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Abundance and distribution of zooplankton communities inhabiting the intertidal zone of the Suez Gulf, Red Sea, Egypt

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ABSTRACT

Zooplankton communities at the Gulf of Suez were investigated during the current study and their abundance was correlated with the physico-chemical parameters of the area. The goal of the study was to estimate the distribution and abundance of zooplankton taxa under various habitat stressors, and update the ecological data base of the study area. The study recorded 39 species of zooplankton in 16 taxa with total abundance of 66300 organisms across all investigated sites. The organisms were distributed between holoplankton that recorded approximately 55560 organisms (84.2 %) and the meroplankton which recorded approximately 10740 organisms (15.8 %). The most abundant groups were Copepoda 52340 organisms (78.9 %), larval stages (11%) and Maxillopoda (3 %). While, Anthomedusea, Leptomeduea, and Pteropoda were rarely recorded. Among the surveyed sites, Zafarana recorded the highest abundance (23537 Organisms) with a percentage of 63 of the total zooplankton populations, whereas the lowest site in abundance was Port-Tewfik which recorded (6656 organisms), represented a percentage of 10 % of the total populations. The current work showed that copepods recorded a significant difference in spatial distribution, while copepods, dissolved oxygen, water temperature and total dissolved solids differed significantly at temporal distribution.

1. INTRODUCTION

The geological structure and geographical position of the Red Sea have a remarkable influence on zooplankton communities. The Red Sea is a flooded valley that can be described as a young ocean, created by pulling a part of Africa and Arabia. It is a North-South elongation extending from 12.5º N in the south to 30º N at Suez in the north **(Sofianos & Johns, 2002)**. It includes the Gulf of Aqaba, the Gulf of Suez and the Red Sea proper (**Thurman, 1997)**. Red Sea is characterized by high temperature and salinity as well as oligotrophic conditions (**Raitsos *et al.*, 2013).**

Few studies were conducted on the diversity of zooplankton in the Red Sea. These studies are rare limited to specific locations in the northern Red Sea and Gulf of Aqaba **(Echelman & Fishelson, 1990; Khalil & Abdel-Rahman, 1997; Cornils *et al.*, 2007; El-Sherbiny *et al.*, 2007)**. Eminently, the Red Sea is ideal for studying the distribution and diversity of zooplankton communities. Zooplankton serve as a vital link between phytoplankton and higher trophic levels in the marine food chain such as fishes and whales **(Wyatt *et al.*, 2012)**. Zooplankton are abundant in all of the world's oceans, seas, and lakes, and their abundance varies horizontally, vertically and seasonally. The primary source of this variability is the phytoplankton availability and the secondary one is the availability of light **(Thurman, 1997)**. Zooplankton play crucial roles in marine biogeochemical cycles and food webs, acting as a link for energy transfer from lower to higher trophic levels. Moreover, they have a fundamental role in the recycling and mediating of macronutrients **(Mitra *et al.*, 2014)** Zooplankton communities usually vary in composition as certain species are highly sensitive to changes in temperature, nutrient cycling, and environmental fluctuations **(Primo *et al.*, 2015).**

Changes in zooplankton community composition can affect the degree of up and down regulations of phytoplankton communities, influence the amount of nutrient availability and processing, and can determine the capacity of aquatic ecosystems as well **(Brucet *et al.*, 2010)**. Some biotic and abiotic parameters, such as temperature, habitat differences, the presence or absence of fish and macrophytes may influence the richness and composition of zooplankton species **(Kaya *et al.*, 2010)**. Moreover, the distribution of zooplankton is useful for assessing environmental issues, such as eutrophication, warming trends, pollution and hydrographic events **(Michael, 1984; ObuidAllah *et al.*, 2005)**, which are very relevant for other biological and ecological researches that require investigation at the Gulf of Suez.

Diversity of zooplankton in the Gulf of Suez seems to be very high where most of the major zooplankton taxa are represented. Tintinnids, foraminifera, copepods, hydromedusa as well as chaetognatha are found in high abundance while other meroplankton groups, such as shrimp larvae, crab larvae, crustacean larvae, mollusks larvae, and chordates larvae were also recorded in large numbers **(Abu El-Regal *et al.*, 2018)**. The most abundant taxa in the Gulf region was Copepoda which formed 78-92% of all zooplankton groups (**Abdel-Rahman, 1993; Dorgham *et al.*, 2012).** Additionally, **Aboul Ezz *et al.* (2014)** found that copepods constituted about 72% of the total zooplankton collected from Matrouh beaches of the Mediterranean Sea.

The present study seeked to estimate the distribution and abundance of zooplankton qualitatively and quantitatively with a list of recorded species in different sites of the Gulf of Suez and determine the role of physicochemical parameters in zooplankton abundance in the Gulf.

