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Recent Variability in the Plankton Structure of a Natural Hypersaline Lagoon; Bardawil Lagoon in Northern Sinai, Egypt

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ABSTRACT: Bardawil Lagoon is a shallow hypersaline lake, with salinity ranging between 38.0 and 56.0. It is a source of good quality fish and wildlife. The phytoplankton and zooplankton were evaluated seasonally at 12 stations during 2015. The water temperature was 22.14 ± 4. 98°C and water salinity was 47.93 ± 5.01. The dissolved oxygen was 5. 14 ± 0.83 mg l^{-1}. The recognized phytoplankton species were 181 taxa from 83 genera and seven classes were recorded. This comprised; 101 Bacillariophyceae, which formed 84.48 % of the total phytoplankton standing crop, 13 Chlorophyceae (6.14 %) and 46 Dinophyceae (5.75 %). The Shannon–Wiener Diversity Index (0.48–3.35) classified Bardawil Lagoon as a not stressed environment. Zooplankton population was represented by 59 genera and 77 species from 16 groups, mainly dominated with Copepada (62.71% of the total community), followed by Mollusca (24.44%) and Protozoa (6.9%). The diversity index ranged from 0.97 to 2.27. The present study, as well as previous research, revealed strong ties between changing structures in plankton communities and salinity. No sign of eutrophication was observed. Results showed an inverse relation between two of the identified communities. The study showed that Bardawil water is still oligotrophic, free of contaminants, so we recommend to dig two or three canals, to facilitate the exchange of water between the Mediterranean Sea and the Lagoon, and to prevent the increase in water salinity of the Lagoon.

Keywords: Bardawil Lagoon; Phytoplankton; Zooplankton; Shannon diversity Index and Similarity indices.

INTRODUCTION: Bardawil Lagoon is a large hypersaline coastal lagoon on the Mediterranean coast of Sinai, Egypt. Although it is shallow and oligotrophic,[1] it is one of the most important lakes in Egypt; being a source of good quality fish and a habitat for Wildlife. The Lagoon represents a spawning area for fish. It is a unique Lagoon, as it is fed only by sea water and the only non-marine water source originates from the scarce winter rain. In addition, the human impact on Bardawil Lagoon is minimal due to the unexploited surrounding area; thus, it is considered to be one of the cleanest water masses in the region.[2] Many studies have been previously conducted on the chemical and biological characteristics of Bardawil Lagoon, most of which was mainly on phytoplankton or zooplankton.

Taha[3] recorded 117 species of phytoplankton belonging to three algal divisions: 84 of Bacillariophyceae, 27 of Dinophyceae and 6 of Cyanobacteria. On the other hand[1], recorded 101 species distributed among algal divisions as follows: 62 species of Bacillariophyceae, 22 of Dinophyceae, 5 of Chlorophyceae, 7 of Cyanobacteria, 4 of Chrysophyceae and one of Cryptophyceae. The study of Konsowa[4] indicated the presence of 114 species, of which Bacillariophyceae represented 56.6 % of the total counts, while Dinophyceae represented 39.5 %. On the other hand, the reports made during 2010–2013 by the Environmental Monitoring Program for the North Lakes[5] showed that the average counts of phytoplankton ranged between $15x10^3$ cells l^{-1} (2012–2013) and $32x10^3$cells l^{-1} (2011–2012). El- Kasses et al.,[6] recorded 186 phytoplankton species were quantified during 2013/2014. Bacillariophyceae made up the highest number (45 genera, 115 species), but there was a remarkably low number of Dinophyceae (31 genera, 45 species). Freshwater Chlorophyceae, Cyanobacteria and Euglenophyceae were represented by 10, 9 and 5 species, respectively.

Despite the importance of zooplankton in the Lagoon food chain; being utilized by early life stages of many species of fishes, little is known about the distribution and standing crop of zooplankton in Bardawil Lagoon. Kimor[7] conducted preliminary studies on the plankton of Bardawil Lagoon, while Fouda et al.,[8] listed 87 zooplankton species in the Lagoon and mentioned that some species occur over a relatively wide range of habitats, while others were confined to certain localities. They added that zooplankton populations were poor in a variety of species. Ibrahim et al.,[9] included zooplankton in their studies on the fishery and management of the Lagoon. El-Shabrawy[10] recorded 57 zooplankton species, where the copepods were the most abundant group (70% to total zooplankton). During 2004, Mageed[11] recorded 58 zooplankton species and taxa belonging to 17 groups. Three groups were dominant; Copepoda, Protozoa, and Mollusca. The holoplankton groups contributed about 81% of the total zooplankton density, while meroplankton represented about 19% to total zooplankton.

Abed El-Hady and Khalifa[12] studied the phytoplankton biochemical contents and zooplankton composition in vegetated and non-vegetated regions in Bardawil Lagoon during 2011/2012. They found that zooplankton community was mainly represented by five groups; Protozoa, Rotifera, Copepoda, Pteropoda and meroplankton. Zooplankton seemed to prefer the vegetated regions. Recently, El-Shabrawy et al.,[13] studied Tintinnina and Foraminifera during the 2009 /2010 in Bardawil Lagoon, in comparison with the previous data during 1985/2010.

The aim of this study is to investigate the dynamic of the community composition, structure, abundance, species diversity and similarity of plankton (phytoplankton and zooplankton) in the Bardawil Lagoon and their seasonal fluctuation. Moreover, the study sets the relationship between the two groups and assesses the recent state of the Lagoon.

MATERIAL AND METHODS: This work is supported by the National Institute of Oceanography and Fisheries.

