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Seasonal Distribution of Epipelagic Copepods at the Different Habitats in the North-Western Red Sea, Egypt.

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ABSTRACT

The present study was conducted at the Egyptian North-Western part of the Red Sea through 2 cruises during winter and summer, 2017. Samples were collected at 12 stations represented four different habitats. This study aims to investigate the community structure, diversity and abundance of copepods in different habitats in relation to some environmental parameters. Salinity increased in shallow sheltered lagoon habitats causing especial environment during summer. A total of 67 species belonging to 35 genera and 23 families of four copepod groups in addition to immature stages were identified. Major differences were detected in copepod community structure and species diversity between both seasons and different habitats. The greatest number of species (55) was found in the open deep water habitat, while the lowest (24 species) was recorded in the seagrass one. Among the copepod groups, calanoids were the most abundant and inhabited all habitats, forming an average of 49.2% of the total adult copepods. Likewise, calanoid copepods were the most diverse group represented by 38 species. Regional means of copepod densities were high in the coral reef habitats (856 ind.m^{-3}). In contrast, the abundance of copepods was low in the seagrass habitats (572 ind. m^{-3}). Finally, the noticed variation in the copepod composition among different habitats reflects the impact of the ecosystem components on the structioning of the community composition.

INTRODUCTION

The Red Sea is characterized by the presence of more than one ecosystem within its coastal areas. These ecosystems include coral reefs, seagrasses, mangrove, in addition to sandy and rocky beaches (El-Sharouny *et al.*, 2001; Böttger-Schnack, *et al.*, 2008). Among all these different types of ecosystems and habitats, a considerable number of species were found to be associated to both a single and/or multiple habitats.

Copepods are the major component of zooplankton abundance in the Red Sea (Abdel-Rahman, 1997; El-Sherbiny *et al.*, 2007), that have adapted to live in all habitats, including seagrass, coral reefs, shallow sheltered lagoons, the deep open sea and others. However, there are some differences in the species composition of copepods among the various habitats of the Red Sea.

The majority of Copepod studies in the northern part of the Red Sea have concentrated on its northern extent, especially the Gulf of Aqaba (e.g. Echelman and Fishelson, 1990; Prado-Por 1990; Aoki *et al.*, 1990; Böttger-Schnack *et al.*, 2001; Al-Najjar *et al.*, 2002; Al-

Najjar, 2004; Cornils *et al.*, 2005; El-Sherbiny *et al.*, 2007; Böttger-Schnack *et al.*, 2008, Schnack-Schiel *et al.*, 2008; Dorgham *et al.*, 2012a). There are also reports on the surface zooplankton from the whole of the Gulf (Khalil and Abdel-Rahman, 1997), in addition to that in the water column at different depths (e.g. Kimor and Golandsky, 1977, Al-Najjar and Rasheed, 2005; Al-Najjar and El-Sherbiny, 2008). Few studies were done in Sharm El-Sheikh coastal area, particularly in the mangal ecosystem (Hanafy *et al.*, 1998), in Sharm El Maiya Bay (Aamer *et al.*, 2007) and in the epipelagic zone (El-Sherbiny *et al.*, 2007). These studies were concerned with the species composition and abundance of zooplankton in relation to the environmental conditions.

Little is known about the diversity and community structure of copepods in the surrounding water of the different Red Sea habitats. Hence, this study aims to investigate the community structure of copepods in the different aquatic habitats, and which of these habitats are the preferable for these organisms and why? In addition, what are the most important environmental parameters that affect the population structure of the dominant species of copepods in Hurghada, North-western part of the Red Sea.

MATERIALS AND METHODS

Study area and sampling

Hurghada is located in the North-western part of the Red Sea at 33° 43′ 40.30″ and 33° 51′ 30.02″ E and 27° 05′ 11.83″ to 27° 18′ 28.92″ N. Twelve stations grouped geographically into 4 different habitats: Stations S1, S2, and S3 with depth 5-6.5 m represent the seagrass habitat; stations C1, C2, and C3 with depth 9-13 m represent the coral reef habitat; while stations L1, L2, and L3 depth were 2-5 m and represent shallow sheltered lagoons, meanwhile stations O1, O2, and O3 recorded depths range 29-65 m and selected to represent the deep open-water habitat (Figure 1). The sampling was done in winter (February) and summer (August) of 2017 between 06:18 and 09:39 (local time), during daylight hours.

