometer. The pH was measured with a pre-calibrated digital pH meter.

Water samples were collected in 250 ml dark ground-glass stoppered bottles from a depth of 70 cm and were fixed in the field by addition of manganous sulphate and alkaline sodium iodide solution for later measurement of dissolved oxygen at the laboratory using the standard macro-Winkler method (Parsons *et al*., 1984). Other water samples were taken to the laboratory in 250 ml bottles and filtered through GF/C paper, for removal of particles, before analysis for other chemical constituents. Nitrite concentrations were measured using the method of Bendschneider and Robinson (1952). Phosphate concentrations were measured using the molybdenum blue method of Murphy and Riley (1962). Silicate concentrations were determined using the method of Mullin and Riley (1955). For chlorophyll *a* concentrations, three 250 ml water samples from each site were filtered separately onto GF/F filters, wrapped in small Petri dishes and aluminum foil, frozen (-18°C) , and measured flurometrically (Parsons *et al*., 1984).

Five replicate 4-litres Van Dorn water-bottle samples were taken from the surface water (50-70 cm) at each site. The entire sampling process at each site was completed within 30 min. The contents of

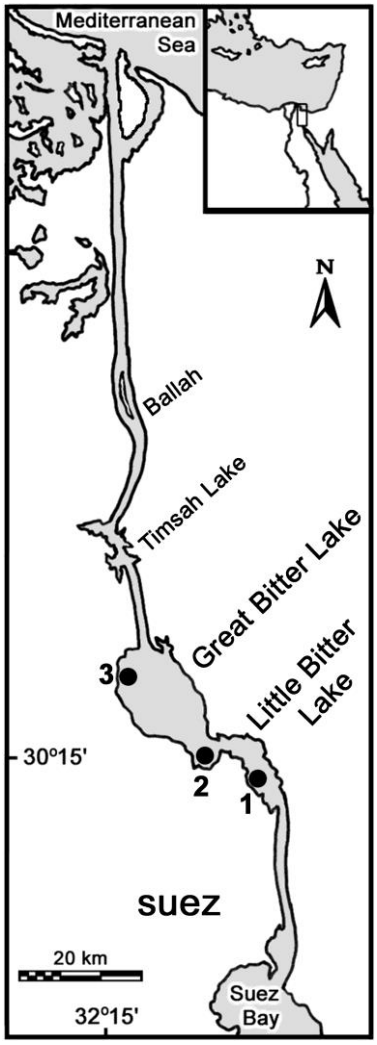

Figure 1. A map of the Suez Canal showing the position of Bitter Lakes and the location of the three sampling sites.

each water bottle were poured through 30 µm mesh plankton net, and then preserved for the analysis of microplankton abundance, whereby two-hundred ml of each replicate sample were preserved in acid Lugol's iodine fixative (Throndnsen, 1978) to give a final fixative concentration of 1.0% and stored in the dark at 5°C.

Microplankton in the Lugol's-fixed samples were identified after settlement by the Utermöhl method (Utermöhl, 1958). The preserved samples were gently stirred and then poured into three 65 ml settling cylinders, each mounted on a shallow circular trough whose base was formed from a cover glass 25 mm in diameter. The samples were left to stand for at least 12 h before the supernatant was carefully removed and the base was transferred for examination of the settled plankton with a Wild M40 inverted microscope (with phase contrast) at a magnification of x 400. The whole settled sample was scanned and all microplanktons were identified and recorded. With five subsamples examined per bottle and five bottles per collection, there were twenty five replicate counts per site sampled; the counts were expressed as numbers per litre of water.

The statistical test, analysis of variance, one-way ANOVA (Underwood, 1981) was followed. The least significant difference test (Steel and Torrie, 1988) was applied to test whether the density of the different microplankton groups varied significantly between sites and seasons. The species richness (D), Shannon-Weaver species diversity index (H) and Evenness (E) (Kawecka and Eloranta, 1994) 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 (Fowler *et al*., 2009). To measure the percentage similarity between different stations in terms of species composition, the similarity index (*J*) was calculated according to Jaccard (1912).