Description of study area: Bardawil Lagoon is the largest lagoon in Egypt with a surface area of about 650 km^2 (Por, 1972). At the present time, the area has recently decreased, reaching 595 km^2, with 95 km long and 25 km wide. The Lagoon is shallow with a maximum depth of 6.5 m in its western arm, a minimum depth of 0.3 m, and an average depth of 1.21 m. It is separated from the Mediterranean Sea by a curving sand barrier with a width between 300 and 2000 m. Bardawil Lagoon lies between 31°03′ N to 31°14′ N and between 32°40′E and 33°30′E in a semi-arid region. The Lagoon has an elliptical shape Three openings (Boughazes) connect the Lagoon to the sea (Abd Ellah and Hussein,[14] of which two are artificial-openings; Boughazes I and II, have been established to decrease the salinity through exchange of water with the Mediterranean Sea (Fig. 1). The third Boughaz is a natural opening at the far eastern end of the Lagoon. The main water supply to the Lagoon comes from the Mediterranean Sea, which flows constantly, mainly through the first two openings. Bardawil Lagoon is a hypersaline coastal lagoon, where the highest salinities are reached along its southern shores. The most extreme eastern part of it (Lagoon Zaranik) is the second oldest protected area in Egypt, established by the Egyptian Government in 1983, and announced as a Ramsar site since 1988[7&15].

Twelve stations were selected for sampling, to represent different microhabitats of the Lagoon (Fig. 1): five at the eastern arm with plant cover *Halophila stipulacea*, (1, 3, 4, 5 & 6), two in the middle, at water circulated area in the northern middle and with plant cover *Cymodocea nodosa* (2 & 11), and five at the western one; with no plant cover (7, 8, 9, 10 &12). Stations 2 and 11 were in-front of the opening of the Lagoon to the Mediterranean Sea directly, representing Boughaz II (BII) and Boughaz I (BI), respectively. The study at the 12 stations was carried out seasonally during 2015: winter, spring, summer and autumn monitoring, respectively.

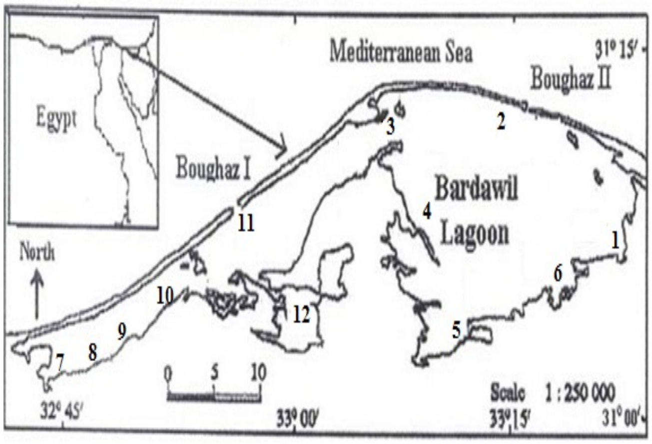

Figure 1: The map showing stations of sample collection in Bardawil Lagoon, North Sinai, Egypt.

A number of physico-chemical, phytoplankton and zooplankton density variables were investigated in Bardawil Lagoon during the sampling program. One liter of subsurface water sample was collected from each location, for which some water variables were measured. Water temperature, pH value, and dissolved oxygen (DO), was recorded and, water samples were analyzed using standard methods for salinity measurement.[16]

Phytoplankton samples were collected for quantitative and qualitative analysis using Ruttiner bottle and were preserved by Lugol's solution and analyzed according to Utermohl's method.[17] The identification and counting of the algal taxa were done and the density was expressed as cells l^{-1}.

Zooplankton samples were collected from each sampling site by filtering 50 liters of surface water through a zooplankton net of 55 µm mesh diameter. Collected samples were kept in 100 ml plastic bottles with some Lagoon's water to which 4% neutral formalin was added as a preservative. Samples were studied under the compound microscope and the specimens were identified at the species level when possible. Zooplankton numbers were expressed as the number of organisms per cubic meters.

***Statistical analysis*:** Two indices were used to estimate the community structure: diversity (H^0) and evenness or equitability (J). [17 & 18] The Spearman rank correlation (r) was applied with the SPSS ® 8.0 Statistical Package Program to evaluate the relations between diversity indices and each of phytoplankton abundance and zooplankton population at each sampling station (N =48). Moreover, cluster analyses for each phytoplankton and zooplankton were carried out by Minitab ®. 12, under Windows ® 2007.

RESULTS AND DISCUSSION:

***Physico-chemical parameters*:** The water temperature fluctuated between 14.5°C (St. 11, winter) and 30.2°C (St.11, summer) with an annual average of 22.14°C ± 4.98 and generally followed that of the air, due to the shallow depth of the Lagoon. The highest dissolved oxygen value of 6.3 mg l^{-1} was recorded at station 7 in winter, while the lowest (4.1 mg l^{-1}) occurred in spring at station 3, with an annual average of 5.14 mg l^{-1} ± 0.83. The pH values has been fluctuating, within the alkaline side in a narrow range of 7.8 (St. 9, summer) to 8.3 (St. 8, summer). The water salinity reached its maximum at station 1, spring (56.0) due to excessive evaporation, while the lowest value of 38.0 was recorded in autumn (St. 9), with an annual average of 47.93 ± 5.01.

***Phytoplankton community structure and composition*:** A total of 181 phytoplankton species was recorded over the study period. Bacillariophyceae made up the highest number (44 genera, 101 species), and there was a remarkably low number of Dinophyceae (18 genera, 46 species). Freshwater Chlorophyceae, Cyanobacteria and Euglenophyceae were represented by 13, 11 and 8 species, respectively. Cryptophyta and silicoflagellates were represented by one species each. Total phytoplankton abundance showed high variability, with average values from 6043 cells l^{-1} (St. 8) to 334918 cells l^{-1} (St. 11), in which phytoplankton abundance was associated with 84.5 % diatoms, 6.1 % chlorophytes and 5.8% dinophytes and Cyanophyceae formed 3.0%.

