

Zooneuston and zooplankton abundance and diversity in relation to spatial and nycthemeral variations in the Gulf of Aqaba and northern Red Sea

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Abstract

Zooplankton and zooneuston observations were made at seven stations (four from the Gulf of Aqaba and three from the northern Red Sea), during September and October 2016. The main objective of this study was to assess the variability of nycthemeral fauna in relation to the sampling methods using two different types of nets namely, WP2 net and Neuston net along the two study sites, i.e., the Gulf of Aqaba and the northern Red Sea. Zooplankton was sampled vertically using a standard WP2 net from a depth of 200 m to the surface, whereas zooneuston was made using a standard Neuston net from a depth of 0–10 cm of the water surface. Total zooplankton density was maximum during night time ((617.83 ± 201.84) ind./m³) at the Gulf of Aqaba and total zooneuston was maximum during night at the northern Red Sea ((60.94 ± 29.48) ind./m³), respectively. The most abundant taxa were Copepoda, Gastropoda, Bivalva, Chaetognatha, Tunicata and Ostracoda. The abundance was almost 50% higher at night time at both the Gulf of Aqaba and the northern Red Sea. Overall, 30 taxa covering 10 phyla and 27 taxa covering 8 phyla were recorded in the Gulf of Aqaba and the northern Red Sea.

Key words: zooplankton, zooneuston, nycthemeral variation, Cyclopoida, Gulf of Aqaba, northern Red Sea

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1 Introduction

The Red Sea, including its gulf ecosystems, despite having ecological importance due to their extreme environmental conditions, being the most saline among the world's ocean (Marcos, 1970; Weikert, 1987), limit plankton diversity compared to its adjacent Indian Ocean or Mediterranean Sea (Halim, 1969). The diversity and abundance of biological communities including zooneuston and zooplankton, besides being directly associated with the availability of nutrients, are related to various other abiotic physical and chemical, and biotic factors, which in turn leads to specific temporal and spatial distributions of these communities in the oceanic environments (Anger, 2001; Sommer et al., 2002; Gibson, 2003; De Albuquerque Lira et al., 2014; Liparoto et al., 2017). Zooneuston forms a highly diverse and complex assemblage of faunal organisms, living in thin layers of the upper surface of the water column, and plays an ecological important role in the marine life (Naumann, 1917; Zaitsev, 1971; Liparoto et al., 2017).

More information on the Red Sea zooplankton is now available, but the general pattern pertaining to abundance and diversity remains unaltered, i.e., the productivity increases from

north to south, both in the main basin and in the Gulf of Aqaba (Halim, 1984). Though, many studies on pelagic ecosystems especially on the zooplankton have been carried out, e.g., Fedorina and Kornilova (1970), Almeida Prado-Por (1983, 1985), Böttger-Schnack (1990), Echelman and Fishelson (1990), Khalil and Abd El-Rahman (1997), Al-Najjar (2002), Cornils et al. (2005, 2007b), Aamer et al. (2006), Dorgham et al. (2012), and El-Serehy et al. (2013) studied the ecology, distribution and community structure; Al-Najjar (2005), Al-Najjar and Rasheed (2005), and Al-Najjar and El-Sherbiny (2008) analysed the biomass of zooplankton; El-Serehy and Abd El-Rahman (2004) studied their distribution along coral reef and sandy areas; El-Sherif and Ezz (2000) gave the checklist; Sommer et al. (2002) observed the grazing of zooplankton; Böttger-Schnack et al. (2008) studied the oncaeid community structure; Cornils et al. (2007b) studied the seasonal abundance and reproduction of clausocalanids; Cornils et al. (2007c) studied the feeding of clausocalanids; Schnack-Schiel et al. (2008) studied the population dynamics of *Rhincalanus nasutus*; Schmidt (1973), and Almeida Prado-Por (1990) observed the vertical distribution and diurnal migration of zooplankton; Kürten et al. (2013) analysed the influence of carbon and nitro-

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gen isotopes on coral reef zooplankton and later Kürten et al. (2015a) observed the ecohydrographic constraints of the diversity and distribution of zooplankton and Kürten et al. (2015b) analysed the ratios among pelagic zooplankton, nonetheless studies pertaining to zooneuston are rarely available in the Gulf of Aqaba and the northern Red Sea.

There has been sporadic works pertaining to the study of zooneuston in the Red Sea, despite several zooplankton works mentioned above. Primary reports on the neustonic organisms was given by Echelman and Fishelson (1990), who mainly carried out the near-reef zooplankton, whereas El-Sherbiny (2009) reported the neustonic calanoid, *Pontella princeps* Dana, 1849 from the Gulf of Aqaba region using a plankton net having 325 microns mesh size. Recently, Pearman and Irigoien (2015) assessed the zooplankton community using molecular methods and observed a higher proportion of operational taxonomic units of 18S rRNA sequence for the cyclopoid genera, *Corycaeus* genus in the epipelagic zone.

The comparison of the two nets showed the neuston net to be a highly selective gear, sampling fewer species than the WP2 net. Therefore, the objective of the present study is to assess the zooplankton and zooneuston abundance and diversity in relation to the nycthemeral (day/night) and spatial (Gulf of Aqaba and northern Red Sea regions) variations. Thus, our findings can be useful as a novel reference for understanding zooplankton and zooneuston in the surface water column.

2 Materials and methods

The Red Sea, being oligotrophic in nature, is considered as unfavorable environment for plankton owing to its high salinity, lack of any freshwater inputs and high evaporation rates (Weikert, 1987), though having its own endemic diversity (Halim, 1984). Owing to high temperatures and higher salinities that prevail in the Red Sea, many Indo-Pacific planktonic organisms that immigrate from the Indian Ocean via the Gulf of Aden to the northern Red Sea cannot thrive well, and hence their survivability during migration from southern to northern Red Sea becomes very difficult, but those that thrive favours the evolution of endemic species (Kimor, 1973). The Gulf of Aqaba, is the northern extension of the Red Sea and is moderately oligotrophic in having oceanic gyre centres, in contrast to the southern Red Sea, which resemble productive oceanic gyre margins (Reiss and Hottinger, 1984). Salinity increases considerably from south to north in the Red Sea, from ca. 37 at Bab al Mandab to more than 40 in the Gulf of Aqaba (Marcos, 1970).

Four stations in the Gulf of Aqaba and three stations in the northern Red Sea were sampled during two cruises via the R/V *Al-Azizi* during 18–26 September 2016 and 25 October to 2 November 2016. Seawater temperature (°C), salinity and oxygen (mg/L) were taken using onboard CTD SBE33-25 Plus sealogger. Each station was sampled for zooplankton and zooneuston during both day and night. The study area and location of stations are given in Fig. 1 and Table 1. Zooplankton was vertically sampled using WP2 net (mouth diameter 60 cm, having 180 µm sized mesh net), and was hauled to a depth of 200 m down the water column. Zooneuston was sampled using a modified neuston net (rectangular mouth dimension 50 cm×15 cm, having 150 µm sized mesh net, with two aluminum wings attached on their sides for floating) and was hauled allowing the net to float within the top 10 cm of the sea surface. A flow meter was used to calibrate the net filtration rate to calculate the volume of water filtered through the net. During this sampling, the speed of the ship was maintained at 1.5–2 knots. Immediately after collection, samples

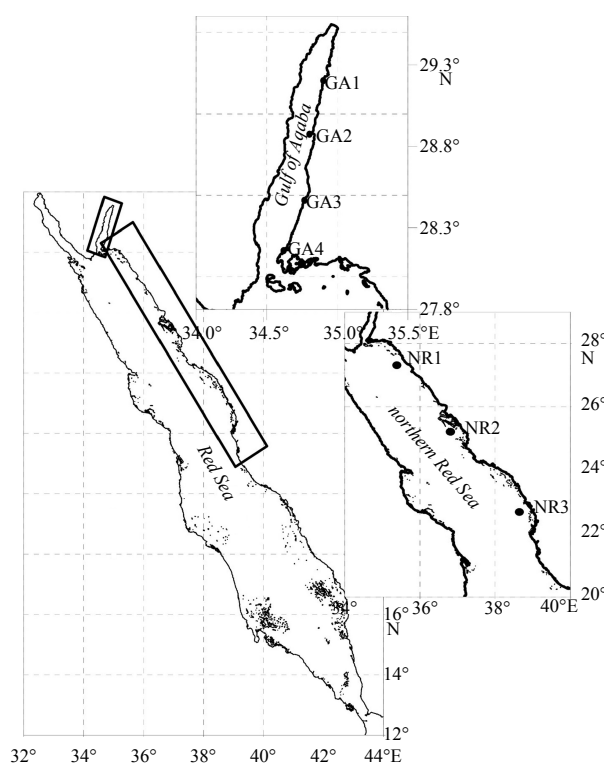


Fig. 1. Map showing the location of the sampled stations during September and October 2016 along the Gulf of Aqaba and the northern Red Sea.

were filtered onto a 100 µm mesh sieve and were then stored in 1 L plastic containers using absolute ethanol until further processing in the laboratory.

In the laboratory, all samples were subsampled using Folsom Splitter (taking care at least ≥ 500 specimens were present in the subsample) for the analysis of abundance and diversity of faunal organisms. The total number of individuals per cubic meter of the volume of water filtered by WP2 net and Neuston net were calculated. Zooplankton and zooneuston were sorted and analysed for their faunal diversity. The organisms were identified to the nearest order level for all, except the subclass Copepoda, where the orders Cyclopoida and Harpacticoida were identified up to the level of species following the standard identification keys of Chihara and Murano (1997), Nishida (1985), Boltovskoy (1999), Böttger-Schnack (1999, 2000, 2001, 2002, 2003, 2005, 2009), Böttger-Schnack and Huys (2001) and Huys and Böttger-Schnack (2007).