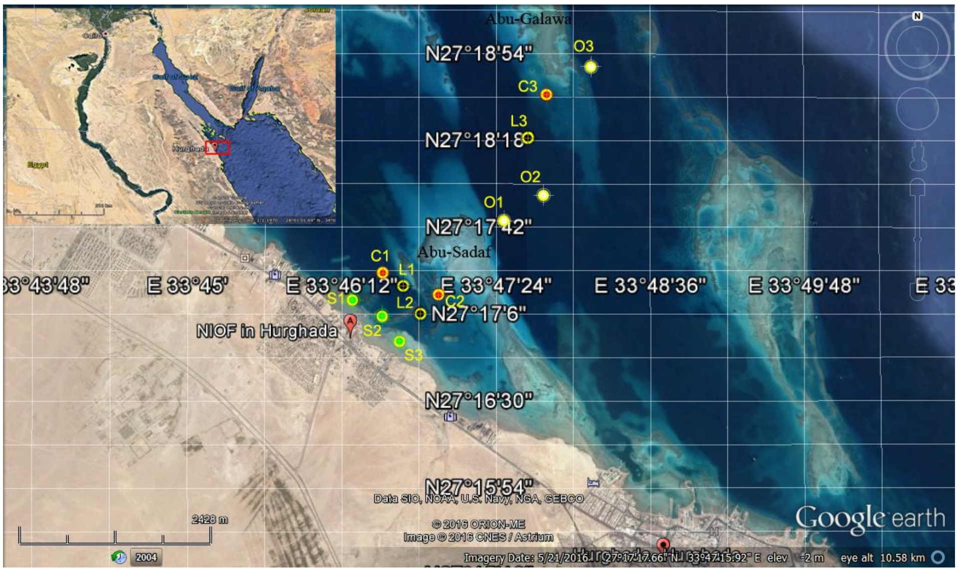


Fig. 1: A map of Egypt showing the location of sampling stations at the Red Sea, in front of Hurghada.

Water temperature was measured with an ordinary mercury thermometer graduated to 0.1°C attached to the water sampler and the pH values with a pocket pH meter (model 201/digital pH meter). Salinity was determined using an optical refractrometer. Dissolved oxygen was determined according to Winkler’s method (APHA, 1985).

For copepod analysis, samples were collected in the epipelagic zone using standard plankton net (No. 25) of 55 µm mesh size and 50 cm mouth diameter. A digital flow meter attached to the mouth of the net to measure the volume of filtered water. After each haul, the net was rinsed thoroughly by dipping in seawater, and the rinsing waters were added to the sample to prevent the loss of any part of the sample. The samples were preserved in 4% neutralized formalin, and then the sample volume was adjusted to 100 ml. Each sample, in a Petri dish, was examined under a stereomicroscope, and non-copepod groups were removed. Triplicate-integrated copepod samples were estimated numerically by counting 5 ml from each concentrated sample in a counting tray under a binocular research microscope. The average of the counted aliquots was calculated and used to estimate the copepod abundance, which was expressed as individual. m^{-3} (ind.m^{-3}).

The copepod samples were identified to genera, and in most cases to species according to Giesbrecht (1892); Sars (1911 and 1918); Rose (1933); Tregouboff and Rose (1957); Newell (1963); Mori (1964); Gonzalez and Bowman (1965); Williamson (1967); Bradford-Grieve and Jillett (1980); Heron and Bradford-Grieve (1995), Bradford-Grieve (1999); Bradford-Grieve *et al.* (1999); Cushing (2000); Conway *et al.* (2003); Boxshall and Hasley (2004).

Statistical analysis

Two indices were used to estimate the community structure: diversity (H`) (Shannon and Wiener, 1963) and evenness or equitability (J) (Pielou, 1975). The Spearman rank correlation (r) was used to evaluate the relations between environmental variables and copepod abundances (N=20) with the SPSS 8.0 Statistical Package Program.

PcOrd statistical software package 5.0 was used to produce the distribution of the studied stations based on the zooplankton species composition in each one versus the environmental condition using Canonical Correspondence Analysis (CCA) methods.

RESULTS

Environmental data

The mean values ±SD and ranges of temperature, pH, salinity and dissolved oxygen of each of the 4 habitats are provided in Table 1. Surface water temperature showed 8.5 °C variations between the minimum in winter (28.0°C) and the maximum in summer (36.5°C). Salinities were higher in the shallow sheltered lagoon than the other habitats during summer (44 **PSU**), and exhibited a wide variation during the sampling period. Salinity in shallow lagoons was the lower during winter when rain was more frequent and abundant; therefore it recorded their minimum value (35.2 **PSU**) among all the habitats.