2. MATERIALS AND METHODS

2.1 Study Sites

Five sites were investigated along the Gulf of Suez, these were Port-Tewfik (site 1), Cabanon (site 2), National Institute of Oceanography and Fisheries, Suez Branch (NIOF) (site 3), Ain-Sokhna (site 4), and Zafarana (site 5) (Fig.1). **Port-Tewfik:** affected mainly by oil pollution and wastes from shipping operations at Port-Tewfik port. **Cabanon:** affected mainly by sewage pollution. **NIOF:** affected mainly by the higher temperature from the cooling water of Ataqa power plant and also by sewage pollution. **Ain-Sokhna:** affected mainly by tourism and human recreational activities. **Zafarana:** is a calm area that has the lowest influence by human activities (Fig.1).

Fig. 1. A map showing study sites in the Gulf of Suez, Red Sea, Egypt.

2.2. Sample collection

Zooplankton samples were collected seasonally from January to November 2019 from the intertidal zone of the Gulf of Suez. Data of date, time, human activities and physico-chemical parameters were collected. For quantitative study; the zooplankton samples were collected by filtering 300 litres of the seawater (collected by plastic bucket) through a fine zooplankton net at each site. The plankton net has 100µm mesh size with a mouth diameter of 44cm and a total length of 100cm. For qualitative samples; plankton net was towed randomly at each site. The zooplankton organisms retained in the net were transferred carefully into suitable plastic bottles, labeled and immediately fixed with 5% neutral formalin solution after measuring the displacement volume. After each haul, the net was washed thoroughly with seawater and the organisms retained were added to the collected sample to prevent any loss of the hauled organisms **(Al-Yamani & Skryabin, 2006).**

In the laboratory, the collected samples were allowed to stand for sufficient time in the graduated cylinders to ensure complete settlement of the zooplankton organisms and the surplus water of each sample was siphoned off until its volume equaled 100 ml. The whole sample was examined by placing in a large Petri dish, and the large organisms such as fish larvae were picked and counted. Sub-sample of 5ml was then transferred into a counting chamber and each plankter was counted separately using an inverted microscope Leitz, Wetzlar, Germany, Type 090-123, 012. For each sample, 3 subsamples were estimated. The samples were preserved in 70 % ethanol for long time fixation.

2.3. Identification of zooplankton

The separated zooplankton species were identified following the descriptive keys of **Bradford-Grieve and Jillett (1980)**, **Bradford-Grieve (1994)**, **Heron and Bradford-Grieve (1995)** and **Al-Yamani *et al.* (2010)**. For accurate identification of copepods, each copepod was dissected with fine needles and mounted semi-permanently in ksiser's Glycerin jelly (**Gatenby & Painter, 1937)**. This mixture was set when cooled but may be melted by gentle heat. Thus, a limb or a whole animal may be observed from different angles. All small or delicate copepods were first left in a mixture of glycerin, alcohol, and water in the proportions 1:1:2, respectively, until the mixture was concentrated, otherwise the integument would collapse and distort the copepod form. The magnitude of the standing crop of zooplankton was calculated as the numbers of the different species per cubic meter in all samples (Individual/m^3).

The recorded zooplankton taxa were divided into constancy classes according to the system adopted by **Abd El-Wakeil (2005)** as follows: Constant taxa: present in more than 50% of the samples; accessory taxa: present in 50-25 % of the samples and accidental taxa: present in less than 25% of the samples.

2.4. Measurement of physico-chemical parameters

Seasonally measurements of water temperature (ºC), hydrogen ion concentration (pH), dissolved oxygen (DO) (mg/l), and total dissolved solids (T.D.S) (‰) were carried out in the field by using Water Quality Checker.

2.5. Statistical analysis

Analysis of variance on Statistical Package for Social Science (SPSS) version 22 (2014). (SYSTAT statistical program) was used to test the present data. In the case of significant difference, the Multiple Range Comparison (Least significant difference; LSD) was selected from the PostHoc window on the same statistical package to detect the distinct variance among means. In addition, Pearson correlation coefficient and multiple regressions were applied in the present data.

Probability value ≤ 0.05 was defined as significant throughout the present study, and the value > 0.05 was defined as non-significant and that less than 0.01 was defined as highly significant.

3. RESULTS

3.1. Species diversity

The current study recorded a total number of 39 species; larvae of 9 groups and Nauplius of two groups. The larvae and Nauplii were distributed at 16 taxa. These taxa were 7 holoplankton groups (Tintinnidea, Foraminifera, Anthomedusea, Leptomeduea, Pteropoda, Copepoda, Chaetognatha) that include the highest abundant groups which represented 84.2 % of the total populations with 55846 individuals, followed by 9 meroplankton groups (Polychaeta, Maxillopoda, Decapoda, Bivalvia, Gastropoda Urochordata, Echinodermata Cephalochordata and Chordata) that represented 15.8 % of the zooplankton populations at the investigated sites with abundance of 10454 individuals (Table 1).