3 Statistical analysis

Univariate and multivariate analysis of the zooplankton and zooneuston community structure were carried out using the PRIMER Version 6.0 statistical package (Clarke and Gorley, 2006). Ecological diversity indices like species richness (S), total individuals (N), Shannon-Wiener diversity index [$H' = -\sum (P_i \times \log_{10} P_i)$], where P_i is proportion of total sample represented by species i (Shannon and Weaver, 1963), Simpson dominance index [$D' = \sum (N_i \times (N_i - 1)) / (N \times (N - 1))$], N_i is the total number of individuals in species (Simpson, 1949) and evenness index [$J' = H' / \log_{10} S$] (Pielou, 1966) were computed to know their species homogeneity among the population. The abundance parameters were calculated for each sampled location by pooling the

Table 1. Sampled stations and their locations with abbreviation

Sample	Station name	North latitude	East longitude	Date	Day/night	WP2/Neuston net
GA1ZooDy	Gulf of Aqaba (GoAq)	29°13'13.80"	34°53'52.20"	19 Sep. 2016	day	WP2
GA1ZooNt				19 Sep. 2016	night	WP2
GA2ZooDy		29°00'28.20"	34°49'08.40"	20 Sep. 2016	day	WP2
GA2ZooNt				23 Sep. 2016	night	WP2
GA3ZooDy		28°32'27.02"	34°46'06.38"	21 Sep. 2016	day	WP2
GA3ZooNt				21 Sep. 2016	night	WP2
GA4ZooDy		28°12'34.20"	34°38'27.60"	24 Sep. 2016	day	WP2
GA4ZooNt				25 Sep. 2016	night	WP2
GA1NeuDy		29°13'13.80"	34°53'52.20"	19 Sep. 2016	day	Neuston
GA1NeuNt				19 Sep. 2016	night	Neuston
GA2NeuDy		29°00'28.20"	34°49'08.40"	20 Sep. 2016	day	Neuston
GA2NeuNt				23 Sep. 2016	night	Neuston
GA3NeuDy		28°32'27.02"	34°46'06.38"	21 Sep. 2016	day	Neuston
GA3NeuNt				21 Sep. 2016	night	Neuston
GA4NeuDy		28°12'34.20"	34°38'27.60"	24 Sep. 2016	day	Neuston
GA4NeuNt				25 Sep. 2016	night	Neuston
NR1ZooDy	northern Red Sea (NRS)	35°21'22.18"	35°21'22.18"	25 Oct. 2016	day	WP2
NR1ZooNt				26 Oct. 2016	night	WP2
NR2ZooDy		25°14'41.32"	36°53'46.34"	29 Oct. 2016	day	WP2
NR2ZooNt				28 Oct. 2016	night	WP2
NR3ZooDy		22°32'53.72"	38°28'37.67"	1 Nov. 2016	day	WP2
NR3ZooNt				31 Oct. 2016	night	WP2
NR1NeuDy		35°21'22.18"	35°21'22.18"	25 Oct. 2016	day	Neuston
NR1NeuNt				26 Oct. 2016	night	Neuston
NR2NeuDy		25°14'41.32"	36°53'46.34"	29 Oct. 2016	day	Neuston
NR2NeuNt				28 Oct. 2016	night	Neuston
NR3NeuDy		22°32'53.72"	38°28'37.67"	1 Nov. 2016	day	Neuston
NR3NeuNt				31 Oct. 2016	night	Neuston

whole data from all the sampled stations. For easiness in analysis, all the taxa were pooled into phyla, except copepod, for multivariate analysis.

For multivariate analysis, the data was pretreated, standardized and then overall transformed using $\log_{10}(x+1)$. Single-linkage Bray-Curtis cluster dendrogram was constructed to determine the similarity in their distribution and abundance using different factors like, sampling sites (GoAq/NRS), sampling methods (WP2 net/Neuston net) and their nycthemeral variability (day or night). Scatter plot diagrams for the principle component analyses were carried out to ascertain the groupings and to determine the nycthemeral contribution of abundance of zooplankton and zooneuston. 2-dimensional ordination of community assemblages using non-metric multidimensional scaling (NMDS) was constructed based on the above factors to ascertain the similarity of zooplankton and zooneuston and their nycthemeral variability. The contribution of individual taxa to the differences observed was calculated using similarity percentages (SIMPER) routine using PRIMER Version 6.0 statistical package (Clarke and Gorley, 2006). The graphs were worked out in SigmaPlot Version 11.0 graphical package and general statistics was carried out using Microsoft Excel (MS Office Version 2013).

4 Results

The abiotic factors like temperature, salinity and oxygen, showed a wide range in their nycthemeral variability at both GoAq and NRS. Temperature ranged between 23.27–26.42°C and 25.37–30.38°C during day at GoAq and NRS, while 24.82–35.60°C and 23.01–30.68°C during night at GoAq and NRS (Figs 2a, d). Sa-

linity ranged between 40.65–41.08 and 39.58–40.4 during day at GoAq and NRS, while 40.54–41.29 and 39.34–40.33 during night at GoAq and NRS (Figs 2b, e). Dissolved oxygen ranged between 2.55–6.82 mg/L and 5.57–7.17 mg/L during day at GoAq and NRS, while 1.79–7.06 mg/L and 5.58–6.4 mg/L during night at GoAq and NRS (Figs 2c, f).

The average zooplankton abundance in the upper 200 m were (332.63±151.53) ind./m³ and (216.83±82.86) ind./m³ during day, while (617.83±201.84) ind./m³ and (415±158.64) ind./m³ during night at GoAq (Table 2) and NRS (Table 3), respectively. Among groups, abundance was higher during night, with maximum being Copepoda ((344.66±102.5) ind./m³ and (271.10±97.47) ind./m³ at both GoAq and NRS, respectively).

Order Cyclopoida showed a total abundance of (354.14±42.98) ind./m³ and (137.49±23.65) ind./m³ during day, and (518.05±19.40) ind./m³ and (172.74±26.63) ind./m³ during night at GoAq and NRS, respectively. Among Cyclopoida, the mean abundance was highest in the family Corycaeiidae ((34.04±15.86) ind./m³) during day and by Oithonidae ((49.12±7.09) ind./m³) during night at GoAq (Table 4), while Corycaeiidae was dominant during both day ((21.66±9.18) ind./m³) and night ((23.79±13.06) ind./m³) at NRS (Table 5), respectively. The highest numerical abundance was observed at Sta. 2 during night ((150.04±5.24) ind./m³) from GoAq and at Sta. 3 during night ((89.49±3.55) ind./m³) from NRS (Table 6), respectively.

The average zooneuston abundance in the surface waters were (12.93±8.13) ind./m³ and (17.68±3.53) ind./m³ during day, while (44.04±12.85) ind./m³ and (60.94±29.48) ind./m³ during night at GoAq (Table 2), and NRS (Table 3), respectively. Among

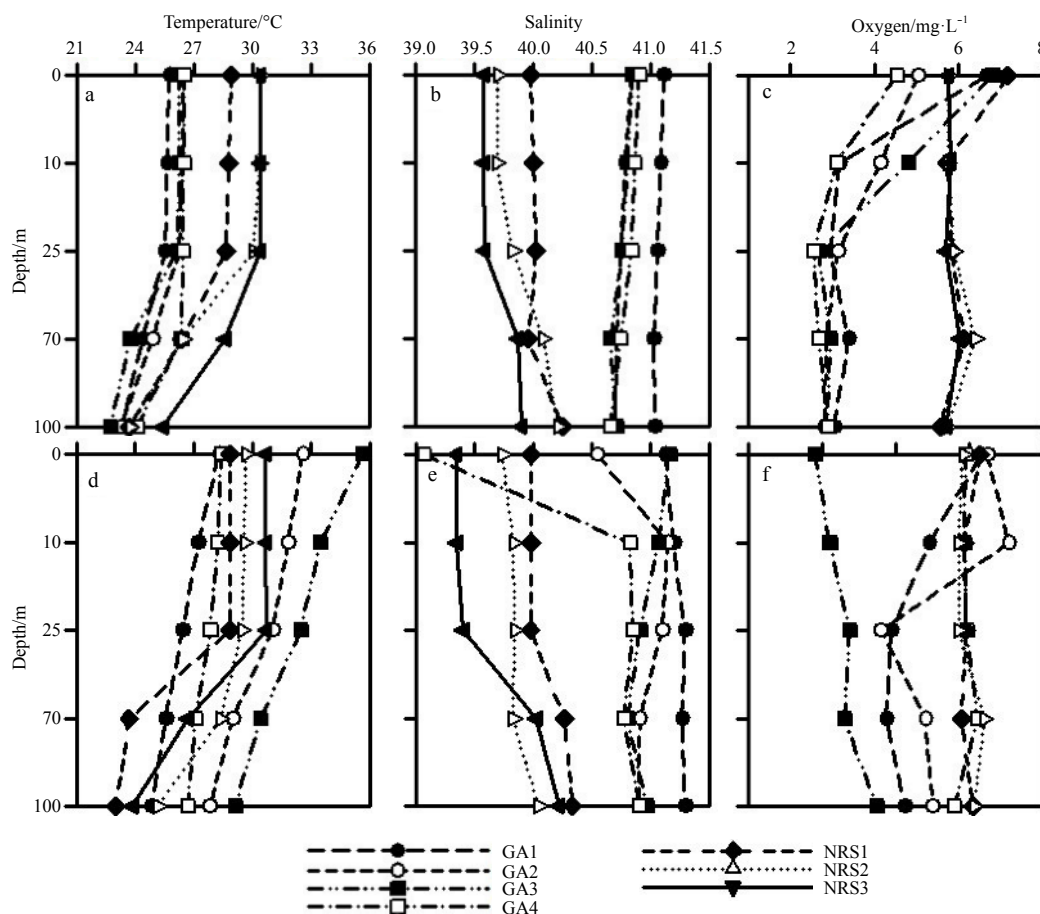


Fig. 2. Nycthemeral variation in temperature ($^{\circ}\text{C}$), salinity and oxygen (mg/L) at different depths at sampled stations during September and October 2016 along the Gulf of Aqaba and the northern Red Sea.

groups, abundance was higher during night time, with maximum for the Gastropoda ($(18.70 \pm 9.22) \text{ ind./m}^3$) at GoAq (Table 2) and Copepoda ($(35.86 \pm 16.34) \text{ ind./m}^3$) at NRS (Table 3), respectively.