Table 1: Range, mean values and standard deviation of abiotic variables in four habitats from Hurghada waters. n = number of samples.

Habitat	**n**	**Depth**	**Salinity**	**Temperature**	**pH**	**Dis. Oxygen**
		(m)	**(PSU)**	**(°C)**		**mg/L**
Seagrass	6	5.0 - 6.5	41.0 - 42.0	29.0- 32.5	7.0 - 7.7	6.0 - 7.7
		5.8 ± 0.76	41.36 ± 0.38	30.33 ± 1.38	7.4 ± 0.24	6.9 ± 0.8
Coral reef	6	9.0 - 13.0	41.11- 41.88	28.4 - 31.0	8.0 - 8.4	6.2 - 7.5
		11.3 ± 2.08	41.56 ± 0.30	29.42 ± 1.05	8.18 ± 0.15	6.8 ± 0.5
Sheltered lagoon	6	2.0 - 5.0	35.2 - 44.0	28.0 - 36.5	7.9 - 9.0	5.5 - 7.2
		3.3 ± 1.55	40.53 ± 3.15	31.24 ± 3.63	8.28 ± 0.41	6.5 ± 0.7
Deep open-water	6	29.0 - 61.0	40.22 - 41.23	28.0 - 30.2	7.8 - 8.2	6.3 - 8.1
		38.7 ± 15.04	40.83 ± 0.44	29.27 ± 0.91	8.0 ± 0.14	7.2 ± 0.8

The average pH values were 7.4 ± 0.24 in the seagrass habitat, while the coral reef habitat recorded pH values ranged between 8.0 - 8.4 with an average of 8.18 ± 0.15. The shallow sheltered lagoon habitat showed variation from slight (7.9) to high alkaline pH (9.0). The dissolved oxygen concentration fluctuated from the minimum of 6.5 ± 0.7 mg l^{-1} in the shallow sheltered lagoon habitat to the maximum of 7.2 ± 0.8 mg l^{-1} in the open deep water habitat (Table 1).

Copepod abundance and community structure

The number of families, genera and species of the copepods occurring in each sampling habitat (Table 2) demonstrated more pronounced variations at both the temporal and spatial scale. A total of 69 species of Copepoda including nauplius larvae and Copepodite stages were identified during winter and summer 2017 at the four habitats of Hurghada, belonging to 30 genera, 23 families and 4 orders; namely: Calanoida, Poecilostomatoida, Cyclopoida, and Harpacticoida. The adult copepods constituted only 25.00% of the total counts. Calanoida was more abundant than the other orders.

Table 2: Number of families, genera and species of copepods occurring in each sampling habitat

Habitat / Order	Seagrass			Coral reefs			Shallow sheltered lagoon			Deep open-water		
	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species
Calanoida	8	8	13	12	14	31	10	14	28	12	16	35
Cyclopoida	1	1	2	2	2	6	1	1	3	2	2	6
Harpacticoida	4	4	5	5	5	7	4	3	5	4	4	6
Poecilostomatoida	2	2	4	3	7	9	2	4	8	3	6	8
Total	15	15	24	22	28	53	17	22	44	21	28	55

Qualitatively, Calanoida made up the highest number (13 families, 18 genera, 38 species); it dominated by the family Acartiidae with six species. The families: Candaciidae, Centropagidae, Pontellidae and Temoridae were represented by 4 species for each. There were three recorded families of Poecilostomatoida included 8 genera, and 15 species The most diversified family was Corycaeidae, which was represented by eight species, followed by Sapphirinidae and Oncaeidae (4 and 3 species, respectively). Cyclopoids and harpacticoids were represented by 7 species for each. Generally, the most diverse genera were *Acartia* and *Oithona* (6 species for each).

Quantitatively, Calanoida was also the dominant, where it constituted 49.2 % of the total copepod adults; *Acartia* was the dominant calanoid genus. On the other hand Cyclopoids, that was the second in the dominance, formed 26.21% of the total copepod orders. Only two cyclopoid families were identified, Oithonidae was the most diversified and involved six species while the family Cyclopoida incertae-sedis represented by one species. The order Pocilostomatoida ranked the third and constituted 15.80% with 15 recorded species. Regard to harpacticoids (8.77%), there were five recorded families, included Canthocamptidae and Ectinosomatidae which represented by two species for each, and the other three families (Miraciidae, Peltidiidae, and Tachidiidae) were represented only by one species.