Regarding the average counts of phytoplankton, the highest standing crop was recorded in spring season (170638 cells l^{-1}), while the lowest was in the summer (7170 cells l^{-1}). Two comparable values appeared during both winter and autumn seasons: 14251 & 14804 cells l^{-1}, respectively. The annual average of phytoplankton attained 51716 cells l^{-1}. This value is higher than that recorded in the same area during the 2013/2014 (24449 cells l^{-1} EL-Kassas et al.[6]

Among the diatoms, the genus *Pseudo-Nitzschia* and *Chaetoceros* (annual average of 27005 cells l^{-1} and 8730 cells l^{-1}, respectively) were the most abundant in the Lagoon. The most abundant genera in the freshwater chlorophytes; *Ankistrodesmus* (1978 cells l^{-1}) and *Chlorella* (559 cells l^{-1}), and within cyanobacteria; *Merismopedia* (1342 cells l^{-1}). The most diverse genus was *Navicula* (10 species).

Bacillariophyceae, Chlorophyceae and Dinophyceae were more abundant both qualitatively (88.38 %) and quantitatively (96.37%) than the other taxonomic groups. They were conspicuous as the three most diverse groups with 84.48% and 6.14% and 5.75 % of the total phytoplankton counts.

Regarding the frequency percentage of the dominant group during different seasons, Bacillariophyceae ranged from 23.7% during winter and 90.9% at spring, this is attributed to the dominance of both *Pseudo-Nitzschia* spp. (63.1%) and *Chaetoceras* spp (18.9%). While Chlorophyceae completely disappeared during summer season and reached 55.5% during winter, due to the presence of *Ankistrodemus* (53.1%). Dinophyceae ranged from 3.1% (spring) to 24.1% (summer), as a result of the increase of *Prorocentrum* spp. (7.3%), *Protoprednium* spp. (5.5%) and *Scrippsiella* spp. (5.0%).

Generally speaking, the numbers of phytoplankton taxa recorded in winter, spring, summer and autumn 2015, were 50 genus (90 spp), 56 genus (115 pp.), 32 genus (70 spp.) and 48 genus (99 spp.), respectively. The maximum number of species in a single sample was 55, at station 2 during autumn, while the lowest number of species (5) was recorded at the extreme eastern station10 during summer season.

***Seasonal variation of phytoplankton standing crop*:** Phytoplankton abundances were generally moderate at most stations; during winter season, station 1 attained the highest counts (Fig.2); attributed to the increased counts of Chlorophyceae (93.5% of the total phytoplankton standing crop) due to the increased of *Ankistrodesmus falcatus var. mirabilis* (92.2%). This has been true all over three seasons, except in spring, when the highest counts were recorded at station 11 (1318200 cell. l^{-1}). This is attributed to the increased counts of *Pseudo-nitzschia seriata* and *Pseudo-nitzshia delicatissima* (64.3% and 31.6% of the total standing crop, respectively). During the summer season, the phytoplankton counts had lower values (Fig.2). On the other hand, during the autumn season, stations 1 and 4 yielded high values (47000 and 13080 cells. l^{-1}). Diatoms; *Nitzschia* spp. shared by 56.4% of the total phytoplankton at station 1. While *Biddulphia* spp. formed 24.5%, in addition to chlorophyceae; *Pediastrum* spp. (24.5%) and dinophyceae; *Scrippsiella* (10.7%) at station 4. With respect to mean values, the phytoplankton abundance was lowest in summer and the highest in the spring. The phytoplankton community consisted mainly of Bacillariophyceae and Dinophyceae at the different stations (Fig. 2). In particular, Bacillariophyceae reached their highest average abundance percentages at station 11 (97.0 %), station 4 (96.1 %) and station 5 (80.5 %) and Dinophyceae at station 10 (32.6 %), station 7 (20.7 %) and station 2 (12.5%). The contribution of Chlorophyceae to the total abundances was 44.2 % at station 1. In contrast, Cyanobacteria dominated the algal community at station 7 (55.9%). During spring, the mean phytoplankton abundance was 170638 cells l^{-1}. Spatial fluctuation in spring varied widely with regard to abundance and dominant species. Bacillariophyceae was the dominant division at all the stations (59.4 –98.9 %), except station at 7 (2.0%), where Cyanophyceae dominated (80.3%) and Dinophyceae shared by 15.2%. The total phytoplankton abundance varied between 10600 cells l^{-1} (station 8) and 1318200 cells l^{-1} (station 11).

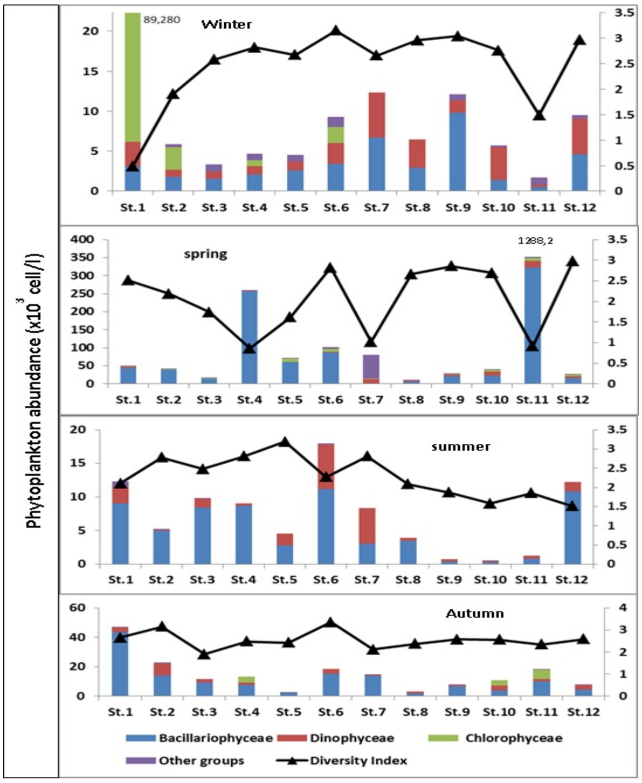

Figure 2: Seasonal variations of phytoplankton standing crop, its main components and diversity values at the different stations in Bardawil Lagoon during 2015.