The total abundance of Cyclopoida was $(8.65 \pm 1.41) \text{ ind./m}^3$ and $(9.45 \pm 1.94) \text{ ind./m}^3$ during day, and $(22.01 \pm 2.35) \text{ ind./m}^3$ and $(19.23 \pm 3.60) \text{ ind./m}^3$ during night at GoAq and NRS, wherein the Cyclopoida family, Corycaidae represented the highest mean abundance during both day $(1.0 \pm 0.83) \text{ ind./m}^3$ and night $(2.17 \pm 0.95) \text{ ind./m}^3$ from GoAq (Table 4), and was also abundant during both day $(1.75 \pm 1.28) \text{ ind./m}^3$ and night $(3.84 \pm 3.02) \text{ ind./m}^3$ at NRS (Table 5), respectively. The highest numerical abundance was observed at Sta. 1 during night $(7.93 \pm 0.38) \text{ ind./m}^3$ from GoAq and at Sta. 2 during night $(10.54 \pm 0.49) \text{ ind./m}^3$ at NRS (Table 6), respectively.

Most taxa occurred in both nets, while copepod dominated during both day and night, at both GoAq and NRS, whereas the Gastropoda dominated during night in the Neuston net at GoAq (Tables 2 and 3). In general, Copepoda, Gastropoda, Bivalva, Chaetognatha, Tunicata, etc. occurred in both the nets, whereas Ctenophora, Cumacea, Euphausiacea, starfish juvenile, brachiolaria larva and squid larvae were observed only in WP-2 net, while Insecta and Platyhelminthes were found only in Neuston net (Tables 2 and 3). Among the taxa, Ctenophora, Platyhelminthes, Cumacea and starfish juvenile (Table 2) and Cyclopoids: *Corycaeus* (*Onychocorycaeus*) *agilis*, *Corycaeus* (*Corycaeus*) *crassicusculus*, *Oithona simplex*, *Oncaea ovalis*, *Sapphirina*

mettalina, *S. nigromaculata*, *S. opalina*, *Vetatoria granulosa*, and Harpacticoids: *Clytmnestrea asetosa* and *Tegastes* sp. (Table 4) were observed only at GoAq, whereas brachiolaria larvae and squid larvae (Table 3), and the cyclopoid *Epicalymma bulbosa* were observed only at NRS (Table 5).

Overall, the total relative abundance (TRA, %) of Copepoda was dominant in both zooplankton and zooneuston, i.e., 65.90% and 55.26% while using WP2 net at GoAq and NRS, and 50.89% in Neuston net at NRS, respectively. Whereas Gastropoda out-reached in the Neuston net (40.04%) at GoAq (Tables 2 and 3). However, the total abundance varied from a minimum zooneuston $(3.08 \pm 0.43) \text{ ind./m}^3$ during the daytime, to a total maximum zooplankton $(883.21 \pm 87.68) \text{ ind./m}^3$ during night time, and from a minimum zooneuston $(14.55 \pm 2.14) \text{ ind./m}^3$ during day time to a maximum zooplankton $(552.79 \pm 60.53) \text{ ind./m}^3$ during night time at GoAq and NRS (Table 6), respectively. Whereas the total Cyclopoida and Harpacticoida abundance varied from a minimum zooneuston $(1.10 \pm 0.06) \text{ ind./m}^3$ during the day time to a maximum zooplankton $(150.04 \pm 5.24) \text{ ind./m}^3$ during night time, and from a minimum zooneuston $(0.92 \pm 0.04) \text{ ind./m}^3$ during night time to a maximum zooplankton $(89.49 \pm 3.55) \text{ ind./m}^3$ during night time at GoAq and NRS (Table 6), respectively.

The nycthemeral zooplankton and zooneuston community from GoAq and NRS are represented by 32 taxa belonging to 10 phyla (Tables 2 and 3). Thirty taxa under 10 phyla in the GoAq (Table 2) and 27 taxa under 8 phyla in the NRS (Table 3) were recorded. The Cyclopoid and Harpacticoid diversity increased from

Table 2. Mean abundance (mean±SD, ind./m³), relative abundance (RA, %) and total relative abundance (TRA, %) of the nycthemeral zooplankton and zooneuston community during September 2016 from the Gulf of Aqaba

	Zooplankton					Zooneuston				
	Day		Night		TRA/%	Day		Night		TRA/%
	Mean±SD	RA/%	Mean±SD	RA/%		Mean±SD	RA/%	Mean±SD	RA/%	
Radiolaria	5.73±1.21	1.72	13.59±6.22	2.20	2.03	0.12±0.12	0.92	0.82±0.42	1.86	1.65
Medusae	0.28±0.23	0.09	3.40±2.73	0.55	0.39	0.00±0.00	0.00	0.01±0.02	0.02	0.02
Siphonophora	0.50±0.67	0.15	2.12±1.42	0.34	0.28	0.02±0.03	0.17	0.03±0.02	0.06	0.09
Ctenophora	–	–	0.28±0.57	0.05	0.03	–	–	–	–	–
Polychaeta	0.42±0.28	0.13	2.12±0.85	0.34	0.27	–	–	–	–	–
Platyhelminthes	–	–	–	–	–	0.01±0.02	0.07	0.00±0.00	0.00	0.02
Insecta	–	–	–	–	–	–	–	0.02±0.02	0.04	0.03
Amphipoda	0.07±0.14	0.02	0.28±0.33	0.05	0.04	–	–	0.02±0.04	0.04	0.03
Cumacea	0.07±0.14	0.02	0.99±0.54	0.16	0.11	–	–	–	–	–
Cladocera	2.69±1.91	0.81	4.25±3.08	0.69	0.73	0.57±0.71	4.38	0.43±0.37	0.98	1.75
Euphausiacea	0.64±0.54	0.19	2.12±0.97	0.34	0.29	–	–	–	–	–
Isopoda	0.07±0.14	0.02	0.57±0.46	0.09	0.07	0.00±0.01	0.04	0.09±0.14	0.21	0.17
Luciferidae	–	–	0.14±0.28	0.02	0.01	–	–	–	–	–
Ostracoda	6.30±2.32	1.89	13.31±10.96	2.15	2.06	0.05±0.09	0.36	0.70±1.30	1.59	1.31
Mysidacea	2.12±0.37	0.64	5.94±1.76	0.96	0.85	–	–	0.11±0.05	0.25	0.19
Bivalvia	12.81±19.41	3.85	23.07±15.83	3.73	3.78	0.84±0.66	6.49	5.23±3.30	11.89	10.66
Gastropoda	31.92±29.80	9.60	72.75±35.47	11.78	11.01	4.11±3.88	31.80	18.70±9.22	42.46	40.04
Pteropoda	2.55±1.41	0.77	15.29±20.29	2.47	1.88	0.13±0.19	1.00	0.52±0.28	1.17	1.13
Starfish juvenile	0.07±0.14	0.02	0.14±0.28	0.02	0.02	–	–	–	–	–
Chaetognatha	30.15±24.38	9.06	54.64±43.09	8.84	8.92	0.28±0.46	2.14	0.35±0.23	0.80	1.10
Tunicata	29.30±12.41	8.81	47.13±27.61	7.63	8.04	0.26±0.16	1.99	0.76±0.65	1.72	1.78
Cirripede larvae	0.57±0.52	0.17	0.99±0.28	0.16	0.16	0.02±0.03	0.19	0.18±0.20	0.42	0.37
Pluteus larvae	0.78±1.21	0.23	0.99±0.97	0.16	0.19	0.02±0.04	0.16	0.03±0.06	0.06	0.08
Polychaete larvae	1.27±0.88	0.38	1.70±0.80	0.27	0.31	0.02±0.03	0.19	0.15±0.13	0.33	0.30
Zoea larvae	1.13±1.03	0.34	5.80±4.04	0.94	0.73	0.05±0.09	0.37	1.08±1.70	2.45	1.98
Mysis larvae	–	–	–	–	–	0.01±0.02	0.07	0.22±0.20	0.50	0.40
Megalopa	0.07±0.14	0.02	–	–	0.01	–	–	–	–	–
Fish larvae	0.28±0.23	0.09	1.56±1.75	0.25	0.19	–	–	0.06±0.05	0.13	0.10
Copepoda	190.73±77.38	57.34	334.47±105.43	54.14	55.26	6.34±3.91	49.02	14.01±3.46	31.81	35.71
Nauplii	12.10±3.87	3.64	10.19±4.83	1.65	2.35	0.08±0.10	0.65	0.53±0.40	1.21	1.09
Total	332.63±151.53		617.83±201.84			12.93±8.13		44.04±12.85		

North to South during day, while it was almost constant at night in GoAq rather than at NRS. Increased North-South gradient was observed in *Lubbockia aculeata* in the GoAq and a decreasing North-South gradient was observed in *Oncaea mediterranea*, *Oncaea venusta*, *Sapphirina nigromaculata*, *Oncaea copepodids* *Sapphirina* copepodids during the day. Cyclopoids like *Corycaeus (Onychocorycaeus) latus*, *Hemicyclops* sp., *Sapphirina metallina*, *Clytemnestra asetosa*, *C. farrani* and *Macrosetella gracilis* were observed only during day, and *Lubbockia squillimana*, *Oncaea ovalis*, *Hemicyclops* sp. and *Tegastes* sp. were observed only during the night at GoAq and NRS (Tables 4 and 5). No significant gradient in the abundance was observed during night sampling.

In general, considering all the samples, the Cyclopoida were represented by 31 species among 11 genera under 6 families, whereas Harpacticoida were represented by 4 species within 3 genera and 3 families (Tables 4 and 5), respectively. Thirty species under 10 genera and 6 families of cyclopoids, and 4 species under 3 genera and 3 families of harpacticoids were represented in GoAq (Table 4), whereas 22 species under 11 genera and 6 families of cyclopoids, and 2 species under 2 genera and 2 families of harpacticoids were represented in NRS (Table 5), respectively.