Table 1. Total number and percentage (%) of zooplankton taxa at different sites during investigated period.

NO.	Zooplankton type	Zooplankton Taxa	Abundance	P (%)
1	Holoplankton	Tintinnidea	1016	1.5
2		Foraminiferida	1413.0	2.1
3		Anthomedusea	140.0	0.2
4		Leptomeduea	146.7	0.2
5		Pteropoda	407	0.6
6		Copepoda	52340.0	**78.9**
7		Chaetognatha	383.3	0.6
Total Holoplankton			**55846**	**84.2**
8	Meroplankton	Urochordata	1576	2.4
9		Polychaeta	1524	2.3
10		Bivalvia	593	0.9
11		Gastropoda	3907	5.9
12		Maxillopoda	2007	3.0
13		Decapoda	279	0.4
14		Echinodermata	110	0.2
15		Cephalochordata	34	0.05
16		Chordate	424	0.6
Total Meroplankton			**10454**	**15.8**
Total zooplankton taxa			**66300**	**100**

Copepoda was represented by 26 species plus two larval stages. Tintinnidea and Urochordata were represented by 3 species. Chaetognatha and Maxillopoda were represented by 2 species. Foraminiferida, Anthomedusea, Leptomeduea and Pteropoda were represented by one species for each group. Decapoda was represented by 2 larvae. Polychaeta, Bivalvia, Gastropoda, Echinodermata, Cephalochordata and Chordate were represented by one species of larvae for each group (Table 3). Zafarana and Ain-Sokhna recorded the highest diversity among all sites surveyed recording 49 species/taxa and larvae. It was followed by NIOF that recorded 47 species/taxa and larvae, followed by Cabanon site that recorded 42 species/taxa and larvae while Port-Tewfik recorded 37 species/taxa and larvae that represented the lowest diversity (Table 2).

Species diversity analysis among different sites showed that site 1 differed significantly from all other sites ($P \leq 0.01$), and site 2 differed significantly from all other sites ($P \leq 0.01$), while there was no significant differences among (site 3, 4 and 5) ($P > 0.05$)as presented in Table (2).

Table 2. Significant differences of total zooplankton diversity among different sites ($P \leq 0.01$). (a,b and c refer to the significant differences).

Sites*diversity	Site 1	Site 2	Site 3	Site 4	Site 5
Site 1	-	**	**	**	**
Site 2	**	-	**	**	**
Site 3	**	**	-	NS	NS
Site 4	**	**	NS	-	NS
Site 5	**	**	NS	NS	-
Sites*diversity	37 c	42 b	47 a	49 a	49 a

3.2. Species density

During the current study, zooplankton species showed both temporal and spatial variation among all species recorded. The most abundant species was *Oithona nana* that belongs to Copepoda . This species recorded the highest abundance during the study period at all sites (6471 individuals), the maximum density was recorded at Zafarana in summer (1000 Ind /m^3) while it recorded the minimum density (20 Ind /m^3) in winter at Ain-Sokhna. While, the lowest abundant species was *Paracalanus indicus* that belongs to Copepoda which recorded 19 individuals during the study period at all sites. The maximum density was recorded in summer at Zafarana (7 Ind /m^3) while the lowest density was recorded in winter, autumn and spring at NIOF, Ain-Sokhna and Zafarana, respectively. Moreover, it was not recorded in other seasons at other different sites (Table 3).

The result showed that, the highest density was achieved at site 5 (23537 individuals), followed by site 4 (14803 organisms), then comes site 3 (12053 individuals), followed by site 2 (92500 individuals). While, the lowest density was recorded at site 1 with 6656 individuals (Table 4). The results showed that the total species density significantly differed among all sites of investigations ($P \leq 0.01$) (Table 4).

Table 3. Density of the recorded zooplankton taxa at different sites and seasons during the investigated period (Ind / m^3). Wi: winter, Sp: spring, Su: summer and Au: autumn.