The highest numbers of copepod species (55) were recorded from the deep open-water followed by coral reef habitat (53 species) and shallow sheltered lagoon (44 species), on the other hand there were only 24 species recorded from the seagrass habitat (Table 3).

Table 3: Number of species and their percentage frequency of copepod groups in four habitats of Hurghada waters (A: Winter; B: Summer; AB: Winter and Summer).

A

Habitat **Order**	**Seagrass**	**%**	**Coral reefs**	**%**	**Sheltered lagoon**	**%**	**Deep open-water**	**%**
Calanoida	7	50.00	28	65.12	9	52.94	34	68.00
Cyclopoida	2	14.29	5	11.63	3	17.65	6	12.00
Harpacticoida	3	21.43	4	9.30	2	11.76	4	8.00
Poecilostomatoida	2	14.29	6	13.95	3	17.65	6	12.00
Total	14	100.00	43	100.00	17	100.00	50	100.00

B

Habitat **Order**	**Seagrass**	**%**	**Coral reefs**	**%**	**Sheltered lagoon**	**%**	**Deep open-water**	%
Calanoida	9	60.00	17	54.84	23	69.70	18	69.23
Cyclopoida	1	6.67	4	12.90	1	3.03	1	3.85
Harpacticoida	3	20.00	5	16.13	5	15.15	3	11.54
Poecilostomatoida	2	13.33	5	16.13	4	12.12	4	15.38
Total	15	100.00	31	100.00	33	100.00	26	100.00

AB

Habitat **Order**	**Seagrass**	**%**	**Coral reefs**	**%**	**Sheltered lagoon**	**%**	**Deep open-water**	**%**
Calanoida	13	54.17	31	58.49	28	63.64	35	63.64
Cyclopoida	2	8.33	6	11.32	3	6.82	6	10.91
Harpacticoida	5	20.83	7	13.21	5	11.36	6	10.91
Poecilostomatoida	4	16.67	9	16.98	8	18.18	8	14.55
Total	24	100.00	53	100.00	44	100.00	55	100.00

Copepod larval stages (Nauplii and copepodites) play an important role in the copepods abundance. Nauplii formed a mean of 74.58% of the total copepods with its highest density of 230.0±166.9 organisms. m^{-3} at the deep open-water during winter and 1153±168 organisms. m^{-3} at the coral reef habitats during summer. While the copepodite stages contributed collectively about 1.44% of total copepods, their maximum abundance (13±0.38 $ind.m^{-3}$) was recorded at the seagrass habitat during winter and 17.0±5.7 ind. m^{-3} at the coral reef habitats during summer (Table 4).

The spatial copepod abundance varied from season to another; during winter it ranged between 156 $ind.m^{-3}$ at the seagrass habitat to maximum of 413 $ind.m^{-3}$ at the deep open-water habitat with a seasonal mean of 326 ± 155 $ind.m^{-3}$. Meanwhile during summer the abundance fluctuated between 979 $ind.m^{-3}$ at the deep open-water habitat to 1364 $ind.m^{-3}$ at the Coral reefs. Copepod larval stages (Nauplius larvae and copepodite stages) represented high percentage; fluctuated between 46.4% (in coral reef habitat) and 63.0% (in shallow sheltered lagoon) with an average of 55.0% of the total copepods (Table 4).

Only two species were wide spread, and recorded during the two studied seasons in all the studied habitats; the calanoid *Nannocalanus minor* (Claus, 1863) and the cyclopoid *Oithona nana* Giesbrecht, 1893.

Some species were restricted to specific habitat like *Pseudodiaptomus hessei* (Mrázek, 1894) and *Oithona robusta* Giesbrecht, 1891, which were restricted to the coral reef during summer; and *Sapphirina gemma ovantolanceolata* Dana, 1852 in the coral reef habitat during winter. *Candacia simplex* (Giesbrecht, 1889) and *Farranula gibbula* (Giesbrecht, 1891) were only found at the deep open-water habitat in winter. *Farranula concinna* (Dana, 1849) and *Farranula curta* (Farran, 1911) appeared during winter; where the first species was restricted to the shallow sheltered lagoon habitat, while the second was seagrass habitat inhabitant.

Table 4: Range, mean values (Individual.m^{-3}), standard deviation of copepod order in the studied habitats and their percentage to the total adult densities.