***Diversity cycle of phytoplankton*:** During winter season, the highest diversity values were attained at stations 6 and 9 (3.15 & 3.04) and number of species of 30 and 28 spp. were recorded respectively. The lowest one was recorded at station 1 (0.48) with a 19 species. However, higher diversity values were attributed to the many species shared in community composition: *Nitzschia* spp. (6.5% & 21.5% by number of the total phytoplankton density of the two stations, respectively); *Synedra* spp. (8.6 % & 6.6 %, respectively); *Coelastrum* spp. at station 6 (15.1%); *Prorocentrum* spp. (12.9%) and *Protoperidinum* spp. In addition to *Psedo Nitzschia* (9.9%) at station 9. Lower diversity, value was at station 1 (Fig.2), due to the blooms of one species: *Ankistrodesmus falcatus* var. *mirabilis* (92.2%). Species richness ranged between 7 (station, 11) and 30 (station, 6). Species evenness (j) varied between 0.162 (station, 1) and 0.978 (station, 3).

In spring season, although the highest standing crop was observed at station 11 (Fig.2), yet the diversity, value was lower (0.91) as well as, species richness (36 spp.). This is attributed to the dominance of one species; *Pseudo-Nitzschia* spp. (95.9% by number of the total phytoplankton density). However, lower phytoplankton counts were recorded at station 12, the diversity, value attained the highest one (2.98). Such high diversity, value is attributed to the dominance of several species; *Pseudo-Nitzschia* spp. (21.1% by number of the total phytoplankton density), *Nitzschia* spp. (5.5%), *Chaetoceros* spp. (5.1%), *Climacosphenia* spp. (4.4%), *Coconeis* spp. (4.4%), *Scrippsilla* spp. (5.1%), *Prorocentrum* spp. (4.4%), *Chlorella vulgaris* (5.1%), *Ankistrodesmus* spp. (4.4%) and *Scenedesmus* spp. (5.8%). Species richness ranged between 18 (station, 2) and 47 (station, 6). Species evenness (j) varied between 0.253 (station, 11) and 0.886 (station, 8).

During the summer season, the lowest count was at station 10, species richness (5 spp.), the diversity, value attained a low value of 1.58. This is attributed to the presence of several species with comparable percentage; *Rizosolenia* spp. (31.0%) *Prorocentrum* spp. (17.2%), *Protoperidinium spp. (*17.2%*)* and *Nitzschia* spp. (17.2%). While higher diversity, values were recorded at station 5 (3.19). This is attributed to the dominance of many species, namely; *Synedra* spp. (18.5%), *Navicula* spp. (18.5%), *Scrippsilla* spp. (9.3%), *Protoperidinium spp* (9.3%), *Nitzschia* spp. (9.3%), *Prorocentrum* spp. (7.7%) and *Coscinodiscus* spp. (4.6%). Species richness ranged between 5 (station, 10) and 29 (station 3). Species evenness (j) varied between 0.671 (station, 1) and 0.98 (station, 10).

In autumn, although the standing crop was similar at stations 3 and 6 (Fig.2), yet the diversity, value and species richness were different (23 &34 spp.). Station

3 recorded lower diversity (1.9). This is attributed to the dominance of one species; *Chaetoceros* spp. (71.6% by number of the total phytoplankton density). While the highest diversity values (3.35) were recorded at station 6. This is related to the dominance of several species; *Navicula* spp. (17.8%), *Pleurosigma* spp. (16.8%), *Prorocentrum* spp. (13.1%); *Synedra spp.* (10.45%) and *Nitzschia* spp (8.4%). Species richness ranged between 12 (station, 8) and 55 (station, 2). Species evenness (j) varied between 0.606 (station, 3) and 0.953(station, 8).

***Species composition of zooplankton population*:** A total of 59 genera and 77 species from 16 groups were identified, beside the larval stages of the different groups. Protozoa represented the highest biodiversity (28 species), followed by Copepoda (14 species), Rotifera (5 species) and; Nematoda (3 species). Chaetognatha, Ostracoda and Appendicularia were represented by two species each, while Coelentrata, Cladocera and Mollusca were recorded by one species each. The other groups; Cirripidea, Decapoda, Annelida, Echinpdermata, Insecta, Fish egg and larvae; were represented by their larval stages. Spatially the highest biodiversity was recorded at station 3 (41 spp.) and the lowest at station 12 (19 spp.), and seasonally it was recorded in winter at station 12 (5 spp.). The holoplankton groups averaged 125425 organisms/m^3 and contributed about 97.2% of the total zooplankton density; while meroplankton represented by an average 3583 organisms /m^3 forming 2.8% of the total zooplankton.

Copepods were the most abundant group during all seasons except during spring where Mollusca exceeded Copepoda by 5%, with an annual average of 87408 organisms/m^3 and made up 67.8% of the total zooplankton population. Their larval stages made up 69% of the total copepods with an average of 60725 organisms/m^3, thus the larval stages of copepods were more abundant than adults. Among the most dominant species were *Oithona nana, O. plumifera*, *Paracalanus parvus* and *Euterpina acutifrons* contributing 12.8%, 2.7%, 2.5% and 1.8% of the total zooplankton and 19%, 4.1%, 4% and 2.6% of the total copepods. Molluscs came on the second order of abundance, although it represented only by one adult species; *Limacina inflate,* which represented 90.2% of the total Mollusca and veligers of Lamillibranchs and Gastropods.

Protozoa accounted for 4.7% of the total zooplankton with an average of 6000 organisms /m^3 and were dominated by *Tintinnopsis nordguisi* (36.5% of the total Protozoa). Rotifers were mostly represented by *Synchaeta vorex* (70.7% of the total Rotifera). Nematoda and Appendicularia appeared infrequently and accounted for 0.2% and 0.1% of the total zooplankton, respectively. Other groups such as; Coelentrata, Chaetognatha, Cladocera and Ostracoda were considered rare groups and their percentages were 0.03%, 0.03%, 0.01% and 0.04%, respectively. The meroplanktonic groups dominated by cirriped larvae which represented by 2% of the total zooplankton.