Results

Physico-chemical Properties of Bitter Lake

The limnological parameters of the Great and Little Bitter Lake are shown in Table 1. The physical conditions, oxygen percentage saturation, nutrient concentrations and chlorophyll *a* values recorded in the water of the lake's three stations are listed in Table 2. Surface water temperature was between 17.2°C in winter at station 3 and 31°C in summer at station 1. Salinity was between 41.1 during winter at station 2 and 44.6 PSU during summer at station 1; the nutrient concentrations (Table 2) were extremely low and did not differ greatly between the three stations. Only nitrate showed some distinct spatial variation, with the values measured at station 1 being two to three times lower than those of the other two stations. Fluctuations in pH around slightly alkaline mean values were generally small (Table 2). Oxygen levels tended to rise gradually through autumn and winter to reach a maximum in spring. Though generally low, the initial concentrations of total chlorophyll *a* showed pronounced temporal and spatial variation (Table 2). The highest concentration (0.89 µg L^{-1}) was measured at station 3 during spring, while the lowest concentration of 0.40 µg L^{-1} was measured at station 1 during summer.

Microplankton of the Bitter Lake

A total of 130 taxa of microplanktons were recorded in the Bitter Lake during the present study: Bacillariophyceae (67 taxa); Dinophyceae (15 taxa); Chlorophyceae (11 taxa); Cyanophyceae (11 taxa); Euglenophyceae (1 taxon); Foraminifera (4 taxa); Tintinnida (18 taxa), and Rotifera (3 taxa). In the Bitter Lake these 130 microplankton taxa were dominated by the following 31 species: *Asterionella*

Table 1. The limnological parameters of the Little Bitter Lake and the Great Bitter Lake of the Suez Canal

Parameter	Little Bitter Lake	Great Bitter Lake
Surface Area (m^2)	40 x 10^3	194 x 10^3
Maximum Depth (m)	28	28
Mean Depth (m)	11	18
Maximum length (m)	15000	24000
Maximum width (m)	2760	13000
Maximum Secchi disc Transparency (m)	11.8	13.5

Table 2. Physical conditions (water temperature, salinity and pH), oxygen percentage saturation, nutrient concentrations (nitrates: NO_3; silicates: Si; Phosphates: PO_4) and chlorophyll *a* values in the Bitter Lake (November 2008 – November 2009)

	Season	Water Temperature (°C)	Salinity (PSU)	pH	Oxygen (% saturation)	NO_3 (µM)	Si (µM)	PO_4 (µM)	Chlorophyll *a* (µg L^{-1})
Site (1)	Winter	18.2±0.1	41.2±0.63	8.08±0.3	68.6±4.6	1.14±0.09	0.55±0.04	0.28±0.04	0.51±0.02
	Spring	20.6±0.2	41.4±0.79	8.08±0.6	70.0±2.9	0.82±0.06	0.52±0.04	0.14±0.5	0.62±0.01
	Summer	31.0±0.6	44.6±0.70	8.08±0.4	49.8±7.3	0.95±0.18	0.56±0.03	0.20±0.01	0.40±0.01
	Autumn	29.1±0.2	42.5±1.0	8.18±0.2	57.5±4.4	0.88±0.04	0.61±0.04	0.18±0.01	0.42±0.02
Site (2)	Winter	17.6±0.3	41.1±1.1	8.14±0.4	71.5±5.8	1.93±0.10	0.73±0.02	0.55±0.02	0.65±0.02
	Spring	18.6±0.2	42.2±0.6	8.04±0.0	77.8±3.6	1.60±0.03	0.73±0.05	0.35±0.00	0.82±0.02
	Summer	30.1±0.4	43.2±0.4	8.11±0.6	72.3±7.2	1.73±0.04	0.75±0.03	0.4±0.010	0.75±0.00
	Autumn	26.2±0.1	43.0±0.9	8.23±0.4	65.8±2.5	2.05±0.07	0.84±0.20	0.44±0.03	0.53±0.01
Site (3)	Winter	17.2±0.5	41.3±0.8	8.12±0.2	73.6±4.9	3.16±0.05	1.03±0.07	0.41±0.02	0.74±0.03
	Spring	19.3±0.3	42.4±0.8	8.07±0.2	88.0±3.5	2.76±0.3	0.91±0.05	0.35±0.03	0.89±0.02
	Summer	29.0±0.2	43.5±1.1	8.18±0.4	76.0±6.4	2.99±0.10	0.95±0.02	0.33±0.00	0.76±0.01
	Autumn	25.4±1.0	44.0±1.2	8.26±0.8	75.7±8.3	2.45±0.08	1.34±0.60	0.41±0.01	0.54±0.01