	A: Winter				**B: Summer**			
Habitat **Order**	**Seagrass**	**Coral reefs**	**Sheltered lagoon**	**Deep open-water**	**Seagrass**	**Coral reefs**	**Sheltered lagoon**	**Deep open-water**
Calanoida **%**	28-29.0 29±0.34 8.8	53.0-70.0 61.5±12.0 18.7	62.0-177.5 104.5±63.5 31.7	115.5-176.0 134.6±28.0 40.8	64-88 76±16.97 17.7	64-160 112±67.9 26.0	75-139 99.7±34.4 23.2	73-199 142.7±60.0 33.2
Cyclopoida **%**	5.0-6.0 5±0.1 7.8	12.0-25.0 18.5±9.2 28.8	12.0-29.0 18.0±9.5 28.0	4.0-60.0 22.8±25.2 35.5	35-49 42±9.90 12.5	25-68 46.5±30.4 13.8	30-170 95.0±70.5 28.2	93-284 153.8±87.7 45.6
Harpacticoida **%**	15-17 16±0.35 38.1	5.0-8.0 6.5±2.1 15.5	0.0-34.0 14.0±17.8 33.3	1.0-9.0 5.5±3.7 13.1	22-29 25.5±4.95 26.5	17-48 32.5±21.9 33.2	10.0-35.0 26.7±14.4 27.2	1.0-25.0 12.8±12.0 13.1
Poecilostomatoida **%**	25-26 25±0.24 32.7	5.0-14.0 9.5±6.4 12.4	12.0-58.0 27.7±26.3 36.2	8.0-17.0 14.3±4.2 18.7	60-84 72±16.97 45.1	3.0-4.0 3.5±0.7 2.2	13.0-77.0 43.3±32.1 27.1	4.0-85.0 40.8±33.4 25.6
Nauplius larvae	65-68 67±0.76	64.0123.0 93.5±41.7	72.0-263.0 173.0±96.1	97.0-470.0 230.0±166.9	699-827 763±90.51	1034-1271 1153±168	589-1153 873±282	360-1144 620±356
Copepodite stages	11.014.0 13±0.38	8.0-17.0 12.5±6.4	1.0-21.0 11.7±10.1	4.0-8.0 5.0±2.0	6.0-10.0 8±2.83	13.0-21.0 17.0±5.7	0.0-13.0 7.0±6.6	0.0-21.0 9.5±9.4
Total	**153-159** **156±4.12**	**147-257** **202±77.8**	**187-481.5** **349.5±149.6**	**254-628.5** **412.9±157.2**	**886-1087** **987±142.13**	**1283-1445** **1364±114.6**	**809-1523** **1145±359**	**690-1687** **979±476**

Copepods diversity

The diversity (H`) and Pielou evenness (J) indices were high in winter and low in summer; the high values were indicating a reduction in the degree of the dominance during winter. Diversity indices varied from 0.867 to 2.723, with an average of 1.574. Species evenness (J) varied between 0.292 and 0.799, with an average of 0.531; the high values were usually occurred in the coral reefs habitat.

Changes in the species diversity index (H`) showed similar patterns to the number of species. During summer, diversity was low in the coral reef habitat (0.867), and was high in the deep open-water (1.358); the H` values increased during winter and fluctuated between 2.293 in the coral reef habitat and 1.671 in the shallow sheltered lagoon one.

The correlation between copepod abundance and diversity was strongly negative (r= -0.784, $p < 0.001$), and it is apparent that the low diversity means a stress increasing with poor water quality, whereas the high values refer to favourable conditions. Testing the diversity-equitability and diversity-species number relationship showed that, the diversity exhibited no significant relation with the species number (r=0.303, p=0.194) and was considerably influenced by equitability (r=0.945, p<0.001).

Seasonal variation of Copepoda

Copepod abundances were generally low at the different habitats during winter. With the respect to mean values, the copepod abundance was about four times higher in summer than that of winter (1084.6 and 286.9 ind.m^{-3}, respectively) and the total density showed also large amplitude between the different habitats, as it ranged between 156 ind.m^{-3} recorded in winter at the seagrass habitat and 1417 ind.m^{-3} in summer at the coral reef one. On the other hand, eighteen species were flourished only in winter and not recorded during summer at all, while six species were only found in summer. The highest densities were recorded in the deep open-water habitat during winter (412.9 ind.m^{-3}) and in the coral reef habitat during summer (1417.0 ind.m^{-3}).