***Spatial distribution of zooplankton density*:** The annual average zooplankton standing crop was 129008 organisms / m^3. The highest density was recorded at station 7 (207800 organisms / m^3), followed by stations 6 and 3 (181900 and 173800 organisms / m^3). On, the other hand, stations 1 and 9 harbored a minimum density (70800 and 73300 organisms / m^3). Based on numerical abundance copepods make the bulk of the population at most stations, where the highest densities were observed at stations 7 and 3, then decreased gradually at stations 10, 2 and 8 and reached the lowest abundance at stations 1 and 9. Both copepod larval stages as well as the dominant adult species showed nearly the same pattern as total zooplankton.

Mollusca increased at stations 6, 7 and 10 and decreased at the other stations to reach its lowest density at station 2. Protozoa showed another pattern of abundance, where it decreased to its lowest values at stations 6 and 7, and reached its maximum standing crop at stations 2 and 3. The meroplanktonic groups followed the total zooplankton abundance where it reached the highest density of stations 6 and 7, and decreased at the other stations to reach its lowest density at station 11.

***Seasonal distribution of zooplankton population*:** The seasonal average standing crop throughout the study area showed that the Lagoon was productive during the year round. The standing crop was at its highest count during the summer (average 285267 organisms / m^3), and decreased during the other seasons to reach its lowest during spring (average 50700 organisms / m^3).

In summer Copepoda dominated the zooplankton population (average 204000 organisms / m^3) constituting 71.5% of the total zooplankton and represented by 12 species dominated by *Oithona nana*, *O. plumifera* and *Paracalanus parvus* (formed 32% of the total copepods) which are recorded as dominant species at all stations. Mollusca ranked the second dominant group with an average of 72167 organisms / m^3 (25.3% of the total zooplankton) and dominated by the species *Limacina inflate* which representing 23.4% of the total zooplankton. Protozoa were the third most abundant group forming 1.3% of the total zooplankton (average 3567 organisms/ m^3) and dominated by *Tintinnopsis nordguisti*.

During autumn, the average counts of zooplankton became less than summer, and Copepoda was the first abundant group (average 76767 organisms / m^3) with a percentage of 69.5% of the total zooplankton and represented by 10 species dominated by *Oithona nana* and *O. Plumifera* (22.9% of the total copepods). Then Mollusca averaged 23467 organisms / m^3 (21.2% of the total zooplankton). But during the autumn the percentage of Protozoa increased to 7.1% (average 7833 organisms/ m^3) due to the increased density of *Tintinnopsis nordguisti* and *Codenellopsis morchella*. The standing stock of zooplankton during winter decreased to become 69567 organisms / m^3, although the number of species reached its maximum (37 species). The contribution of copepods was nearly the same as in autumn (69.8% of the total zooplankton), but with less abundance (48533 organisms/ m^3), dominated by *Euterpina acutifrons*, *Oithona nana*, *O. plumifera* and *Paracalanus parvus*. But Mollusca decreased to average 3767 organisms/ m^3 with the percentage of 5.4%. On the other hand, Protozoa increased in number (18 species) and density (average 10366 organisms/ m^3) to reach the percentage of 14.9% of the total zooplankton.

In spring, the zooplankton standing crop was the smallest (50700 organisms/ m^3), also the number of species was the smallest (24 species). Copepoda represented 40.1% of the total zooplankton with an average of 20333 organisms/ m^3 and was represented by 6 species only, dominated by *Euterpina acutifrons* and *Oithona nana*. Mollusca increased in counts and percentage (average 23233 organisms/ m^3 and 45.8% of the total zooplankton), and Protozoa decreased than winter (average 2233 organisms/ m^3 and 4.4%) of the total zooplankton.

Generally speaking, the numbers of zooplankton species recorded in winter, spring, summer and autumn 2015, were 37, 24, 27 and 30, respectively. The maximum number of species in a single sample was 30, at station 3 during winter, while the lowest number of species was 4 at station 7 during the spring season.

***Diversity cycle of zooplankton*:** During winter season, the highest diversity values were attained at stations 5 and 1 (Fig.3) and number of species of 15 and 12 spp. were recorded respectively. Where the lowest one was recorded at station 7 (1.28) with a 8 species. However, higher diversity values were attributed to the many species shared in community composition: Nauplius larvae (45.6% & 22.6% of the total zooplankton density of stations 5 & 1, respectively), *Synchaeta* spp. (2.2% & 18.9%), *Oithona* spp. (16.2% at station 5), *Euterpina* (8.8, station 5) and *Limacina inflate* (30.2% at station 1). Lower diversity, value of station 7, due to the blooms of two species: Nauplius larvae (59.%) and Cirriped larvae (14.8%) as shown in Fig. 3. Species richness ranged between 5 (station, 12) and 30 (station, 3) Species evenness (j) varied between 0.541 (station, 3) and 0.873 (station, 12).

In spring season, although the highest standing crop was observed at station 10 (Fig. 3), yet the diversity, value was lower (0.97) as well as, species richness (15 spp). This is attributed to the dominance of one species; *Lamellibranch veiliger* (77.5% by number of the total zooplankton density). However, lower zooplankton counts were recorded at station 11 (Fg.3), the diversity, value attained the highest one (2.27). Such high diversity, value is attributed to the dominance of several species; Nauplius larvae (29.1%), *Favella* spp. (25.5%), *Euterpina* spp. (10.9%), *Limacina inflate* (7.3%) and *Gastropod veliger* (7.3%). Species richness ranged between 4 (station, 8) and 17 (station, 11). Species evenness (j) varied between 0.358 (station, 10) and 0.803 (station, 11).