japonica, *Amphiprora paludosa*, *A. alata*, *Chaetoceros decipiens*, *C. curvisetus*, *C. tortissimus*, *C. anastomosans*, *Coscinodiscus granii*, *Hemiaulus heibergii*, *Navicula. sigma*, *N. longissima*, *N. Kützingiana*, *N. pungens var. atlantica*, *Rhizosolenia alata f. gracillima Skeletonema costatum*, *Ceratium furca*, *C. fusus*, *C. egyptiacum*, *Protoperidinium cerasus*, *P. depressum*, *Scenedesmus obliquus*, *Lyngbya* sp., *Globigerina glutinata*, *G. inflata*, *Favella panamensis*, *Helicostomella subulata*, *Tintinnopsis cylindrica*, *T. tocantinensis*, *Ascomorpha sultans*, *Keratella quadrata*, *Polyarthra vulgaris* (Table 3).

The magnitude of the standing crop of microplankton attained its highest density (23091 inds L^{-1}) at station 3 at the northern part of the lake, but a marked decline in the density was observed southward at station 1 (Table 4). Bacillariophyceae appeared as the most abundant group. Their average standing crop was 11594 ind. L^{-1} and they represented 67.2% of the total microplankton community. The Dinophyceae occupied the second rank and constituted approximately 16.5% of the total microplankton, with an average of 2847 ind. L^{-1}. Chlorophyceae and Foraminifera occupied the third rank with an average of 5.6 and 5% respectively. The Tintinnidae, Rotifera and Cyanophyceae groups came next, with an average of around 2.0% for each. The other components, which comprised the Euglenophyceae and benthic forms of ciliated Protozoa and other taxa, were rarely encountered and contributed collectively just 0.06 % of the total microplankton.

It is clear that there is a highly significant difference in the microplankton density between the three sites ($P<0.05$). The ANOVA test also showed that season had a significant effect on the density of microplankton communities in the three sites. The value of p was <0.05 for all groups.

Concerning the seasonal variations, the main peak of microplankton abundance started in spring and reached its maximum in late summer and early autumn (August) with an average of 37,498 ind. L^{-1}, while January was characterized by the lowest density (9,251 ind. L^{-1}) (Figure 2). The relative concentrations of the different categories of microplankton in monthly samples collected from the Bitter Lake are shown in Figure 3. In almost every month the diatoms formed the largest group. The Dinoflagellate group formed a significant proportion of microplankton community in several months, but its population varied erratically. The green algae were common through most months of the year. Blue-greens were generally present in the samples but never reached high numbers and the abundance of this group tended to be more seasonal than that of the other groups of phytoplankton. For example, blue green algae were present in summer but not in winter. A similar trend was observed for Rotifera, although these were encountered during both winter and summer. The protozooplankton (tintinnids and foraminifera) were present in almost every sample, reaching their highest numbers in July-August, when they were overshadowed by the high numbers of phytoplankton.

Table 3. List of planktonic taxa and species collected from November 2008 to November 2009, in the coastal water of the Bitter Lake.