Five cyclopoid species (*Corycaeus (Onychocorycaeus) agilis* Dana, 1849, *Corycaeus (Onychocorycaeus) catus* F. Dahl, 1894, *Lubbockia aculeata* Giesbrecht, 1891, *Oithona attenuata* Farran, 1913, *Vetoriagranulosa* Giesbrecht, 1891, and a single harpacticoid species (*Clytemnestrafarrani* Huys & Conroy-Dalton, 2000) were newly recorded for the GoAq region. Family Corycaidae was the most dominant, contributing 10 species (7 *Corycaeus* species and 3 *Farranula* species), followed by Oithonidae (6 *Oithona* species); Oncaeidae (5 *Oncaea* species and 1 *Triconia* species) and Sapphirinidae (4 *Sapphirina* sp., 1 *Copilia* sp. and 1 *Vetoria* sp.) each contributing 6 species, respectively.

The interactions between the nycthemeral, and WP2 and Neuston nets were not significant. The one-way analysis of similarity percentages on the overall abundance showed that the average dissimilarity was maximum for zooplankton and zooneuston variability (21.88%) and minimum for nycthemeral variability (19.02%), whereas average similarity was maximum for zooplankton (85.67%) and minimum for day time (80.24%), respectively. While in the multivariate analysis, the results obtained by the single-linkage Bray-Curtis cluster dendrogram was used to construct the non-Metric Dimensional Scaling scatter plot, which showed the zooplankton and zooneuston (Fig. 3a)

Table 3. Mean abundance (mean±SD, ind./m³), relative abundance (RA, %) and total relative abundance (TRA, %) of the nycthemeral zooplankton and zooneuston community during October 2016 from the northern Red Sea

	Zooplankton					Zooneuston				
	Day		Night		TRA/%	Day		Night		TRA/%
	Mean±SD	RA/%	Mean±SD	RA/%		Mean±SD	RA/%	Mean±SD	RA/%	
Radiolaria	6.56±6.09	3.03	12.27±4.17	2.95	2.98	0.13±0.08	0.72	0.42±0.23	0.69	0.66
Medusae	0.47±0.43	0.22	1.51±0.65	0.36	0.31	0.00±0.00	0.00	0.03±0.03	0.05	0.01
Siphonophora	–	–	0.76±0.65	0.18	0.12	0.02±0.02	0.09	0.03±0.03	0.05	0.04
Polychaeta	–	–	0.19±0.33	0.05	0.03	0.01±0.01	0.06	0.00±0.00	0.00	0.01
Insecta	–	–	–	–	–	0.02±0.01	0.09	0.01±0.02	0.02	0.02
Amphipoda	0.28±0.28	0.13	0.38±0.65	0.09	0.10	0.02±0.02	0.09	0.01±0.02	0.02	0.04
Cladocera	0.19±0.33	0.09	0.19±0.33	0.05	0.06	0.20±0.35	1.13	1.30±1.28	2.13	2.16
Euphausiacea	0.57±0.98	0.26	0.94±0.33	0.23	0.24	–	–	–	–	–
Isopoda	0.47±0.59	0.22	1.32±1.82	0.32	0.28	0.02±0.03	0.09	0.12±0.06	0.20	0.11
Ostracoda	6.99±9.75	3.22	14.35±8.35	3.45	3.37	0.10±0.09	0.58	0.15±0.24	0.25	0.16
Mysidacea	0.38±0.65	0.17	2.27±1.96	0.55	0.42	0.06±0.11	0.35	0.11±0.15	0.18	0.12
Bivalvia	2.12±1.53	0.98	7.36±3.96	1.77	1.50	0.51±0.25	2.87	1.75±0.43	2.87	2.49
Gastropoda	22.61±20.47	10.43	60.60±57.42	14.58	13.16	5.16±5.06	29.15	18.57±11.56	30.48	31.41
Pteropoda	3.02±2.62	1.39	11.33±10.07	2.73	2.27	0.31±0.21	1.74	0.58±0.16	0.96	1.09
Chaetognatha	12.46±8.19	5.75	19.45±4.02	4.68	5.05	0.50±0.19	2.81	0.47±0.27	0.77	1.20
Tunicata	2.83±0.98	1.31	2.08±0.87	0.50	0.78	0.19±0.11	1.07	0.75±0.53	1.23	1.21
Cirripede larvae	0.00±0.00	0.00	0.38±0.65	0.09	0.06	–	–	0.00±0.03	0.05	0.01
Pluteus larvae	0.19±0.33	0.09	1.32±0.87	0.32	0.24	0.01±0.01	0.03	0.02±0.04	0.03	0.04
Brachiolaria larvae	0.19±0.33	0.09	0.00±0.00	0.00	0.03	–	–	–	–	–
Polychaete larvae	0.61±0.50	0.28	1.89±1.73	0.45	0.40	0.03±0.04	0.17	0.00±0.00	0.00	0.04
Zoea larvae	0.00±0.00	0.00	1.32±1.82	0.32	0.21	0.35±0.44	1.97	0.59±0.80	0.97	1.24
Mysis larvae	1.60±1.34	0.74	2.08±1.18	0.50	0.58	0.00±0.00	0.00	0.12±0.12	0.20	0.12
Megalopa	0.57±0.98	0.26	1.32±1.82	0.32	0.30	0.01±0.01	0.03	0.00±0.00	0.00	0.01
Squid larvae	0.09±0.16	0.04	0.00±0.00	0.00	0.01	–	–	–	–	–
Fish larvae	0.05±0.08	0.02	1.13±0.00	0.27	0.19	0.02±0.02	0.12	0.00±0.00	0.00	0.03
Copepoda	149.76±47.34	69.07	266.95±100.71	64.24	65.90	9.60±5.58	54.31	31.14±13.51	51.09	50.89
Nauplii	4.81±3.81	2.22	4.15±3.98	1.00	1.42	0.45±0.39	2.55	4.72±6.21	7.75	6.89
Total	216.83±82.86		415.53±158.64			17.68±3.53		60.94±29.48		

and nycthemeral variability (Fig. 3b) at overall 60% similarity for the GoAq and NRS. The overall zooplankton and zooneuston (Figs 4a–d), and Cyclopoid and Harpacticoid copepod (Figs 5a–d) similarity using WP2 and neuston nets were almost grouped together at less than 85% and 90% when analyzed individually for nycthemeral abundance at GoAq and NRS, respectively. The results obtained by complete-linkage Bray-Curtis cluster dendrogram was used to construct the scatter plot diagrams of the principal component analysis (PCA) to show the relatedness of different organism groups of zooplankton and zooneuston abundance (Fig. 6a) and different families of Cyclopoida and Harpacticoida copepods (Fig. 6b) towards GoAq and NRS, respectively.

Ecological indices showed that among the zooplankton and zooneuston, Shannon's diversity was maximum with WP2 net at Sta. 3 and Sta. 4 during night at GoAq. Simpson's dominance was maximum with WP2 net Sta. 1 during day at NRS. Pielou's evenness was high even with Neuston net at Sta. 3 during day. Whereas with Cyclopoida, Shannon's diversity was observed to be maximum with Neuston net at Sta. 4 during night at GoAq. Simpson's dominance was maximum with WP2 net at Sta. 2 during day. Pielou's evenness was high even with WP2 net at Sta. 1 during night at NRS (Table 6).

5 Discussion

In general, zooplankton abundance varies with sampling

depth, and mesh size used at different seasons, stations and other abiotic parameters like speed of the boat towed, clogging, wind speed and direction, water current circulation etc. For example, calanoids dominate in the larger mesh size of about <150 µm (Gordeyeva, 1970; Weikert, 1982; Beckmann, 1984), whereas smaller copepods like *Oncaea* sp. dominate over the whole depth range of the Red Sea, using a smaller mesh size of <100 µm (Böttger, 1987). Temperature plays an important role in the prevailing summer in the GoAq (Goldman and Heron, 1983; Reiss and Hottinger, 1984), wherein the majority of the zooplankton is concentrated within the upper 100 m (Cornils et al., 2005). Temperature increases the growth and feeding rates of zooplankton species within the range of their thermal tolerance (Omori and Ikeda, 1984). When the fluctuations are stronger than other subtropical seas, the zooplankton abundance may be related not only to water temperature but also indirectly on their food sources (Arnemo, 1965). During summer, the water column is stratified and the surface layers are depleted of nutrients. This seasonal pattern of mixing and stratification has indirect influence on zooplankton via controlling the nutrient and light regime for phytoplankton (Reiss and Hottinger, 1984).

The nycthemeral zooplankton and zooneuston composition of GoAq and NRS showed variability in their community composition both in terms of their diversity and abundance (Tables 2 and 3), which correlates with the observations made by Khalil and Abd El-Rahman (1997), Cornils et al. (2007a), Dorgham et al.