The highest copepod richness during winter was noticed in the deep open-water habitat (50 species) followed by the coral reef habitat, which exhibited 43 species, while a notable smaller numbers (14 and 17 species) were found at the seagrass and the shallow sheltered lagoon habitats, respectively. On the other hand, summer showed low diversity, in which the shallow sheltered lagoon and the coral reef habitats hold 33 and 31 species, decreased to 26 species in the deep open-water habitat, while seagrass habitat registered the lowest noticed diversity (15 species).

The contribution of Calanoida, Cyclopoida, Harpacticoida and Poecilostomatoida to total abundance of the adult copepods during winter was 18.59-33.93%, 3.21-7.23%, 1.33-10.26% and 3.45-16.03%, respectively. However, the order of the relative contribution by the four groups differed during summer, which was 7.70-14.57%, 4.26-15.71%, 1.3-2.63% and 1.98-7.29%, respectively. Throughout the study period, Calanoida (13.89%) and Cyclopoida (7.4%) were the dominant groups.

Copepod abundance was low during winter (average: 286.9 ± 105.0 ind.m^{-3}). The contribution of calanoid copepods to the total copepod has been represented by 19.95% and to 64.39% of the total adult copepods. Larval stages represented by 38.02% of the total counts (Figure 2). Moreover, there were no clear dominant species during winter, except *Oncaea scottodicarloi* Heron & Bradford-Grieve, 1995 at the seagrass, *Calocalanus pavo* (Dana, 1852) at the coral reefs, *Labidocera pavo* Giesbrecht, 1889 in the shallow sheltered lagoon, and *Oithona nana* Giesbrecht, 1888 at the deep open-water habitat.

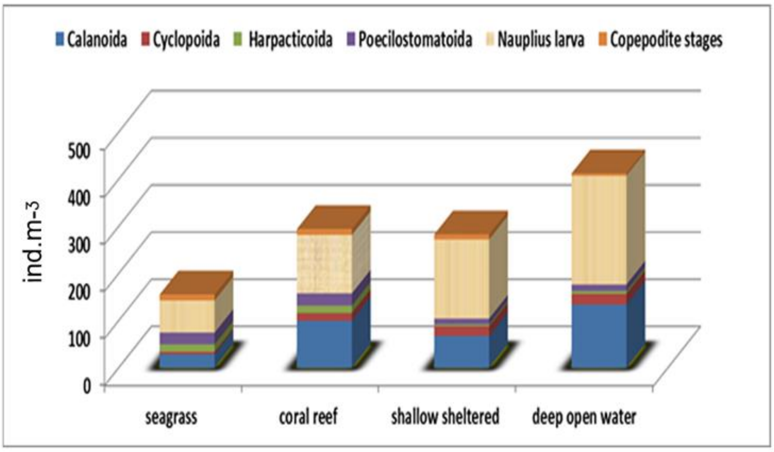


Fig. 2: Spatial variations of copepods (ind.m^{-3}) and their orders in the different habitats during winter

In summer, the copepod density registered an average of 1342.9 ± 222.0 ind.m^{-3}. Cyclopoida was the most dominant order in the deep open-water habitat, representing 15.71% of the total copepods (Figure 3), in which *Oithona nana* made up 43.94% of the total adult copepods; its abundance was 143.8 ind.m^{-3}. While calanoid copepods were the dominant order in the other three habitats (7.03-11.72%). Larval stages represented by 64.25-82.45% of the total counts. The dominant adult species was *Oncaea bispinosa* Böttger-Schnack, 2001 at the seagrass habitat and *Oithona nana* was the dominant species in the remaining habitats (26.32-43.94% of the total adult copepods).