Bacillariophyceae
1. *Asterionella japonica** Cleve
2. *Amphiprora paludosa** W. Smith
3. *A. alata** Kützing
4. *Bacillaria paradoxa* (Müller) Grunow
5. *Biddulphia longicruris* Greville
6. *B. farus* Ehrenberg
7. *B. obtuse* Kützing
8. *B. mobiliensis* Bailey
9. *Campylodiscus noricus var. hibbernica* Ehrenberg
10. *Cerataulina bergonii* H. Pergallo
11. *Chaetoceros decipiens** Cleve
12. *C. curvisetus** Cleve
13. *C. tortissimus** Grunow
14. *C. lorenzianus* Grunow
15. *C. peruvianus* Brightwell
16. *C. anastomosans** Grunow
17. *Climacodium biconcavum* Cleve
18. *Climacosphenia moniligera* Ehrenberg
19. *Cocconeis placentula* Ehrenberg
20. *Coscinodiscus granii** Gough
21. *C. radiates* Ehrenberg
22. *Cyclotella meneghiniana* Kützing
23. *Cymbella ventricosa* Kützing
24. *Diploneis interrupta* Kützing & Cleve
25. *Fragillaria* sp.
26. *Guinardia flaccid* H. Peragallo
27. *Gyrosigma attenuatum* Ehrenberg
28. *G. balticum* Ehrenberg
29. *Hemiaulus heibergii** Cleve
30. *Lauderia borealis* Grunow
31. *Leptocylindrus danicus* Cleve
32. *Licmophora gracilis* Ehr. (Grunow)
33. *L. abbreviate* C. A. Agardh
34. *L. flabellata* (Grunow) Agardh
35. *Melosira granulata* (Ehrenberg) Ralfs
36. *M. sulcata* (Her.) Kützing
37. *M. varians* C. A. Agardh
38. *Navicula gracilis* Cleve
39. *N. cryptocephala* Kützing
41. *N. cuspidate* Kützing
42. *N. dicephala* Ehrenberg
43. *N. sigma** Kützing
44. *N. longissima** Ehrenberg
45. *N. pungens var. atlantica** Cleve
46. *N. pacifica* Grunow
47. *N. seriata* Cleve
48. *N. closterium* (Ehr.) W. Smith
49. *N. Kützingiana** Hilse
50. *Pleurosigma angulatum* Quekett W. Smith
51. *Rhizosolenia alata f. gracillima** (Cleve) Gran
52. *R. alata f. indica* H. Peragallo
53. *R. imbricate* (Cleve) Schroder
54. *R. calcaravis* M. Schultz
55. *R. stolterfothii* H. Peragallo
56. *R. styliformis* Brightwell
57. *Schroderella delicatula* H. Peragallo
58. *Skeletonema costatum** (Greville) Cleve
59. *Stephanopyxis nipponica* Grunow &Yendo
61. *Surirella ovata* Kützing
62. *S. robusta* Ehrenberg
63. *Synedra crystallina* (C. Agardh) Kützing
64. *S. ulna* (Nitzsch) Ehrenberg
65. *Thalassionema nitzschioides* Grunow
66. *Thalassiothrix longissima* Cleve &Grunow
67. *T. frauenfeldii* Grunow

Dinophyceae
68. *Ceratium furca** Ehrenberg
69. *C. fusus** Ehrenberg
70. *C. trichoceros* (Ehrenberg) Kofoid
71. *C. tripos* (O.M. Muller) Nitzsch
72. *C. egyptiacum** Halim
73. *Dinophysis caudate* Savielle-Kent
74. *D. rotunda* Lebour (Wood)
75. *Oxytoxum scolopax* Stein
76. *Phalacroma rapa* Jörgensen
77. *Prorocentrum marina* Otenfeld
78. *P. micans* Ehrenberg
79. *Protoperidinium cerasus** Paulsen
80. *P. depressum** (Bailey) Balech
81. *P. divergens* Ehrenberg
82. *Pyrophacus horologicum* Stein

Chlorophyceae
83. *Actinastrum hantzschii* Lagerh
84. *Chlamydomonas* sp.
85. *Chlorella vulgaris* Beijerinck
86. *Closterium* sp.
87. *Pediastrum clathratum* Lemmermann
88. *Scenedesmus quadricauda* Brébisson
89. *S. bijuga* (Turpin) Lagerheim
90. *S. dimorphus* (Turpin) Kützing
91. *S. obliquus** Turpin
92. *Staurastrum gracile* Ralfs
93. *Stigoclonium* sp.

Cyanophyceae
94. *Chroococcus turgidus* (Kützing) Nägeli
95. *Gomphospheria aponina* Kützing
96. *Lyngbya* sp*.
97. *Merismopedia punctata* Meyen
98. *Oscillatoria erythraeum* Drouet
99. *O. tenuis* Agardh
100. *O. constricta* Szafer
101. *O. limnetica* Lemmermann
102. *Phormidium* sp.
103. *Spirulina major* Kützing & Gomont
104. *S. platensis* Nordst

Euglenophyceae
105. *Euglena* sp.

Foraminifera
106. *Bolivina* sp.
107. *Globigerina glutinata** Egger
108. *G. inflata** d'Orbigny
119. *Textularia* sp.