Table 4. Mean abundance (mean±SD, ind./m³), relative abundance (RA, %) and total relative abundance (TRA, %) of the nycthemeral Cyclopoida and Harpacticoida community during September 2016 from the Gulf of Aqaba

	Zooplankton					Zooneuston				
	Day		Night		TRA/%	Day		Night		TRA/%
	Mean±SD	RA/%	Mean±SD	RA/%		Mean±SD	RA/%	Mean±SD	RA/%	
<i>Corycaeus (Onychocorycaeus) agilis</i> Dana, 1849*	0.50±0.99	0.15	0.71±0.28	0.11	–	0.04±0.03	0.29	0.05±0.04	0.10	0.15
<i>Corycaeus (Onychocorycaeus) catus</i> F. Dahl, 1894*	0.50±0.36	0.15	1.42±0.73	0.23	0.20	0.01±0.01	0.09	0.00±0.00	0.00	0.02
<i>Corycaeus (Urocorycaeus) furcifer</i> Claus, 1863	0.99±0.49	0.30	2.41±1.42	0.39	0.36	–	–	–	–	–
<i>Corycaeus (Onychocorycaeus) latus</i> Dana, 1849	0.21±0.27	0.06	0.00±0.00	0.00	0.02	–	–	–	–	–
<i>Corycaeus (Ditrichocorycaeus) erythraeus</i> Cleve, 1904	0.07±0.14	0.02	0.57±0.65	0.09	0.07	0.00±0.00	0.00	0.01±0.02	0.02	0.02
<i>Corycaeus (Corycaeus) speciosus</i> Dana, 1849	0.28±0.23	0.09	0.14±0.28	0.02	0.04	0.01±0.02	0.09	0.01±0.02	0.02	0.04
<i>Corycaeus (Corycaeus) crassiusculus</i> Dana, 1849	0.28±0.23	0.09	0.28±0.33	0.05	0.06	–	–	–	–	–
<i>Farranula curta</i> (Farran, 1911)	7.86±5.75	2.36	6.51±1.35	1.05	1.51	0.32±0.29	2.46	0.00±0.00	0.00	0.56
<i>Farranula gibbula</i> (Giesbrecht, 1891)	1.06±1.47	0.32	1.13±2.26	0.18	0.23	0.20±0.18	1.55	0.37±0.54	0.84	1.00
<i>Farranula rostrata</i> (Claus, 1863)	7.08±4.22	2.13	5.10±3.07	0.82	1.28	0.04±0.07	0.29	0.64±0.13	1.44	1.18
<i>Hemicyclops</i> sp.	0.07±0.14	0.02	0.14±0.28	0.02	0.02	0.02±0.03	0.19	0.00±0.00	0.00	0.04
<i>Lubbockia aculeata</i> Giesbrecht, 1891*	1.27±0.67	0.38	0.57±0.46	0.09	0.19	–	–	–	–	–
<i>Lubbockia squillimana</i> Claus, 1863	0.00±0.00	0.00	0.28±0.57	0.05	0.03	–	–	–	–	–
<i>Oithona attenuata</i> Farran, 1913*	3.68±1.89	1.11	10.33±4.61	1.67	1.47	0.00±0.00	0.00	0.03±0.06	0.06	0.05
<i>Oithona brevicornis</i> Giesbrecht, 1891	6.72±8.03	2.02	5.38±4.07	0.87	1.27	0.24±0.13	1.89	0.65±0.59	1.49	1.58
<i>Oithona nana</i> Giesbrecht, 1892	0.99±0.37	0.30	4.25±1.76	0.69	0.55	0.08±0.14	0.65	0.00±0.00	0.00	0.15
<i>Oithona plumifera</i> Baird, 1843	2.12±1.47	0.64	3.26±2.46	0.53	0.57	0.09±0.10	0.70	0.32±0.27	0.73	0.73
<i>Oithona similis</i> Claus, 1866	0.78±0.88	0.23	3.40±1.39	0.55	0.44	0.10±0.13	0.81	0.33±0.19	0.75	0.77
<i>Oithona simplex</i> Farran, 1913	1.77±1.41	0.53	2.97±1.56	0.48	0.50	0.01±0.02	0.12	0.03±0.06	0.06	0.07
<i>Oncaea media</i> Giesbrecht, 1891	5.87±6.10	1.77	6.65±1.42	1.08	1.32	0.21±0.11	1.60	0.82±0.24	1.86	1.80
<i>Oncaea mediterranea</i> (Claus, 1863)	6.09±4.16	1.83	6.79±4.89	1.10	1.36	0.01±0.02	0.09	0.09±0.18	0.21	0.18
<i>Oncaea ovalis</i> Shmeleva, 1966 (F, M)	0.00±0.00	0.00	1.42±0.73	0.23	0.15	–	–	–	–	–
<i>Oncaea scottodicarloi</i> Heron & Bradford-Grieve, 1995	1.91±0.63	0.57	3.96±3.03	0.64	0.62	–	–	–	–	–
<i>Oncaea venusta</i> Philippi, 1843	2.41±2.14	0.72	6.65±5.52	1.08	0.95	0.05±0.04	0.36	0.11±0.05	0.25	0.27
<i>Triconia minuta</i> Giesbrecht, 1892	0.42±0.67	0.13	0.71±0.85	0.11	0.12	–	–	–	–	–
<i>Copilia quadrata</i> Dana, 1849	0.07±0.14	0.02	0.42±0.28	0.07	0.05	–	–	–	–	–
<i>Sapphirina metallina</i> Dana, 1849	0.07±0.14	0.02	0.00±0.00	0.00	0.01	–	–	–	–	–
<i>Sapphirina nigromaculata</i> Claus, 1863	1.63±1.32	0.49	2.83±3.24	0.46	0.47	0.00±0.00	0.00	0.01±0.02	0.02	0.02
<i>Sapphirina opalina</i> Dana, 1849	0.21±0.42	0.06	0.00±0.00	0.00	0.02	–	–	–	–	–
<i>Vetoria granulosa</i> (Giesbrecht, 1891)*	0.07±0.14	0.02	0.00±0.00	0.00	0.01	–	–	–	–	–
<i>Corycaeus</i> copepodid	7.78±4.47	2.34	10.76±4.51	1.74	1.95	0.14±0.23	1.05	0.37±0.32	0.84	0.88
<i>Farranula</i> copepodid	7.43±2.56	2.23	12.46±6.32	2.02	2.09	0.25±0.17	1.96	0.74±0.39	1.67	1.74
<i>Lubbockia</i> copepodid	0.85±1.08	0.26	0.99±0.97	0.16	0.19	0.01±0.01	0.08	0.01±0.02	0.02	0.03
<i>Oithona</i> copepodid	12.24±2.97	3.68	19.53±4.73	3.16	3.34	0.27±0.21	2.10	0.71±0.42	1.61	1.72
<i>Oncaea</i> copepodid	4.18±2.22	1.26	5.66±2.70	0.92	1.03	0.05±0.04	0.37	0.19±0.08	0.44	0.42
<i>Sapphirina</i> copepodid	1.06±0.94	0.32	1.84±2.19	0.30	0.31	0.00±0.00	0.00	0.02±0.02	0.04	0.03
<i>Clytemnestra asetosa</i> Huys & Conroy-Dalton, 2000	0.21±0.27	0.06	0.00±0.00	0.00	0.02	–	–	–	–	–
<i>Clytemnestra farrani</i> Huys & Conroy-Dalton, 2000*	0.07±0.14	0.02	0.00±0.00	0.00	0.01	–	–	–	–	–
<i>Macrosetella gracilis</i> (Dana, 1848)	0.21±0.14	0.06	0.00±0.00	0.00	0.02	–	–	–	–	–
<i>Tegastes</i> sp.	0.00±0.00	0.00	0.14±0.28	0.02	0.01	–	–	–	–	–
<i>Clytemnestra</i> copepodid	0.21±0.42	0.06	0.00±0.00	0.00	0.02	–	–	–	–	–
<i>Macrosetella</i> copepod	–	–	–	–	–	0.00±0.00	0.00	0.01±0.02	0.02	0.02
Calanoida	101.49±50.44	30.51	204.81±88.61	33.15	32.23	4.18±2.85	32.30	8.50±1.48	19.29	22.24
Nauplii	12.10±3.87	3.64	10.19±4.83	1.65	2.35	0.08±0.10	0.65	0.53±0.40	1.21	1.09
Total copepoda	202.83±78.75	60.98	344.66±102.15	55.78	57.60	6.42±3.82	49.67	14.54±3.84	33.02	36.80
Total diversity	332.63±151.53		617.83±201.84			12.93±8.13		44.04±12.85		

Note: * means new records for the gulf.

Table 5. Mean abundance (mean±SD, ind./m³), relative abundance (RA, %) and total relative abundance (TRA, %) of the nycthemeral Cyclopoida and Harpacticoida community during October 2016 from the northern Red Sea