Zooplankton taxa	Site 1 Port-Tewfik				Site 2 Cabanon				Site 3 NIOF				Site 4 Ain Sokhna				Site 5 Zafarana				Total
	Wi	Sp	Su	Au	Wi	Sp	Su	Au	Wi	Sp	Su	Au	Wi	Sp	Su	Au	Wi	Sp	Su	Au	
COPEPODA																					
Nauplius larvae	433	567	**390**	700	700	850	967	867	963	1060	1167	1000	1050	1150	1267	1533	1700	1833	1383	**2290**	21870
Copepodite stage	**233**	323	400	317	317	493	667	383	333	450	700	317	333	350	667	577	1300	773	827	**1400**	11160
Paracalanus crassirostris	3	67	73	7	17	43	67	20	33	70	87	7	0	40	117	217	153	100	107	143	1371
Paracalanus parvus	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	50	0	67	10	150	280
Paracalanus indicus	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	3	7	3	19
Acrocalkanus gibber	0	37	23	40	0	23	17	30	0	23	0	30	0	17	33	33	50	100	0	100	556
Centropages furcatus	3	7	0	10	3	3	0	7	7	3	7	10	3	10	3	0	10	0	0	0	86
Acartia negligens	10	20	17	3	33	10	3	17	33	3	7	13	13	10	33	0	7	100	107	0	439
Acartia centrura	0	10	0	3	0	7	7	3	0	3	17	3	0	10	17	0	43	7	0	17	147
Clausocalanus furcatus	7	0	10	3	33	0	0	3	417	7	0	3	150	0	0	200	110	250	250	250	1693
Calanopia elliptica	0	0	3	0	0	3	3	0	0	3	0	0	0	3	0	0	3	0	0	0	18
Calanus minor	7	0	0	0	17	0	0	0	50	0	3	0	17	0	3	0	10	7	140	0	254
Mecynocera clause	0	0	0	0	3	0	0	0	7	0	0	0	0	0	0	7	0	7	23	10	57
Oithona nana	**3**	567	33	233	33	500	73	367	33	477	367	283	20	567	867	57	317	617	**1000**	57	**6471**
Oithona plumifera	3	7	7	7	17	3	33	3	27	30	17	7	10	7	33	0	7	0	1003	0	1221
Oncaea media	0	3	33	3	60	3	0	0	240	20	3	3	100	3	33	50	283	200	283	50	1370
Oncaea conifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	27
Corycaeus erythraeus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	7	90	50	197
Corycaeus speciosus	0	0	0	0	57	0	0	0	63	0	0	0	23	0	0	60	0	103	7	33	346
Euterpina acutifrons	0	23	17	233	0	10	10	217	0	133	33	233	0	50	67	0	7	53	87	0	1173
Microsetella norvegica	0	7	90	17	0	7	67	43	0	107	67	43	0	3	117	0	10	0	0	0	578
Clytemnestra scutellata	0	0	17	27	0	0	83	17	0	0	83	10	0	0	133	0	0	0	0	0	370
Paracalanus aculatus	0	0	40	3	0	0	83	7	0	0	67	3	0	0	200	0	37	0	0	0	440
Centropagus elongates	0	0	0	0	3	0	17	0	17	0	10	0	0	0	17	17	0	3	3	83	170
Clausocalanus arcuicornisl	10	0	0	0	20	0	0	0	100	0	0	0	23	0	0	33	0	7	3	50	246
Ctenocalanus vanus	0	0	0	0	37	0	0	0	3	0	0	0	0	0	0	33	0	3	7	33	116
Farranula gibbula	0	0	0	0	17	0	0	0	140	0	0	0	83	0	0	433	217	307	250	167	1614
Copilia mirabilis	0	0	0	0	7	0	0	0	3	0	0	0	0	0	0	17	0	0	20	0	47
TINTINNIDEA																					
Tintinnopsis campanula	27	30	43	7	23	93	43	20	20	63	40	7	37	70	57	23	50	53	57	23	786

Favella ehrenbergii	7	0	7	0	10	7	3	0	0	23	7	0	3	3	10	10	23	7	10	13	143
Stenosemella ventricosa	3	0	0	0	3	20	0	0	7	20	3	3	3	3	0	7	3	3	0	7	85
FORAMINIFERA																					
Globigerina inflate	23	93	57	63	27	57	57	100	67	57	40	117	140	107	67	50	73	63	107	50	1415
Anthomedusea,																					
Podocoryne areolate	3	0	0	0	23	0	3	0	0	0	0	7	0	0	0	33	7	0	0	63	139
Leptomeduea																					
Obelia sp.	3	0	0	7	3	3	0	7	0	3	0	20	3	0	3	17	0	0	3	73	145
PTEROPODA																					
Cresis virgule	0	0	0	0	0	0	0	0	33	0	3	0	20	0	3	0	50	0	10	0	119
Pteropod larvae	0	0	0	10	0	0	0	10	0	0	0	33	0	0	0	117	0	0	0	117	287
CHAETOGNATHA																					
Krohnitta subtilis	3	0	0	0	10	13	0	0	3	10	0	0	57	13	0	0	63	37	0	0	209
Sagita enflata	0	0	0	0	0	0	0	0	10	0	0	0	50	0	0	3	107	0	0	3	173
UROCHORDATA																					
Appendicularia sicula	7	3	0	3	7	0	3	17	3	13	7	7	13	10	10	27	10	17	10	3	170
Oikopleura longicauda	23	0	23	0	57	0	23	3	167	30	33	43	233	33	33	83	317	50	100	107	1358
Doliolum denticullatum	0	0	0	0	0	0	0	0	0	0	3	0	3	7	3	0	13	7	10	0	46
Polychaet larvae	23	7	50	0	40	7	123	0	150	17	40	0	267	23	117	37	333	53	237	0	1524
Lamellibranch larvae	180	0	0	0	113	0	0	0	107	3	0	0	83	0	0	0	100	7	0	0	593
Gastropod larvae	277	97	43	20	277	33	73	57	720	33	83	17	617	380	33	30	667	267	33	150	3907
Cirripedia sp.	7	40	183	57	7	43	217	57	17	150	187	50	27	180	190	167	30	173	57	140	1979
Cirriped nauplii	0	10	0	0	0	7	0	0	0	13	0	0	0	0	0	0	0	0	0	0	30
Penaeid larvae	17	0	0	0	10	3	0	0	0	0	0	0	3	0	0	0	43	0	0	0	76
Other decapod larvae	7	0	0	23	17	0	0	10	3	0	0	40	23	0	0	33	17	0	0	30	203
Echinoderm larvae	0	3	0	3	0	0	0	3	0	7	0	0	0	30	7	0	10	40	7	0	110
B. lanceolatum larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	17	34
Fish larvae	17	0	33	3	30	7	50	10	27	20	0	0	30	117	3	0	37	17	3	20	424
Total	1340	1920	1593	1803	2030	2250	2693	2277	3810	2853	3080	2310	3440	3197	4143	4023	6217	5367	6250	5703	66300