Tintinnida
110. *Codonella aspera* Kofoid & Campbell
111. *Codonellopsis longa* Kofoid & Campbell
112. *C. morchella* Kofoid & Campbell
113. *C. schabi* (Brandt) Kofoid & Campbell
114. *Eutintinnus fraknoi* Kofoid & Campbell
115. *Favella campanula* Schmidt
116. *F. ehrenbergi* Claparede & Lachmann
117. *F. panamensis** Kofoid & Campbell
118. *Helicostomella subulata** Ehrenberg
119. *Metacylis jorgensenii* (Cleve)
120. *Tintinnopsis buetschlii* Ehr.(Clap. & Lachm.)
121. *T. campanula* Ehrenberg
122. *T. cylindrica** Daday
123. *T. mortensenii* Schmidt
124. *T. tocantinensis** Kofoid & Campbell
125. *T. tubulosa* Levander
126. *Proplectella claparedei*
127. *Stenosemella ventricosa* Claparede & Lachmann

Rotifera
128. *Ascomorpha sultans** Bartsch
129. *Keratella quadrata** Muller
130. *Polyarthra vulgaris** (Carlin)

*Dominant taxa

Table 4. Mean values for the abundance of total microplankton (ind. L^{-1}), species richness (D), diversity index (H), and evenness (E) at each station of the Bitter Lake during the present study

Microplankton	Little Bitter Lake	Great Bitter Lake	
	Site (1)	Site (2)	Site (3)
No of ind. L^{-1}	10,900	17,600	23,091
Species Richness	0.46	0.49	0.63
Shannon-Weaver diversity index	1.07	1.04	1.28
Evenness	0.51	0.50	0.62

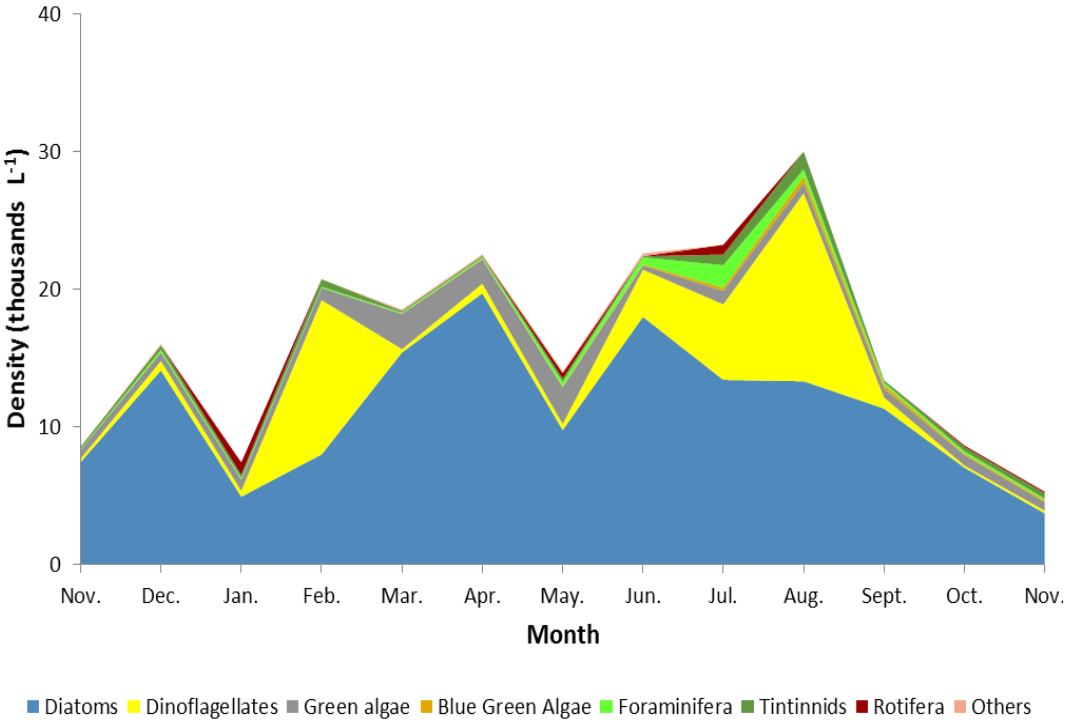

Figure 2. Monthly variation of the total microplankton at the Bitter Lake (November 2008 – November 2009).