	Zooplankton					Zooneuston				
	Day		Night		TRA/%	Day		Night		TRA/%
	Mean±SD	RA/%	Mean±SD	RA/%		Mean±SD	RA/%	Mean±SD	RA/%	
<i>Corycaeus (Onychocorycaeus) agilis</i> Dana, 1849	0.42±0.42	0.20	0.57±0.57	0.14	0.16	0.06±0.01	0.32	0.14±0.17	0.24	0.25
<i>Corycaeus (Urocorycaeus) furcifer</i> Claus, 1863	0.47±0.82	0.22	1.89±2.36	0.45	0.37	0.01±0.01	0.03	0.01±0.02	0.02	0.02
<i>Corycaeus (Onychocorycaeus) latus</i> Dana, 1849	0.57±0.98	0.26	0.00±0.00	0.00	0.09	0.00±0.00	0.00	0.16±0.26	0.27	0.21
<i>Corycaeus (Ditrichocorycaeus) erythraeus</i> Cleve, 1904	0.52±0.90	0.24	0.00±0.00	0.00	0.08	–	–	–	–	–
<i>Corycaeus (Corycaeus) speciosus</i> Dana, 1849	0.14±0.25	0.07	0.00±0.00	0.00	0.02	0.01±0.01	0.03	0.00±0.00	0.00	0.01
<i>Farranula curta</i> (Farran, 1911)	5.24±3.47	2.42	2.45±2.14	0.59	1.22	0.00±0.00	0.00	0.39±0.40	0.64	0.49
<i>Farranula gibbula</i> (Giesbrecht, 1891)	1.70±0.49	0.78	1.70±2.47	0.41	0.54	0.39±0.29	2.23	0.72±0.66	1.18	1.41
<i>Farranula rostrata</i> (Claus, 1863)	2.17±1.93	1.00	5.66±6.31	1.36	1.24	0.55±0.44	3.13	0.66±1.14	1.08	1.54
<i>Hemicyclops</i> sp.	–	–	–	–	–	0.00±0.00	0.00	0.01±0.02	0.02	0.01
<i>Lubbockia aculeata</i> Giesbrecht, 1891	–	–	–	–	–	0.02±0.03	0.09	0.00±0.00	0.00	0.02
<i>Lubbockia squillimana</i> Claus, 1863	0.28±0.49	0.13	0.76±1.31	0.18	0.16	–	–	–	–	–
<i>Oithona attenuata</i> Farran, 1913	0.00±0.00	0.00	0.19±0.33	0.05	0.03	–	–	–	–	–
<i>Oithona brevicornis</i> Giesbrecht, 1891	5.62±2.26	2.59	5.47±0.87	1.32	1.75	0.08±0.10	0.43	0.15±0.11	0.25	0.29
<i>Oithona nana</i> Giesbrecht, 1892	1.94±2.30	0.89	2.64±3.64	0.64	0.72	0.16±0.14	0.93	0.29±0.26	0.47	0.57
<i>Oithona plumifera</i> Baird, 1843	3.02±2.14	1.39	3.78±3.64	0.91	1.07	0.21±0.17	1.19	0.13±0.12	0.22	0.44
<i>Oithona similis</i> Claus, 1866	0.14±0.25	0.07	0.00±0.00	0.00	0.02	0.00±0.00	0.00	0.35±0.55	0.57	0.44
<i>Epicalymma bulbosa</i> Btger–Schnack, 2009	–	–	–	–	–	0.01±0.01	0.03	0.00±0.00	0.00	0.01
<i>Oncaea media</i> Giesbrecht, 1891	5.19±4.48	2.39	5.47±2.14	1.32	1.69	0.27±0.16	1.53	0.36±0.32	0.59	0.80
<i>Oncaea mediterranea</i> (Claus, 1863)	1.32±1.43	0.61	0.76±0.65	0.18	0.33	0.07±0.07	0.38	0.04±0.07	0.07	0.14
<i>Oncaea scottodicaloi</i> Heron & Bradford–Grieve, 1995	1.04±1.07	0.48	3.02±2.36	0.73	0.64	0.03±0.03	0.17	0.06±0.05	0.10	0.12
<i>Oncaea venusta</i> Philippi, 1843	0.38±0.65	0.17	3.02±2.36	0.73	0.54	0.07±0.05	0.41	0.10±0.11	0.17	0.22
<i>Copilia quadrata</i> Dana, 1849	0.19±0.33	0.09	0.00±0.00	0.00	0.03	0.01±0.01	0.03	0.01±0.02	0.02	0.02
<i>Corycaeus</i> copepodid	5.19±2.84	2.39	5.10±3.15	1.23	1.63	0.41±0.31	2.32	0.80±0.84	1.31	1.54
<i>Farranula</i> copepodid	5.24±4.76	2.42	6.42±6.83	1.54	1.84	0.33±0.31	1.85	0.96±0.60	1.58	1.64
<i>Lubbockia</i> copepodid	0.94±0.91	0.44	2.08±1.82	0.50	0.48	0.03±0.02	0.14	0.00±0.00	0.00	0.03
<i>Oithona</i> copepodid	3.26±5.04	1.50	4.72±3.77	1.14	1.26	0.33±0.22	1.88	0.77±0.19	1.26	1.40
<i>Oncaea</i> copepodid	0.76±0.87	0.35	1.13±1.13	0.27	0.30	0.12±0.17	0.67	0.30±0.23	0.49	0.53
<i>Sapphirina</i> copepodid	0.09±0.16	0.04	0.76±1.31	0.18	0.13	0.01±0.01	0.03	0.00±0.00	0.00	0.01
<i>Clytemnestra farrani</i> Huys & Conroy–Dalton, 2000	0.19±0.33	0.09	0.00±0.00	0.00	0.03	–	–	–	–	–
<i>Macrosetella gracilis</i> (Dana, 1848)	0.09±0.16	0.04	0.76±1.31	0.18	0.13	0.01±0.02	0.06	0.03±0.05	0.05	0.05
<i>Macrosetella</i> copepodid	–	–	–	–	–	0.00±0.00	0.00	0.05±0.05	0.08	0.07
Calanoida	103.65±31.61	47.80	208.61±83.48	50.20	49.38	6.45±3.63	36.45	24.65±10.49	40.44	39.54
Nauplii	4.81±3.81	2.22	4.15±3.98	1.00	1.42	0.45±0.39	2.55	4.72±6.21	7.75	6.58
Total copepoda	154.57±51.14	71.29	271.10±97.47	65.24	67.32	10.05±5.47	56.86	35.86±16.34	58.84	57.78
Total diversity	216.83±82.86		415.53±158.64			17.68±3.53		60.94±29.48		

(2012) who observed that if there is enough time gap between two sampling periods then variability in their community structure can be much pronounced. The GoAq and Red Sea proper have dominant tropical species in the epipelagic zone, but decrease rapidly below 300 m depth (Beckmann, 1984; Cornils et al., 2005). Patterns of zooplankton vertical distribution in the Red Sea is different from most oligotrophic waters of the world, as its biomass and individual numbers decrease with depth to be completely negligible at around 1 100 m (Schmidt, 1973; Weikert, 1982; Böttger, 1987; Böttger–Schnack, 1990; Cornils et al., 2007b).

Although the NRS and GoAq show similar zooplankton community composition, they exhibit a clear difference in their species density. In the winter zooplankton is dominated by copepods (Echelman and Fishelson, 1990; Cornils et al., 2005), show-

ing up to 75% of total zooplankton in the GoAq (Khalil and Abd El-Rahman, 1997). There is a clear difference in density stratification between the GoAq and NRS, which showed an abundance of copepods ranging between 76%–95% (Cornils et al., 2005), which was observed in the present study. The copepod diversity appeared to be higher in near-reef than offshore collections in the GoAq Sea (Echelman and Fishelson, 1990) and their productivity is also higher in reef-bound coastal zone areas of the whole Red Sea compared with that of offshore areas (Levanon–Spanier et al., 1979), which might be another reason for higher zooplankton abundance at GoAq at NRS.

The present study showed that higher abundance was observed during night time in both WP2 and Neuston nets, showing a significant faunal aggregation at the surface due to vertical

Table 6. Ecological indices of nycthemeral zooplankton and zooneuston communities, and copepod orders (Cyclopoida and Harpacticoida) during September and October 2016 at the Gulf of Aqaba

Sample	Total zooplankton and zooneuston					Cyclopoida and Harpacticoida				
	<i>S</i>	<i>N</i> ±SD	<i>D</i>	<i>H'</i>	<i>J'</i>	<i>S</i>	<i>N</i> ±SD	<i>D</i>	<i>H'</i>	<i>J'</i>
GA1ZooDy	18	363.20±43.39	0.474	1.346	0.202	21	147.20±5.36	0.079 6	2.732 0	0.590 6
GA1ZooNt	21	478.99±53.21	0.414	1.505	0.205	19	125.12±4.41	0.076 2	2.819 0	0.698 4
GA2ZooDy	19	212.88±22.89	0.390	1.518	0.228	22	95.68±3.29	0.071 4 [#]	2.932 0 [*]	0.695 3
GA2ZooNt	21	665.23±58.33	0.270 [#]	1.836 [*]	0.285	22	150.04±5.24 [*]	0.075 8	2.882 0	0.637 6
GA3ZooDy	17	534.75±49.96	0.302	1.613	0.279	20	52.09±1.75	0.073 4	2.880 0	0.659 5
GA3ZooNt	22	883.21±87.68 [*]	0.337	1.627	0.221	22	138.71±4.87	0.075 1	2.866 0	0.627 3
GA4ZooDy	19	219.64±21.57	0.330	1.674	0.267	24 [*]	62.00±2.32	0.083 2	2.784 0	0.558 0
GA4ZooNt	22	443.90±43.79	0.333	1.688	0.235	21	104.74±3.72	0.077 0	2.833 0	0.629 8
GA1NeuDy	10	3.08±0.43 [#]	0.650	0.875	0.218	9	1.10±0.06	0.134 4	2.206 0	0.698 7
GA1NeuNt	18	38.76±3.50	0.284	1.599	0.261	10	7.93±0.38	0.122 9	2.254 0	0.680 7
GA2NeuDy	11	9.58±0.97	0.346	1.326	0.314	11	1.59±0.08	0.118 4	2.307 0	0.669 6
GA2NeuNt	15	28.63±2.82	0.333	1.445	0.265	10	6.97±0.32	0.112 3	2.378 0	0.673 8
GA3NeuDy	9 [#]	20.62±2.16	0.372	1.182	0.326 [*]	10	1.73±0.08	0.123 3	2.309 0	0.718 6
GA3NeuNt	16	51.65±5.34	0.362	1.350	0.227	9	4.35±0.20	0.113 4	2.313 0	0.673 7
GA4NeuDy	15	18.45±1.98	0.389	1.456	0.268	12	4.24±0.19	0.106 0	2.385 0	0.724 0
GA4NeuNt	14	57.11±5.33	0.301	1.578	0.323	7 [#]	2.80±0.14	0.126 6 [*]	2.206 0	0.825 0
NR1ZooDy	11	128.85±18.98	0.704 [*]	0.771	0.180 [#]	12	18.55±0.85	0.113 7	2.442 0	0.676 5
NR1ZooNt	17	552.79±60.53	0.403	1.383	0.222	10	49.84±2.06	0.096 1	2.461 0	0.836 9 [*]
NR2ZooDy	15	228.26±25.73	0.425	1.288	0.227	14	35.68±1.49	0.094 5	2.555 0	0.677 4
NR2ZooNt	20	241.86±26.73	0.410	1.510	0.216	11	58.62±2.40	0.098 0	2.479 0	0.795 0
NR3ZooDy	16	293.37±35.45	0.484	1.317	0.220	11	61.17±2.70	0.106 4	2.410 0	0.742 6
NR3ZooNt	16	451.96±57.25	0.529	1.206	0.196	11	89.49±3.55	0.090 2	2.552 0	0.802 4
NR1NeuDy	14	17.02±1.96	0.443	1.247	0.232	8	5.50±0.31	0.121 1	2.282 0	0.816 7
NR1NeuNt	16	82.76±7.96	0.318	1.417	0.243	10	0.92±0.04 [#]	0.157 8	2.016 0 [#]	0.536 5 [#]
NR2NeuDy	18	21.53±2.43	0.426	1.380	0.209	15	4.48±0.21	0.116 2	2.395 0	0.548 4
NR2NeuNt	12	72.68±8.25	0.430	1.138	0.240	12	10.54±0.49	0.114 4	2.390 0	0.641 8
NR3NeuDy	10	14.55±2.14	0.701	0.758 [#]	0.194	10	3.44±0.15	0.113 1	2.355 0	0.702 4
NR3NeuNt	16	27.40±2.95	0.390	1.440	0.248	9	4.07±0.19	0.103 0	2.418 0	0.802 0

Note: *S* represents number of taxa, *N* total number (ind./m³) (sum±SD), *D* Simpson's dominance index, *H'* Shannon diversity index, *J'* evenness index, * maximum, and # minimum.