Table 4. Significant differences of total zooplankton densities among different sites (P≤ 0.01). (a,b,c,d and e refer to the significant differences).

Sites*density	Site 1	Site 2	Site 3	Site 4	Site 5
Site 1	-	**	**	**	**
Site 2	**	-	**	**	**
Site 3	**	**	-	**	**
Site 4	**	**	**	-	**
Site 5	**	**	**	**	-
Sites*density	6656 e	9250 d	12053 c	14803 b	23537 a

3.3. Frequency of zooplankton taxa

The samples collected during the current study included 20 samples (4 seasons x 5 sites) from different locations in the studied area (Fig. 1). The constant taxa were 19 species, 5 larvae, Nauplius larvae and Copepodite stage, and the accessory taxa were 17 species and 2 larvae, while the rare taxa were 3 species, 2 larvae and Cirriped nauplii (Table 5).

Table 5. Frequency and percentage (%) of different zooplankton taxa collected from the investigated sites during the period of collection.

	Port-Tewfik		Cabanon		NIOF		Ain Sokhna		Zafarana		all 5 sites	
Zooplankton taxa.	**F**	**%**	**F**	**%**	**F**	**%**	**F**	**%**	**F**	**%**	**F**	**%**
COPEPODA												
Nauplius larvae	4	100	4	100	4	100	4	100	4	100	20	100
Copepodite stage	4	100	4	100	4	100	4	100	4	100	20	100
Paracalanus crassirostris	4	100	4	100	4	100	3	75	4	100	19	95
Paracalanus parvus	-	0	-	0	1	25	1	25	3	75	5	25
Paracalanus indicus	-	0	-	0	1	25	1	25	3	75	5	25
Acrocalkanus gibber	3	75	3	75	2	50	3	75	3	75	14	70
Centropages furcatus	3	75	3	75	4	100	4	100	1	25	15	75
Acartia negligens	4	100	4	100	4	100	3	75	3	75	18	90
Acartia centrura	2	50	3	75	3	75	2	50	3	75	13	65
Clausocalanus furcatus	3	75	2	50	3	75	2	50	4	100	14	70
Calanopia elliptica	1	25	2	50	1	25	1	25	1	25	6	30
Calanus minor	1	25	1	25	2	50	2	50	3	75	9	45
Mecynocera clause	-	0	1	25	1	25	1	25	3	75	6	30
Oithona nana	4	100	4	100	4	100	4	100	4	100	20	100
Oithona plumifera	4	100	4	100	4	100	3	75	2	50	17	85
Oncaea media	3	75	1	25	4	100	4	100	4	100	16	80
Oncaea conifer	-	0	-	0	-	0	-	0	1	25	1	5
Corycaeus erythraeus	-	0	-	0	-	0	1	25	3	75	4	20
Corycaeus speciosus	-	0	1	25	1	25	2	50	3	75	7	35
Euterpina acutifrons	3	75	3	75	3	75	2	50	3	75	14	70
Microsetella norvegica	3	75	3	75	3	75	2	50	1	25	12	60
Clytemnestra scutellata	2	50	2	50	2	50	1	25	-	0	7	35
Paracalanus aculatus	2	50	2	50	2	50	1	25	1	25	8	40
Centropagus elongates	-	0	2	50	2	50	2	50	3	75	9	45