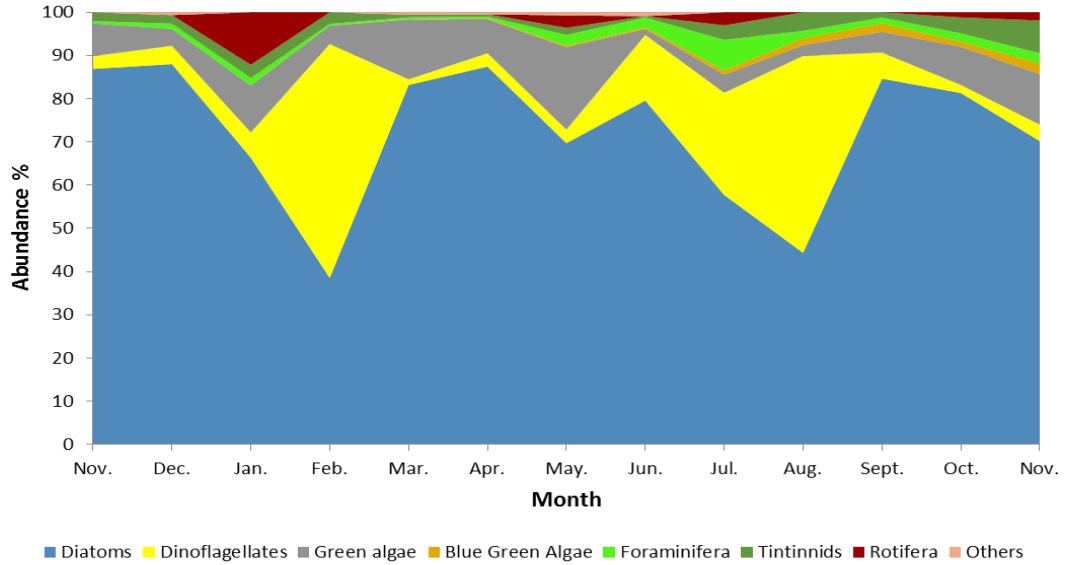

Figure 3. The percentage contribution of diatoms, dinoflagellates, green algae, blue green algae, foraminifers, tintinnids, rotifers and other groups (euglenoids and benthic ciliates) to the microplankton community at the Bitter Lake through the annual cycle.

Species Diversity and Similarity

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's relative abundances. However, spatial and seasonal variations in the number of species and individuals were reflected by the species diversity (Shannon-Weaver index). Bitter Lake showed relatively low species richness with a minimum of 0.46 at site 1 and a maximum of 0.63 at site 3 (Table 4). The maximum species diversity values of 1.28 generally coincided with maximum evenness (0.62) and richness (Table 4). Moreover, the percentage similarity in microplankton communities between the three stations as revealed by the Jaccard index (*J*) showed very high similarity of 87.2% between the northern stations (2 and 3) and indicated higher degree of homogeneity of microplankton communities at these two stations. This high similarity was not so clearly shared with the southern station (station 1). Although, station 3 and station 1 were the least similar to one another (31.3%) they also reflected some degree of homogeneity in microplankton communities between the northern and southern parts of the lake.

Discussion

Physico-chemical Conditions for Plankton in the Bitter Lake

The seawater temperature at shallow depths in the Bitter Lake followed the expected annual cycle. The range of temperature (17.2-31°C), however, is interesting in relation to the species of organisms that live in the lake and also in relation to the influence of temperature on such features as oxygen solubility and, through evaporation, on salinity. The salinity near the surface at all stations tended to show higher values in the summer and lower values in winter. The mean salinity level (41.1-44.6 PSU) in the Bitter Lake is probably above the salinity of the sea. Miller and Munns (1974) and Por (1971) have confirmed that the salinity of the Great Bitter Lake would always remain above normal sea salinity, even after complete dissolution of its salt bed.

The annual cycle of changes in oxygen concentrations can be related to seasonal changes in plant growth, because the combination of the increase in respiratory rate with temperature, and the decrease in the solubility of oxygen in water with rising temperature and with increasing salinity would all tend to produce opposite trends. It is therefore informative to calculate the percentage saturation of water with oxygen at different sites throughout the year (Table 2). The oxygen content of the water was consistently under saturation level at all stations. The highest levels were at stations 2 and 3 and this can be related to the fact that plant population densities were greatest at these sites (Table 4), whilst the lowest level was at site 1; consistent with this being the most polluted site with least evident plant life. The increase in oxygen concentrations in the near-surface water in spring coincided with a fall in silicate levels (Table 2) at the three stations. These falls in silicate levels are presumably associated with the increased growth of diatoms (Figure 2). The observed silicate levels must, therefore, represent a balance between consumption for incorporation into diatom frustules (cell walls) and the rate of dissolution of silicate from the frustules of dead diatoms. In the Bitter Lake, consumption of silicate exceeds supply mainly in the spring season. The smaller range of fluctuations at station 1 probably relates to the shallow depth (4m) and the smaller silica reserve at that site compared with station 3, which is deeper (13 m) and can therefore provide a greater reserve of silica for diatom growth. The growth of plants also consumes nitrate and phosphate ions, accounting for the marked falls in the concentrations of these ions during the spring months (Table 2). There is assumed to be a balance between the consumption of these nutrients and their remineralization through metabolism or decay; the more rapid response of these ions may reflect their more rapid turnover and remineralization, giving an earlier rise through autumn and early winter. In addition, the intensive increase in spring and summer diatom populations are most likely due to the effects of phosphorus reductions on the silica mass balance in this lake, and suggests that diatom populations might be a sensitive indicator for oligotrophication in the Bitter Lake.