During the summer season, the lowest count was reached at station 2 (Fig. 3), the species richness (20 spp.), and the diversity, attained its highest value (2.22). This is attributed to the presence of several species; Nauplius larvae (32.8%), *Oithona* spp. (15.6%) and *Limacina inflate* (13.0%). While lower diversity, values were recorded at station 3 (1.20). This is attributed to the dominance of two species, namely; Nauplius larvae (69.1%) and *Oithona* spp. (11.7%). Species richness ranged between 13 (station, 6) and 17 (station, 8). Species evenness (j) varied between 0.434 (station, 3) and 0.748 (station, 11).

Autumn season, although the standing crop was similar at stations 1 and 2 (Fig. 3), yet the diversity, value and species richness were different (11 &17 spp.). Station 1 recorded lower diversity (1.43). This is attributed to the dominance of two species; Nauplius larvae (50.5%) and *Limacina inflate* (27.2%). While the highest diversity values (2.14) were recorded at station 2. This is related to the dominance of several species; Nauplius larvae (35.2%), *Oithona* spp. (19.6%) and *Limacina inflate* (17.6%). Species richness ranged between 7 (station, 8) and 22 (station, 4). Species evenness (j) varied between 0.554 (station, 5) and 0.809 (station, 7).

The Bardawil Lagoon climate is arid; the rainy season extends from October to May and the average annual rainfall amount is about 82 mm [20&21]. The temperature is extremely high, varies from one place to another and has a significant impact on increasing humidity and increasing evaporation rates. Moreover, temperature affects Lagoon's salinity, which by the end impacts on the Lagoon's ecosystem. The water temperature of the Lagoon varies between 14.6°C (St. 4, in winter) and 30.2°C (St. 11, summer), with an annual average of 22.14°C ± 4.98.

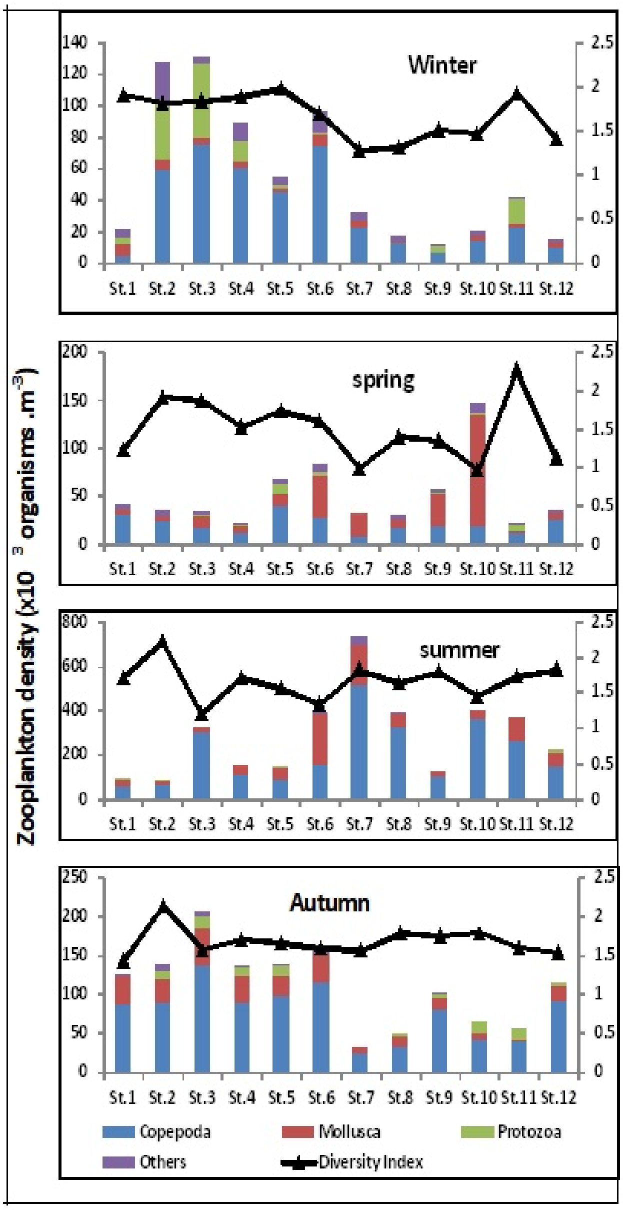

Figure 3: Seasonal variations of zooplankton population, its main groups and diversity values at the different stations in Bardawil Lagoon during 2015.

The pH values usually lie on the alkaline side, it fluctuated between 7.8 (St. 9, 11 and 12; winter) and 8.3 at most stations during autumn season. The water of Bardawil Lagoon had dissolved oxygen concentration values usually above the minimum WHO standard of 5 mg l^{-1} required for water quality assessment [22] and so the Lagoon water is considered as a well-oxygenated ecosystem with an annual average of 5.14 mg l^{-1} ± 0.83.

The salinity of the Lagoon is much higher than in the open Mediterranean Sea, due to the high evaporation rates, and is fluctuating seasonally, with the lowest value of 38 (St. 9) in autumn, while the maximum, 56 (St.1) in the summer was due to the high evaporation rate of nearly 3 m/year.[9] Salinity may be responsible for the variations in phytoplankton community structure. Euryhaline species, particularly diatoms that were developed in the last decades, were largely replaced by stenohaline species which were dominant in the more saline water species.

Phytoplankton abundance was significantly correlated to the environmental variables because of the ecological peculiarity of Bardawil Lagoon. The data of this study showed that there were marked spatial and seasonal differences in the quantitative and qualitative composition of the phytoplankton communities; this spatial variation might further reflect the surrounding environmental factors over time [23]. In winter, significant positive correlation between dinoflagellates and water temperature ($r= 0.75$, $p> 0.011$), in spring, total phytoplankton standing crop and water temperature ($r= 0.56$, $p>0.05$) and between dinoflagellates with pH ($r= 0.54$, $p>0.07$). While in summer season, diatoms with water temperature ($r= 0.56$, $p>0.06$).