Clausocalanus arcuicornisl	1	25	1	25	1	25	2	50	3	75	8	40
Ctenocalanus vanus	-	0	1	25	3	75	1	25	3	75	8	40
Farranula gibbula	-	0	1	25	1	25	2	50	4	100	8	40
Copilia mirabilis	-	0	1	25	3	75	1	25	1	25	6	30
TINTINNIDEA												
Tintinnopsis campanula	4	100	4	100	4	100	4	100	4	100	20	100
Favella ehrenbergii	2	50	3	75	2	50	4	100	4	100	15	75
Stenosemella ventricosa	1	25	2	50	4	100	3	75	3	75	13	65
FORAMINIFERA												
Globigerina inflata	4	100	4	100	4	100	4	100	4	100	20	100
Anthomedusea,												
Podocoryne areolata	1	25	2	50	1	25	1	25	2	50	7	35
Leptomeduea												
Obelia sp.	2	50	3	75	2	50	3	75	2	50	12	60
PTEROPODA												
Cresis virgule	-	0	-	0	1	25	2	50	2	50	5	25
CHAETOGNATHA												
Krohnitta subtilis	1	25	2	50	2	50	2	50	2	50	9	45
Sagita enflata	-	0	-	0	1	25	1	25	2	50	4	20
UROCHORDATA												
Appendicularia sicula	3	75	3	75	4	100	4	100	4	100	18	90
Oikopleura longicauda	2	50	3	75	4	100	4	100	4	100	17	85
Doliolum denticullatum	-	0	-	0	1	25	3	75	3	75	7	35
Polychaet larvae	3	75	3	75	3	75	4	100	3	75	16	80
Lamellibranch larvae	4	100	1	25	2	50	1	25	2	50	10	50
Gastropod larvae	4	100	4	100	4	100	4	100	4	100	20	100
Pteropod larvae	1	25	1	25	1	25	1	25	1	25	5	25
Cirripedia sp.	4	100	4	100	4	100	4	100	4	100	20	100
Cirriped nauplii	1	25	1	25	1	25	0	0	0	0	3	15
Penaeid larvae	-	0	2	50	-	0	1	25	1	25	4	20
Other decapod larvae	2	50	2	50	2	50	2	50	2	50	10	50
Echinoderm larvae	2	50	1	25	1	25	2	50	3	75	9	45
B. lanceolatum larvae	-	0	-	0	-	0	1	25	1	25	2	10
Fish larvae	3	75	4	100	2	50	3	75	4	100	16	80

3.4. Physico-chemical parameters

The values of water temperature varied considerably between sites and seasons of investigation from winter 2018 to autumn 2019. The minimum water temperature was recorded in autumn at Port-Tewfik (17.50 ºC), while the maximum value was recorded at Cabanon and NIOF in summer (31 ºC). The minimum pH was recorded in winter at Port-Tewfik and in autumn at NIOF with 7.77, respectively, while the maximum value was recorded in autumn at NIOF (8.18). The minimum value of dissolved oxygen concentration was recorded in summer at NIOF (5.10 mg/l), while the maximum value was recorded in winter at Ain-Sokhna (8.2 mg/l). On the other hand, the minimum value of the total dissolved solids (T.D.S) concentration was recorded in autumn at Ain-Sokhna, (36.30 g/l), while the maximum value was recorded in spring at Port-Tewfik (39.5 g/l) (Table 6).

Table 6. Mean ± standard deviation (SD) of physico-chemical parameters at the studied sites during different seasons.

Sites	Seasons	W.Temp (°C).	pH	O_2 (mg/l)	T.D.S (g/l)
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Port-Tewfik	Winter	19.00 ± 0.5	7.77 ± 0.21	6.80 ± 0.21	37.1 ± 0.2
	Spring	23.50 ± 0.26	8.00 ± 0.199	6.00 ± 0.19	39.5 ± 0.15
	Summer	28.00 ± 0.26	7.86 ± 0.17	6.10 ± 0.02	37.7 ± 0.17
	Autumn	17.50 ± 0.2	7.87 ± 0.11	6.50 ± 0.18	36.7 ± 0.21
	Annual mean	**22 ± 0.3**	**7.8 ± 0.17**	**6.35 ± 0.15**	**37.75 ± 0.18**
Cabanon	Winter	20.00 ± 0.36	7.84 ± 0.17	7.80 ± 0.05	37.80 ± 0.12
	Spring	25.50 ± 0.26	8.00 ± 0.14	5.60 ± 0.034	38.30 ±0.3
	Summer	31.00 ± 0.46	7.88 ± 0.24	5.30 ± 0.085	38.30 ±0.14
	Autumn	20.50 ± 0.26	7.75 ± 0.07	7.70 ± 0.053	37.90 ±0.19
	Annual mean	**24.25 ± 0.34**	**7.87 ± 0.16**	**6.6 ± 0.06**	**38.08 ± 0.19**
NIOFF	Winter	20.00 ± 0.5	8.13 ± 0.13	6.20 ± 0.18	38.00 ± 0.18
	Spring	26.00 ± 0.56	8.10 ± 0.15	5.50 ± 0.105	38.50 ± 0.08
	Summer	31.00 ± 0.2	8.18 ± 0.18	5.10 ± 0.12	38.60 ± 0.12
	Autumn	20.00 ± 0.34	7.77 ± 0.07	5.80 ± 0.09	38.60 ± 0.25
	Annual mean	**24.25 ± 0.4**	**8.045 ± 0.13**	**5.65 ± 0.123**	**38.4 ± 0.16**
Ain-Sokhna	Winter	20.50 ± 0.36	7.89 ± 0.22	8.20 ± 0.04	36.40 ± 0.11
	Spring	25.00 ± 0.36	7.83 ± 0.15	6.10 ± 0.12	37.40 ± 0.14
	Summer	30.50 ± 0.26	7.86 ± 0.11	6.30 ± 0.17	37.60 ± 0.2
	Autumn	19.00 ± 0.2	7.93 ± 0.15	8.00 ± 0.026	36.30 ± 0.13
	Annual mean	**23.75 ± 0.295**	**7.88 ± 0.16**	**7.15 ± 0.089**	**36.9 ± 0.15**
Zafarana	Winter	18.50 ± 0.17	7.83 ± 0.14	7.80 ± 0.03	36.60 ± 0.14
	Spring	24.50 ± 0.44	7.90 ± 0.23	6.20 ± 0.105	39.10 ± 0.18
	Summer	29.50 ± 0.36	7.85 ± 0.15	5.50 ± 0.26	38.50 ± 0.22
	Autumn	18.50 ± 0.25	7.88 ± 0.07	7.20 ± 0.04	36.50 ± 0.19
	Annual mean	**22.75 ± 0.3**	**7.87 ± 0.15**	**6.68 ± 0.11**	**37.68 ± 0.18**