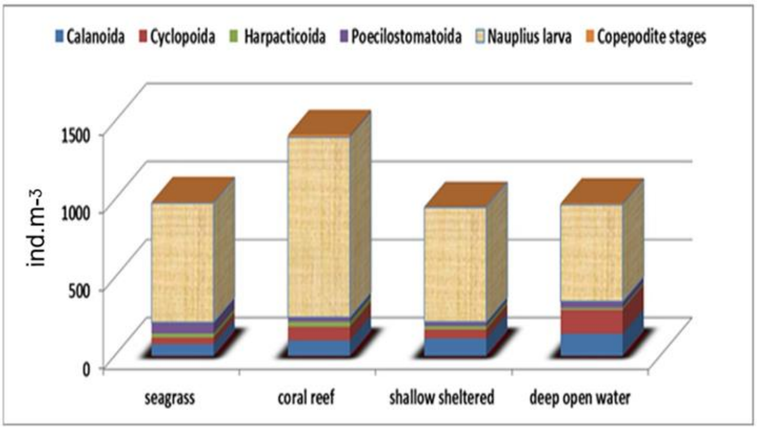
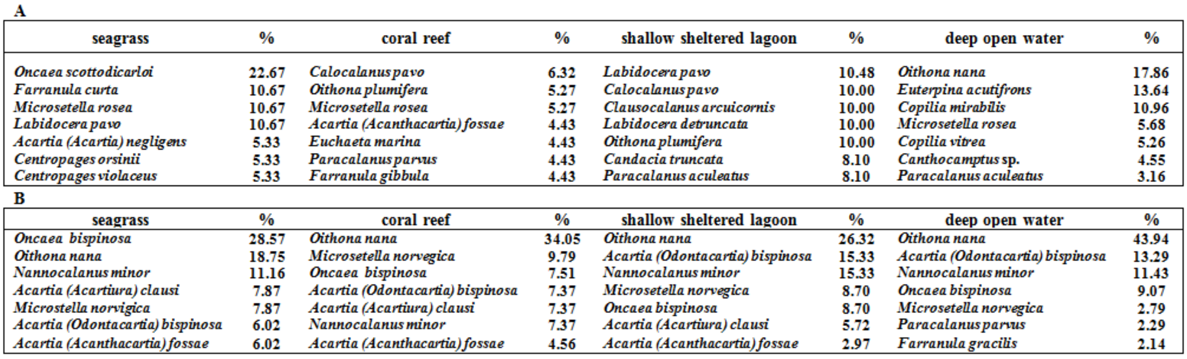


Fig. 3: Spatial variations of copepods (ind.m^{-3}) and their orders in the different habitats during summer.

The seven most abundant and frequently sampled species are listed in Table 5.

Table 5: Top 7 dominant copepod species recorded in winter and summer and their percentage to the total adult copepods in the different habitats (A: Winter; B: Summer).



A

seagrass	%	coral reef	%	shallow sheltered lagoon	%	deep open water	%
Oncaea scottodicarloi	22.67	*Calocalanus pavo*	6.32	*Labidocera pavo*	10.48	*Oithona nana*	17.86
Farranula curta	10.67	*Oithona plumifera*	5.27	*Calocalanus pavo*	10.00	*Euterpina acutifrons*	13.64
Microsetella rosea	10.67	*Microsetella rosea*	5.27	*Clausocalanus arcuicornis*	10.00	*Copilia mirabilis*	10.96
Labidocera pavo	10.67	*Acartia (Acanthacartia) fossae*	4.43	*Labidocera detruncata*	10.00	*Microsetella rosea*	5.68
Acartia (Acartia) negligens	5.33	*Euchaeta marina*	4.43	*Oithona plumifera*	10.00	*Copilia vitrea*	5.26
Centropages orsinii	5.33	*Paracalanus parvus*	4.43	*Candacia truncata*	8.10	*Canthocamptus* sp.	4.55
Centropages violaceus	5.33	*Farranula gibbula*	4.43	*Paracalanus aculeatus*	8.10	*Paracalanus aculeatus*	3.16

B

seagrass	%	coral reef	%	shallow sheltered lagoon	%	deep open water	%
Oncaea bispinosa	28.57	*Oithona nana*	34.05	*Oithona nana*	26.32	*Oithona nana*	43.94
Oithona nana	18.75	*Microsetella norvegica*	9.79	*Acartia (Odontacartia) bispinosa*	15.33	*Acartia (Odontacartia) bispinosa*	13.29
Nannocalanus minor	11.16	*Oncaea bispinosa*	7.51	*Nannocalanus minor*	15.33	*Nannocalanus minor*	11.43
Acartia (Acartiura) clausi	7.87	*Acartia (Odontacartia) bispinosa*	7.37	*Microsetella norvegica*	8.70	*Oncaea bispinosa*	9.07
Microstella norvigica	7.87	*Acartia (Acartiura) clausi*	7.37	*Oncaea bispinosa*	8.70	*Microsetella norvegica*	2.79
Acartia (Odontacartia) bispinosa	6.02	*Nannocalanus minor*	7.37	*Acartia (Acartiura) clausi*	5.72	*Paracalanus parvus*	2.29
Acartia (Acanthacartia) fossae	6.02	*Acartia (Acanthacartia) fossae*	4.56	*Acartia (Acanthacartia) fossae*	2.97	*Farranula gracilis*	2.14