Fresh water forms of Chlorophyceae and Cyanophyceae have been relatively rare; their presence in the Lagoon may attribute to fresh water or domestic runoff. This agrees with the result of Konsowa.[4]

Diversity is dependent on key ecological processes such as competition, predation, succession, and therefore changes in these processes can alter the species diversity index through changes in evenness[24]. Rich phytoplankton species was recorded in Bardawil Lagoon (181 taxa). In such shallow Lakes high diversity may occur because these Lakes are always fully mixed with the bottom layer and therefore occurrence of numerous species is not restricted to mixing rather may be limited by other environmental factors such as nutrients.[25] The species diversity index of plankton communities can be considered as an indicator that the ecosystem is under the influence of pollution, stress or eutrophic state.[26]

Generally speaking, the species diversities values (H′) fluctuated between 1.1 (station 11) and 3.6 (station 8). The highest phytoplankton density was recorded at stations 11 (334918 cells l^{-1}) with lower diversity, value (1.1) and 61species was recorded. While the lowest counts was attained at station 8 (6043cell.l^{-1}) as well as, the number of species (51 spp.) and the highest diversity value (3.6). This was accompanied with many species shared in the community composition;

Cheactoceros. (9.9%), *Nitzschia* spp. (9.1%), *Protoperidinium* spp. (9.02), *Prorocentrum* spp. (8.9%), *Synedra* spp. (7.5%), *Leptocylindrus* spp. (4.6%) and *Melosira* spp. (4.1%). Lower diversity, value of station 11 accompanied with the community composition was dominated by only two species, *Pseudo-nitzshia* and *Cheactoceros* since they contributed 63.4 % and 31.1% by number of the total phytoplankton standing crop, respectively. Species richness ranged between 51 (station, 8) and 81 (station 2). Species evenness (j) varied between 0.245 (station 11) and 0.914 (station 8).

The present results revealed a significant correlation between diversity index and number of species during winter ($r = 0.61$, $p < 0.037$). The majority of phytoplankton diversity indices fluctuated between 2 and 3 formed 62.5% of the recorded data. However, 8% was formed over diversity values 3, which demonstrates the low degree of pollution levels. In general, the diversity indices showed that the Bardawil Lagoon has a more or less well balanced phytoplankton community that liked an even representation of several species indicating the dynamic nature of the aquatic ecosystem.

The dendrogram with complete linkage correlation coefficient distance during the investigated period showed that the similarity level of the twelve stations varied from 32% at station 11 to 65% of stations 1 and 6. In which delineates three main groups, but the number of sub-groups are different (Fig.4), as classified in homogeneous or inhomogeneous sub-groups. In general, it can be clearly seen that the similarity of station 11 at 30% (which is in front of Boughaz 1), was almost separate than the other sites (Fig.4). This is due to the effect of sea water discharge from the Mediterranean Sea. As well as, station 7 at similarity 35%, which may be attributed to the high salinity value at this station due to its shallowness. The highest similarity values (58%) were recorded between 1 and 6; showed a homogenous sub-group; this is met with the similar environment (Fig. 1). The same observation was recorded for stations 3 and 4 at similarity 55% and stations 8 and 10 at similarity 50%.

A total of 59 zooplankton taxa (77 species, including larval stages) representing 16 groups was recorded in Bardaweel Lagoon during the present study with the dominance of 7 species. Mageed (2006), Fouda et al. (1985) and El-Shabrawy (2002) recorded 58, 49 and 55 taxa, respectively in the Lagoon. The variation in the species number is not considerable, but the community composition was highly changed with time.

The present study recorded an average count of zooplankton population of 129 x 10^3 organisms /m^3. This is a low value compared to the previous results during 2004 (200x10^3organisms / m^3, Mageed[11]) and in 2011/2012 (178 x10^3 organisms / m^3, Abed El-Hady and Khalifa [12]).

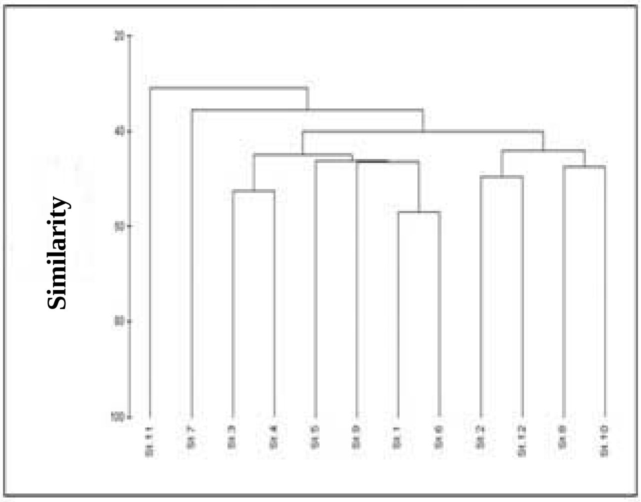

Figure 4: Cluster analysis of phytoplankton composition between sampling stations of Bardawil Lagoon during 2015.

Copepoda was the most dominant group due to the richness of their larvae. The presence of copepod larval stages all the year round indicates the continuous production of copepods all the year. Juvenile stages were the major constituents of copepod populations in the whole Egyptian Mediterranean and Red Sea coast [27]. Most of the copepod species were recorded by El-Sherbiny[28] in the Mediterranean Sea, which may be originating from the Sea and entered the Lagoon via the Boughazes.

The present study showed that, copepoda nauplii attained its outstanding peak in the summer season and less so in autumn. The low population density of these larvae occurred in winter and spring seasons, spatially, stations 3 and 10. Nauplii and copepodit stages proved to be the most common forming 66.7% and 2.7% of the total copepod density, while adult stages of copepods contributed about 20.7%. This is higher than that recorded during 2004 (only10%; Mageed [11]).

Predation also affects the abundance of zooplankton as they constitute a significant food source for fish larvae [29]. Predation of tintinnids by macro zooplankton as copepods [13& 30] and mollusca larvae [29]was accompanied by a decrease of their density with the richness of these groups. This may explain the reduced counts of tintinnids observed during summer coinciding with high counts of copepods and mollusc larvae, while the opposite trend was observed during the winter. These results agreed with those of Aboul-Ezz et al.,[31] in Suez Bay, Egypt.