By pooling data at the five sites and applying the correlation analysis between total numbers of zooplankton groups with physico-chemical parameters (ecological factors) concentrations in the seawater (Table 7), it was concluded that, the abundance of Tintinnidea was positively correlated with water temperature (r=0.456). To illustrate, the abundance of Anthomedusea was positively correlated with Leptomeduea (r=0.887) and negatively correlated with the total dissolved salts T.D.S (r=-0.466). Furthermore, the abundance of Leptomeduea was positively correlated with Anthomedusea (r=0.887). While, the abundance of Pteropoda was positively correlated with Chaetognatha (r=-0.8), Uorochordata (r=0.89) and other larval stages (r=0.89). In addition, the abundance of Chaetognatha was positively correlated with dissolved oxygen (r=0.486), Uorochordata (r=0.868) and Pteropoda (r=0.89). While, the abundance of Uorochordata was positively correlated with dissolved oxygen (r=0.524), Pteropoda (r=0.89), Chaetognatha (r=0.868), while negatively correlated with the total dissolved salts (r=0.474) and the other larval stages (r=-0.872). The abundance of Maxillopoda was positively correlated with water temperature (r=0.635). It was also noted that, the abundance of other larval stages was positively correlated with dissolved oxygen (r=0.494), Pteropoda (r=0.846), Chaetognatha (r=0.778) and Uorochordata (r=0.872).

Table 7. The values of correlation coefficients (r) for different ecological parameters (Water Temperature (WT), Hydrogen Ion (pH), Dissolved Oxygen (O_2), Total Dissolved Solids (T.D.S), Tintinidia (Tin), Formanifera (Form), Anthomedusea (Ant), Leptomeduea (Lep), Pteropoda (Pte), Chaetognatha (Cha), Copepoda (Cop), Uorochordata (Uro), Maxillopoda (Max), and Other larval species (Other).

Factors	Tin.	Form.	Ant.	Lep.	Pte.	Cop.	Cha.	Uro	max	Other.
	(r)	(r)	(r)	(r)	(r)	(r)	(r)	(r)	(r)	(r)
WT	0.**456***	NS	NS	NS	NS	NS	NS	NS	0.**635****	NS
pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
O_2	NS	NS	NS	NS	NS	NS	**0.486***	**0.524***	NS	**0.494***
T.D.S	NS	NS	**-0.466***	NS	NS	NS	NS	**- 0.474***	NS	NS
Tin	-	NS	NS	NS	NS	NS	NS	NS	NS	NS.
Form	NS	-	NS	NS	NS	NS	NS	NS	NS	NS
Ant	NS	NS	-	**0.887****	NS	NS	NS	NS	NS	NS
Lep	NS	NS	0.**887****	-	NS	NS	NS	NS	NS	NS
Pte	NS	NS	NS	NS	-	NS	**0.805****	**0.89****	NS	**0.846****
Cop	NS	NS	NS	NS	NS	-	NS	NS	NS	NS
Cha	NS	NS	NS	NS	**0.8****	NS	-	**0.868****	NS	**0.778****
Uro	NS	NS	NS	NS	**0.89****	NS	**0.868****	-	NS	**0.872****
Max	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Other.	NS	NS	NS	NS	**0.89****	NS	NS	**-0.872***	NS	-

*: The mean difference is significant at the 0.05 levels.