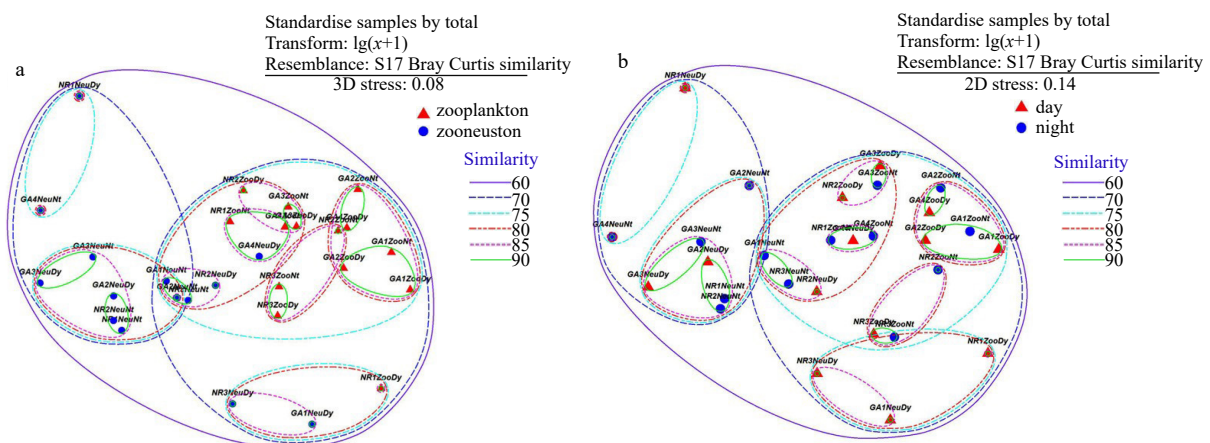


Fig. 3. Non-metric Dimensional Scaling scatter plot showing the similarity (%) among total abundance at sampled stations during September and October 2016 along the Gulf of Aqaba and the northern Red Sea. a. Zooplankton and zooneuston abundance, and b. nycthemeral abundance.

migration of mid-water and deep water organisms at night, leading to increased abundances at night (De Albuquerque Lira et al., 2014). Zooplankton aggregation at the surface in higher abundance during night, as observed in our present study, is a common predation avoidance feature, wherein the organisms des-

cend into darkness in the daytime, and ascend during the night so as to feed in more productive surface layers (Roe, 1974; Forward, 1988; Schlacher and Wooldridge, 1995; De Almeida e Silva et al., 2003; Rawlinson et al., 2005). Copepods are often considered to migrate vertically to feed, whose intensity of diel ver-

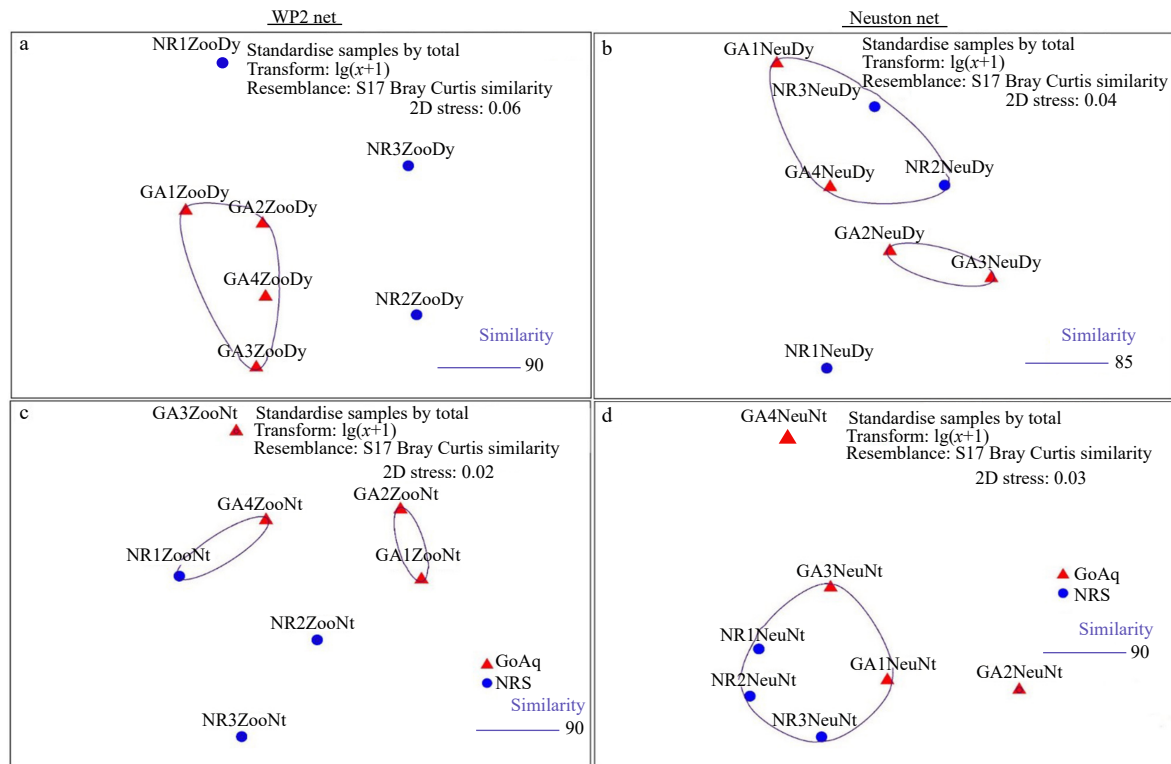


Fig. 4. Non-metric Dimensional Scaling scatter plot showing the similarity (%) of zooplankton and zooneuston at sampled stations during September and October 2016 along the Gulf of Aqaba and the northern Red Sea. a. WP2 net during day, b. Neuston net during day, c. WP2 net during night, and d. Neuston net during night.

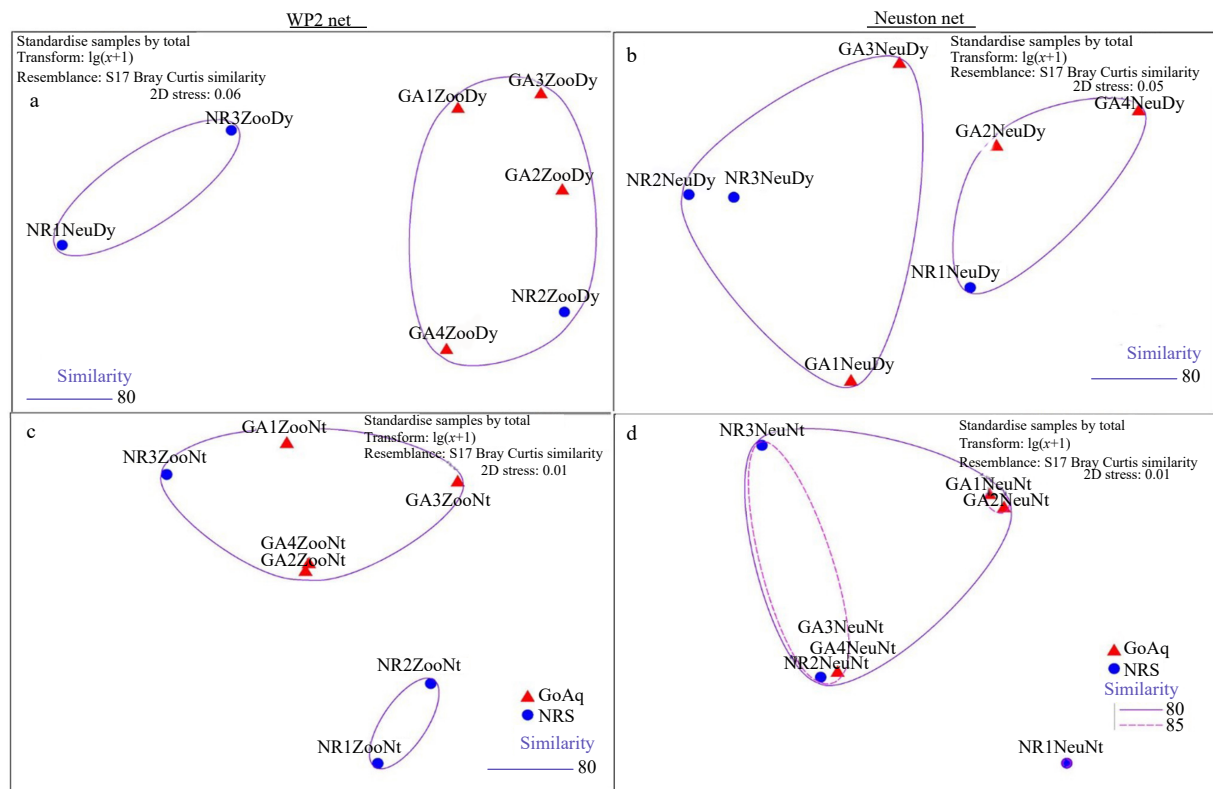


Fig. 5. Non-metric Dimensional Scaling scatter plot showing the similarity (%) among Cyclopoida and Harpacticoida at sampled stations during September and October 2016 along the Gulf of Aqaba and the northern Red Sea. a. WP2 net during day, b. Neuston net during day, c. WP2 net during night, and d. Neuston net during night.