The seasonal pattern of the zooplankton counts, showed a high outstanding peak in the summer and a lower in autumn, while the minimum density was recorded in spring, where in summer the temperature was 29-30C°. This is in agreement with Rodriguez et al.,[32] who found that the temperature was the main factor affecting zooplankton production. This is confirmed with a significant positive correlation of water temperature with each, total zooplankton (r= 0.55, p < 0.00), Copepoda (r= 0.53, p < 0.00) and Mollusca (r= 0.56, p < 0.00).

Oithona nana; formed the main bulk of copepods, in addition 3 other species (*Oithona plumifera, Paracalanus previews' and Euterpina acutifrons*) was frequently counted. These species are the main component of the zooplankton population along the Egyptian Mediterranean Coast.[33&34] *Oithona nana* was the most dominant copepod in Bardawil Lagoon (16458 organisms/m^3), forming 18.8% and 12.7% to the total counts of copepods and zooplankton respectively. The peak was in summer and decreased in autumn. This finding agrees with that reported by Hussein and Abdel- Aziz [35] in the Egyptian Mediterranean coast. This species is widely distributed in estuaries, oceanic and neritic waters, it is a cosmopolitan species, and it prefers deeper shelf and coastal waters [36,37 &]. It is a euryhylain species tolerating a wide range of salinity and temperature [39]. It was abundant in the eastern Mediterranean Sea [40].

The species diversities values (H′) fluctuated between 1.52 (station 6) and 2.13 (station 2). The high zooplankton density was recorded at stations 6 (181900 organisms/ m^3) with lower diversity, value and 27species was recorded. While the low counts was attained at station 2 (1418000 organisms/ m^3) as well as the number of species (35 spp.) and the highest diversity value. This was accompanied with many species shared in the community composition; Nauplius larvae of copepod (46.2% of total zooplankton density), *Oithona* spp. (13.5%), *Limacia inflate* (8.6%) and *Tintinnopsis* spp. (7.8%). Lower diversity, value of station 6 accompanied with the community composition was dominated by two species, Nauplius larvae of copepod and *Limacia inflate,* since they contributed 40.5 % and 40.4% by number of the total zooplankton population, respectively. Species richness ranged between 19 (station, 12) and 35 (station 2). Species evenness (j) varied between 0.441 (station 3) and 0.517 (station 1).

The majority of zooplankton diversity indices fluctuated between 1 and 2 formed 89.6% of the recorded data. However, 6.3% was formed over diversity values 2.

Regarding the similarity of zooplankton community between different stations (Fig. 5), results revealed that the similarity level of the twelve stations varied from 65% at station 1 to 80% of stations 4 and 5. In general, it can be clearly seen that the similarity of station 1, was almost separate than the others (Fig. 5), due to its high salinity value. As well as station 2 at similarity 67% (which is in front of Boughaz 2) was almost separate than the other stations (Fig. 5). The highest similarity values were recorded between 4 and 5; showed a homogenous sub-group at similarity 80%; this is due to the same number of species, abundance and diversity values. Also similarity was high (77%) between stations 6 and 7, which lies at the eastern and western ends of the Lagoon, where the water is more or less stable, these situations characterized by their highest abundance of zooplankton and nearly the same diversity.

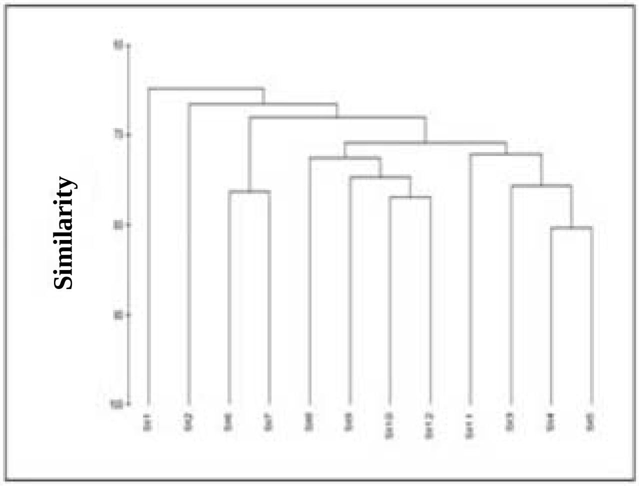

Figure5: Cluster analysis of zooplankton population between sampling stations of Bardawil Lagoon during 2015.

Regarding the relationship between both phytoplankton and zooplankton populations, it is an inverse correlation. The average counts of phytoplankton during different seasons indicated that phytoplankton standing crop attained the highest value during the spring season (170638 cell l^1). This was met with the lowest value of zooplankton (50700 organisms /m^3). On the other hand, the opposite results were recorded during summer season; i.e. lowest counts of phytoplankton (7170 cell. l^{1-}) met with the highest value of zooplankton (285267 organisms/ m^3). Those results are confirmed by Caramujo et al., [41], thus, diatoms, the dominant group of phytoplankton in Bardawil Lagoon, were better food for copepods as indicated by shorter development time, in addition to their higher survival and high fatty acid content. As well as, life histories of copepods revealed that while juvenile stages are herbivores, the adult stages are not, so they are frequently carnivores [42]. The increase in water temperature causes stress in zooplankton grazing rate, this is confirmed with a positive significant correlation between water temperature and each of the total zooplankton ($r= 0.554$, $p < 0.00$), copepods ($r= 0.527$, $p < 0.00$) and Mollusca ($r= 0.562$, $p < 0.00$).

CONCLUSION: The present study showed that Bardawil Lagoon water attained higher phytoplankton density than that previously recorded. While the opposite is true for the recorded zooplankton populations. The authors recommend digging two or three canals, to facilitate the exchange of water between the Mediterranean Sea and the Lagoon, and to prevent the increase in water salinity of the Lagoon. Salinity was the most important factor influencing both phytoplankton standing crop and zooplankton assemblage.

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