**: The mean difference is significant at the 0.01 levels.

NS: the mean difference is not significant

4. DISCUSSION

Zooplankton serves as an intermediate link between phytoplankton and higher consumers in both marine and freshwater ecosystems. Zooplankton providing food for larger animals and indirectly for humans through plankton-dependent fisheries, such as Sardines that feed on zooplankton in Egypt **(Abou-Zeid, 1990)**. Because of their role in the marine food chain, zooplankton populations appear to be particularly helpful for assessing ecosystem health.

The current study showed spatial variations in zooplankton density and diversity among the surveyed sites. The maximum diversity was recorded from both Ain-Sokhna and Zafarana due to the lower pollution loads and the suitability of environmental conditions such as temperature and oxygen.While, the minimum diversity was recorded at Port-Tewfik due to the oil pollution from ships and less oxygen concentration, and the same conclusion was recorded in the study of **Koppelmann *et al.* (2009)**. The statistical analysis evoked this finding, where there is a similarity (no significant differences) between three of the five investigated sites; NIOF, Ain-Sokhna and Zafarana, because they share similar conditions of low types of pollution, suitable ranges of temperature, the pH value and other environmental conditions. While, the other two sites (Port-Tewfik and Cabanon) showed significant differences in all the investigated sites due to the fact that, Port-Tewfik is oil polluted from ships' operations and human wastes, while Capanon is mainly affected by sewage pollution. The current finding agrees with that of **Primo *et al.* (2015)** who found that, the difference in the environmental conditions is of a prime importance causing the difference in zooplankton diversity, while **Paturej *et al.* (2017)**, reported that anthropogenic activities greatly impact zooplankton diversity.

On contrary, the study revealed that all the sites investigated were significantly different in zooplankton density, which indicates that both environmental factors and human impacts have greater effect on density than diversity, these determined facts coincide with those of **Thurman (1997)**, **Brucet *et al.* (2010)**, **Mitra *et al.* (2014)** and **Primo *et al.* (2015)**.

The current study recorded 16 taxa, and Copepods dominated the community structure of zooplankton in the study sites accounting for 79 % of the total zooplankton sampled. This finding concurs with previous studies conducted in the Red Sea (**Dorgham *et al.*, 2012; Abu El-Regal *et al.*, 2018)**, and Gulf of Aqaba (**Michel *et al.*, 1986; Dorgham & Hussein, 1997)**. Additionally, **Aboul Ezz *et al.* (2014)** reported that, Copepods made up around 72 % of the total zooplankton collected from Matrouh shore in the Mediterranean Sea. Copepods also dominated zooplankton communities in other regions, such as the Arctic (Greenland Sea, White Sea, Icelandic waters, Beaufort Sea, Kara Sea, Arctic Ocean) **(Mumm, 1991; Richter, 1994; Auel & Hagen, 2002; Fetzer *et al.*, 2002; Walkusz *et al.*, 2009; Dvoretsky & Dvoretsky, 2013)**, whereas the

Maxillopoda taxa was highly abundant; a phenomenon that may be attributed to being closer to the navigation route so the Cirripida larvae showed high abundance as a mean of biofouling.

The data obtained found that *Oithona nana* recorded the highest density during the current study from all sites that was attributed to their relatively lower metabolic rate and their wide-ranging dietary preferences **(Lampitt & Gamble, 1982; Castellani *et al.*, 2005)**. **Lampitt and Gamble (1982)** classified the *Oithona nana* as a raptorial feeder, with an opportunistic diet able to consume particulates from detritus to phytoplankton including earlier stages of calanoid nauplii and even copepodite stages. The present result agrees with that of **ObuidAllah *et al*. (2005**), who found that the *O. nana* was the highest zooplankton species in the northern part of the Red Sea.

The study showed seasonal variations in zooplankton density at all study sites. The highest density was recorded in summer followed by spring, while it recorded the lowest density in winter. Notably, the suitable temperature for increasing densities of zooplankton species is 30ºC which agrees with the result of **Abu El-Regal *et al*. (2018)**. Hence, the reason for zooplankton peaked in summer is attributed to the suitable temperature, while the lowest temperature recorded from the area was 18.5 ºC, that is why the lowest density was recorded in winter. These findings coincide with those of **Al-Najjar (2000)** and **Dorgham *et al.* (2012)** in the Gulf of Suez and **Abu El-Regal *et al*. (2018)** in the northern part of the Red Sea. On the contrary, the studies carried out at the Gulf of Aqaba recorded maximum density of zooplankton in winter (**Echelman & Fishelson, 1990; Khalil & Abdel-Rahman, 1997)**. The density variations in zooplankton are affected by variations in the environmental conditions (**Suresh *et al.*, 2011; Paturej *et al.*, 2017)**.

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