The slight alkalinity of the water of the Bitter Lake was presumably due to bicarbonate ions. Since these would be consumed during photosynthesis, this may account for the slight fall in pH through the spring and the rise in autumn (Table 2). The high values of Chlorophyll *a* during spring at station 3 reflect the high number of autotrophic forms at this site with particular reference to diatoms.

Great efforts have been taken to establish quality criteria and thresholds to classify lakes according to their trophic status based on nutrient concentrations, and on certain physical and biological characteristics (OECD, 1982). Classification of trophic level in relation to total phosphorus, chlorophyll *a* and transparency was determined according to the rules for lakes water adopted by OECD (Organization for Economic Cooperation and Development) (1982), Environment Canada (2004) and MDDEP (2007). Overall, these criteria present very close limits and indicate a specific trophic level for the Bitter Lake. On this scale trophic status is categorized as being respectively, at ultra-oligotrophic, oligotrophic, mesotrophic, meso-eutrophic, eutrophic and hypereutrophic. The classification –in respect to the trophic levels found in this study is given in Table 5. Judging by the present results, Bitter Lake can be considered as an ultra-oligotrophic lake.

Table 5. Internationally accepted criteria for trophic status classification of the water bodies

Trophic status	TP (µg L^{-1})	Chlorophyll *a* (µg L^{-1})		Transparency (m)	
		Mean	Maximum	Mean	Maximum
OECD criteria[a]					
Ultra-oligotrophic	< 4	<1	<2.5	>6	>12
Oligotrophic	< 10	<2.5	<8	>3	>6
Mesotrophic	10-35	2.5-8	8-25	1.5-3	3-6
Eutrophic	35-100	8-25	25-75	0.7-1.5	1.5-3
Hypereutrophic	> 100	> 25	> 75	< 0.7	< 1.5
Canadian criteria[b]					
Ultra-oligotrophic	< 4	<1	<2.5	>6	>12
Oligotrophic	4-10	<2.5	<8	>3	>6
Mesotrophic	10-20	2.5-8	8-25	1.5-3	3-6
Meso-eutrophic	20-35	--	--	--	--
Eutrophic	35-100	8-25	25-75	0.7-1.5	1.5-3
Hypereutrophic	> 100	> 25	> 75	< 0.7	< 1.5
Quebec criteria[c]					
Oligotrophic	4-10	1-3	--	5-12	--
Mesotrophic	10-30	3-8	--	2.5-5	--
Eutrophic	30-100	8-25	--	1-2.5	--
Hypereutrophic	--	--	--	--	--
Bitter Lake criteria[d]					
Ultra-oligotrophic	0.04-0.18	0.63	0.89	7	13
Oligotrophic	--	--	--	--	--
Mesotrophic	--	--	--	- -	- -
Eutrophic		--	--	--	--

[a]Ryding and Rast (1994); [b]Environment Canada (2004); [c]MDDEP (2007) and [d]Present study

Microplankton of the Bitter Lake

The micrplankton communities investigated in this study refer to the major groups of marine biota, comprising phytoplankton, protozooplankton and microzooplankton. A total of 130 microplankton taxa were recorded during the one-year study in the Bitter Lake water, dominated by Bacillariophyceae (diatoms 67 taxa). Previous works indicated that diatoms were always increasing in relation to other taxonomic groups in the Bitter Lake (Heimdal *et al*., 1977; Nassar and Shams El-Din, 2006). The taxonomic composition and seasonal abundance of microplankton communities at the Bitter Lake's three stations were broadly similar to one another, with the majority of taxa present at each site. This similarity reflects the hydrographic characteristics of the site, as revealed by their similar salinity and temperature regimes, and their proximity to each other.