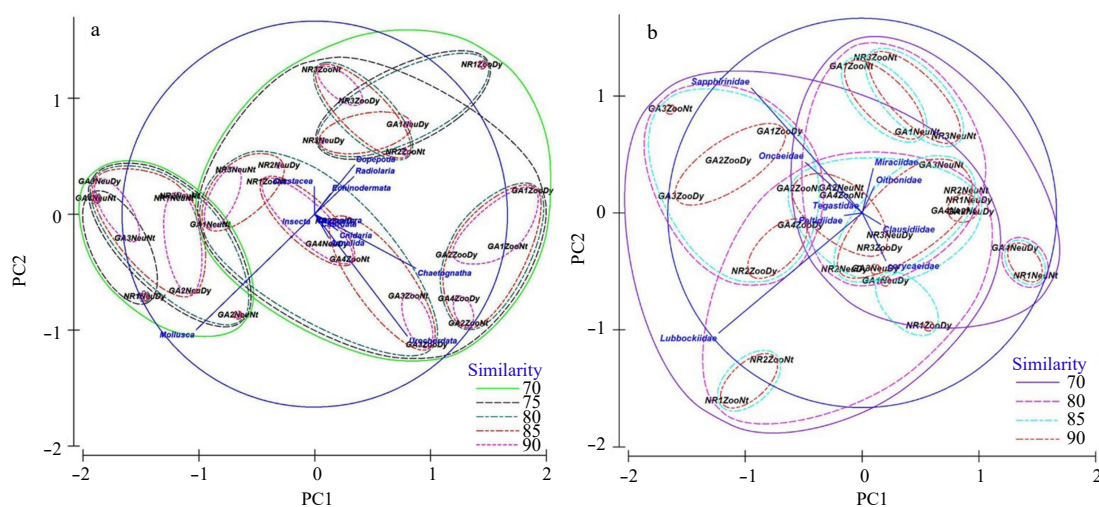


Fig. 6. Scatter plot of Principal Component analysis showing the similarity (%) at sampled stations during September and October 2016 along the Gulf of Aqaba and the northern Red Sea. a. Total zooplankton and zooneuston abundance, and b. Cyclopoida and Harpacticoida abundance.

tical migration changes with food density (e.g., no migration during food scarcity, to maximum migration at intermediate food levels, and reduced migration again at high food densities (Fiksen and Giske, 1995). Northern migration of the epipelagic mesozooplankton species around Sharm El-Sheikh area, NRS from the southern Red Sea implies marked seasonal variations in their vertical distribution (El-Sherbiny et al., 2007; Dorgham et al., 2012). Diel vertical migration of oncaeids indicate considerable differences between the Red Sea basin and Gulf communities, which can be related to deviating hydrographic conditions (Böttger-Schnack et al., 2001).

Most Red Sea copepods are found in the upper 100 m layer (e.g., Weikert, 1982; Al-Najjar, 2002, 2005; Amer et al., 2006; Cornils et al., 2007a, b; El-Sherbiny et al., 2007; Dorgham et al., 2012). In the northern Red Sea, only a small number of mesopelagic species dominate, whereas in the Gulf of Aqaba region, the epipelagic species predominate, because of the high salinities and the high temperature in the deep waters at the entrance of the Red Sea and the GoAq (Weikert, 1982). The numerical abundance of the copepodids of both calanoids and cyclopoids were observed to be equal in the epipelagic zone, with an increase in cyclopoids with depth, showing *Oithona* and *Paroithona* to be predominant in the epipelagic zone and *Oncaea* in the mesopelagic zone (Böttger, 1987); which persist down till 1050 m and thereafter harpacticoid copepods outnumber cyclopoids. The microcopepods, mainly the Oncaeidae family, increase with depth showing the numerical importance of the smaller genus *Oncaea* (Böttger, 1987). However, in a study by Böttger (1987) genera like, *Oithona* and *Oncaea* were abundant at all sampled depths, and genera like *Corycaeus*, *Copilia* and *Sapphirina* were abundant in the epipelagic zone. The seasonal abundance of epipelagic mesozooplankton in the GoAq shows that copepods dominate the zooplankton community with a mean of 79%, where cyclopoids contribute about 37% (Cornils et al., 2007b) during summer. In the Sharm El Sheikh area, adult copepods dominate with 22.3% of the total zooplankton, comprising mainly *Oithona nana*, *Corycaeus gibbulus* and *Corycaeus* sp., during summer (El-Sherbiny et al., 2007), wherein the present study shows a relative percentage composition of copepod to be 55%–78% in the WP2 net and 33%–58% in the Neuston net, re-

spectively.

Using WP2 net, the present study recorded a mean copepod abundance of 811 and 1 378 ind./m³ during day and night at GoAq, whereas 463 and 813 ind./m³ were present during day and night at NRS using WP2 net. Others who reordered for copepods in the GoAq range inbetween 1 945 ind./m³ (Khalil and Abd Rahman, 1997), 94–431×10³ ind./m³ (Cornils et al., 2005), 1 326–9 824 ind./m³ (Amer et al., 2006), 1 206 ind./m³ (Cornils et al., 2007), 1 510–2 712 ind./m³ (El-Sherbiny et al., 2007), 1 124–4 952 ind./m³ (Dorgham et al., 2012), 251–1 940 ind./m³ (El-Serehy et al., 2013), respectively. This decrease might be due to their small sized plankton net and also might be due to the difference in the vertical sampling plasticity (Böttger-Schnack et al., 2001), mainly due to the prevailing environmental differences. However, the total numerical abundance is higher compared to Echelman and Fielshon (1990) who recorded 155–317 ind./m³ which might be due to their sampling using larger mesh sized nets. Thirty species of cyclopoids are recorded in the present (Tables 4 and 5), whereas previous studied showed lesser diversity, i.e., Echelsen and Fielshon (1990) recorded 5 species, Khalil and Abd El-Rahman (1997) recorded 9 species, Al-Najjar (2002) recorded 17 species, Amer et al. (2006) recorded 9 species, and El-Serehy et al. (2013) recorded 14 species. This increase in diversity might be due to the day and night sampling and also near-reef intrusions of plankton within the sampled stations.

In general, Copepoda shows significant diurnal migration (Schmidt, 1973; Almeida Prado-Por, 1990; El-Serehy et al., 2013). The concentration gradient within the epipelagic zone for the smaller cyclopoids is less pronounced and their vertical distribution revealed their dominance in the deeper layers (Böttger, 1987). Higher species diversity of cyclopoids were observed in the lower epipelagic zone, i.e., 40–100 m, which is below the strong seasonal thermocline, whereas lower species diversity was observed in the upper part of the upper mesopelagic zone (100–250 m) characterized by a strong dissolved oxygen gradient, showing distinct distributional patterns among sexes and developmental stages (Böttger-Schnack et al., 1990).

The results of the present study coincides with that of Pearman and Irigoien (2015), who observed that *Corycaeus* genera is dominant in the epipelagic layer using next generation sequen-

cing technologies. The lesser abundance of cyclopoids (particularly family Oncaeidae) might be due to the use of larger mesh size plankton net for sampling (Böttger, 1985; Cowles et al., 1987), wherein the smaller copepods would have passed the net without getting caught. Moreover, according to Böttger-Schnack (2002) family Oncaeidae does not follow the general northward trend of reduced species diversity in the Red Sea and this has to be revised which might appear similar to other non-calanoid copepod families (Halim, 1969; Böttger-Schnack, 1995). Compared to larger calanoid copepods, the regional decrease in oncaeid species numbers appears to be somewhat lower, as such only about half of calanoid species found in the southern Red Sea extend to the northern parts and the Gulf of Aqaba (Almeida Prado-Por, 1983; Weikert, 1987). Therefore, it may still be assumed that oncaeid species are less sensitive to the strong horizontal gradients in the Red Sea, in particular the increasing salinity, than larger taxa, which may be related to their different mode of life in the GoAq than the NRS (Böttger-Schnack, 2002).

Though, Echelman and Fishelson (1990) observed some non-dominant groups (e.g., pteropods, ostracods) abundantly in the neuston net from the Gulf of Aqaba, our findings showed contradictory results with its higher abundance in WP2 net and at night time using both the nets, which might be due to several reasons like the density of other organisms, size of mesh used, and the depth at which the neuston net was towed. Moreover, the abundance was higher in GoAq rather than NRS, which might be due to the sampling effect, i.e., sampled stations at GoAq were coastal and somewhat nearer to the coral reef areas rather than the sampled stations at NRS, which is oceanic. According to Hempel and Weikert (1972) the surface water column serves as a refuge for less diverse well-adapted organisms during day time, while considerable immigration or vertical migration occurs during dusk and at night time. The zooneuston is not clearly separated from the rest of the water column or from the zooplankton community, such that during certain conditions, e.g., during dim light, at night, and in turbid waters, the community loses its major characteristic feature and becomes less distinct or even almost identical to the zooplankton community of the adjacent strata. Whereas in other ecosystem like boreal waters, the ecological difference between the uppermost layer and deeper strata is less pronounced than in lower latitudes which develops more evolutionary pressure to become a typical euneustonic fauna.

The abundance of copepods in both WP2 and neuston nets from the present study is augmented by Pearman and Irigoien (2015), who showed that copepods were dominant in both WP2 and neuston nets in the central Red Sea using next generation sequencing. The interactions between the two factors (day/night and the two different nets) were not significant, showing a constant accumulation at the air-water interface, which was independent of nycthemeral variability.

6 Conclusions

In conclusion, the zooplankton and zooneuston communities represent complex aggregations of organisms at both the air-water interface and the water column, showing higher abundance at night time, which might be probably due to vertical migration from deeper water layers. Since our study is a preliminary step to compare the different nets types between zooplankton and zooneuston, with respect to nycthemeral variation, further studies are necessary to understand the distribution of species specific taxonomic groups, and to verify whether there is a retention and/or larval contribution originating from benthic parental populations in the GoAq and deep water vertical migration in the NRS.

tion in the NRS.

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