The magnitude of the standing crop of microplankton attained its highest density at station 3 at the northern part of the lake, which sustained an average annual number of 23091 ind. L^{-1}. On the other hand, a marked decline in the microplankton densities from the northern site (station 3) towards the southern one (station 1) was noticed. This may be due to the very poor nutrients available to the phytoplankton community at the southern site, as well as to the proximity of this site to the northern part of the Red Sea which in its turn provokes an increasing degree of oligotrophy (Almogi-Labin, 1984).

The microplankton community in the Bitter Lake, therefore, is characterized by low species diversity at the northern part (Great Bitter Lake) and very low species diversity at the southern part (Little Bitter Lake) (Table 4), indicating low levels of nutrients, low values of chlorophyll *a*, low productivity, instability or pollution, and confirming the oligotrophic status of the lake. The trophic status of the Bitter Lake can also be affected by its morphometric features. The morphometric features differ greatly from the northern part of the lake to the southern one (Table 1), suggesting an oligotrophic status at the large northern part and an ultraoligotrophic status to the small southern one. Moreover, the analysis for the similarity of species diversity between the different stations indicated a relatively high degree of homogeneity in the microplankton composition between the northern stations (2 and 3). This similarity was not so clearly shared with the southern site, and may be attributed to the limnological and morphometric differences between the northern and southern parts of the lake. The dominance of a specific algal group in the water of many lakes has been taken as an indication of trophic status. For example, Munawar *et al*. (1991); Gligora *et al*. (2003); Nixdorf *et al*. (2003); Romo and Villena (2005); Çelik and Ongun (2008); Zębek (2009); Soylu and Gönülol (2010) and Demir *et al.* (2014). Moreover, as certain species of algae can be used as indicators of trophic condition, it would seem reasonable that some zooplanktons could also serve this purpose. Järnefelt (1952) attributed the increased number of Cladocera and Rotifera as an indicator for eutrophic lakes in Finland. Several species of rotifers in the lakes of northern Europe and North America

were considered to indicate eutrophic conditions (Gulati, 1983). The greater increase in population densities of diatoms compared to all other algal groups in the Bitter Lake, as well as the lower number of rotifers tend, therefore, to support the suggestion of oligotrophy of the Bitter Lake of the Suez Canal.

All microplankton taxa recorded in the present study occurred in the Bitter Lake in one or more of the stations sampled, and appeared to survive the spring in the lake in high numbers. But how did these species originally come to the Suez Canal and its Bitter Lake, and are these microplanktons annually re-introduced into self-sustaining isolated populations? Migration of marine fauna may take place by passive transport, by currents (common for plankton organisms and planktonic larvae of benthic forms), by other animals or man, and by active migration which is common for large active animals. All 130 taxa of microplankton most likely enter the Suez Canal, and in turn, the Bitter Lake, by water currents. To do so from the south, they need to be carried over a distance of 20 km along the canal from the Gulf of Suez into the Bitter Lakes. In contrast, transport of these 130 planktonic taxa southward along the canal from the Mediterranean Sea is unlikely to take place during most seasons of the year because it would require transport against the dominant water flow, and is only possible, therefore, during a brief period (July-September) of reversal of flow. As majority of the 80 km from the Red Sea is canalized, passive transport of planktonic species by water currents from the south could occur within a week even at the low speed of 0.5 km hour^{-1}. As all microplanktonic species seem to thrive better in spring and autumn than in winter and summer, these species are more likely to have originated from the Red Sea and migrated along with the dominant water currents rather than from the Mediterranean against the water currents. The success of planktonic species in inhabiting the canal ecosystem suggests that the Suez Canal and its lakes are able to contain at least some self-sustaining isolated populations of phyto and zooplankton species, which reflects the fact that the Suez Canal, together with its lakes, is a habitat of its own and should not merely be considered as a funnel or corridor through which planktonic organisms pass like ships from one end to the other.

In conclusion, the Bitter Lake is regarded as one among the most oligotrophic marine habitats when considering the magnitude of the standing crop of microplankton especially with particular reference to the phytoplankton groups. Diversity is low in the northern part of the lake, the Great Bitter Lake, and further low in the southern part, the Little Bitter Lake, which has been disturbed by pollution. In addition, the intensive increase in spring and summer diatom populations suggests that diatom populations might be a sensitive indicator for oligotrophication in the Bitter Lake. Based on nutrients, physical and biological characteristics obtained in this study, the Bitter Lake of the Suez Canal can be considered as an ultraoligotrophic lake. Moreover, this tropphic status was confirmed especially when compared with the internationally accepted criteria for trophic status classification of the water bodies.

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