Copepods structure and environmental conditions

The results revealed that, temperature is the primary factor influencing copepod densities, but the responses of different species are vary. So that at p≤ 0.05 water temperature positively correlated with the density of the calanoid copepods *Acartia (Odontacartia) bispinosa* Carl, 1907 (r= 0.479), *Acartia (Acartiura) clausi* Giesbrecht, 1889 (r=0.518) and *Nannocalanus minor* (Claus, 1863) (r=0.542) and with the cyclopoids (*Oithona nana* Giesbrecht, 1893) (r= 0.340), and the harpacticoid; (*Euterpina acutifrons* (Dana, 1847) (r= 0.154). On the other hand it was negatively correlated with the poecilostomatoids (*Copilia mirabilis* Dana, 1852) (r= -0.511). The effect of temperature was very marked on *Microsetella norvegica* (Boeck, 1865) (r= 0.713, p< 0.001).

On the other hand, the data revealed the dependence of the distribution of the four copepod orders on the water salinity variation; salinities relatively separate the studied stations and exhibited a wide variations between the different habitats especially the shallow sheltered lagoons and the deep open-water ones, the effect of the salinity variations was very noticed on the numbers of nauplius larvae (r=0.616, p < 0.05), and there was a reverse correlation between the water salinity and the adult copepods (r=0.57, p < 0.001).

The dissolved oxygen was negatively correlated with water salinity (r= -0.755 at p= 0.01), while it was positively correlated with the water depth (r= 0.93) at $p < 0.001$. The correlation between water salinity and water depth was strong negative (r= -0.89 at p= 0.001). Water temperature showed positive correlation (r= 0.62) with the water salinity and negative trend (r= -0.58) with the depth at $p \leq 0.05$.

Principal component analysis

In order to reveal the correlations between the various measured physico-chemical parameters in the different four habitats with taking in consideration the zooplankton distribution and abundance in each habitat, PcOrd statistical software package 5.0 using Canonical Correspondence Analysis method (CCA) was used and the components of the ecological data biplot of the first two axes are shown in Figs. 4 and 5. Five physico-chemical parameters were used: water temperature (°C), pH, water salinity, dissolved oxygen (mg.l^{-1}), and water depth (m). A correlation matrix between the components was constructed to give each variable an equal importance and simplified analysis of a large data set. The relationship of these environmental variables with the first two axes of variation showed which is the most effective and influential variables.

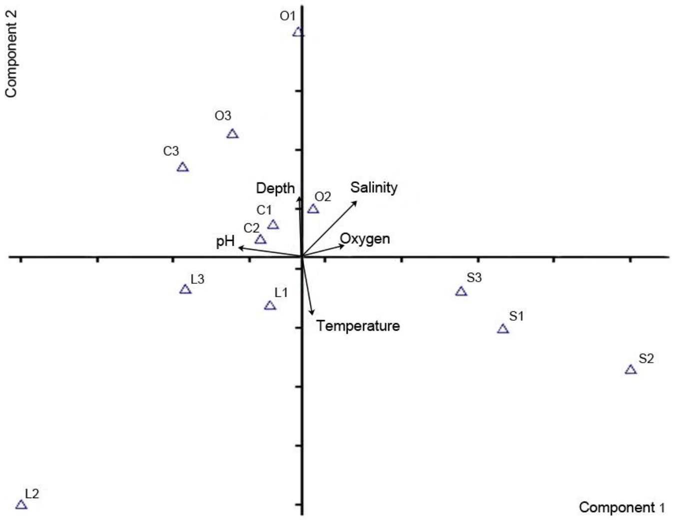


Fig. 4. CCA components projection on the Axis 1 and Axis 2 showing the distribution of the stations based on the prevailing environmental condition during winter.

Canonical Correspondence Analysis method (CCA) was applied on the environmental data components that correlated to species associated with each stand. This highlighted the close correlation between the water temperature and the species occupying the sea grass stands during winter. While sheltered shallow lagoon stands characterized with low salinity, depth, and dissolved oxygen content. The coral reef stands along with the open deep-water stands feature a high depth with pH values. It was clear that the most important environmental variable was the salinity.

On the other hand, during summer these highlight the close correlation between water salinity, temperature and pH, which is in contrast to the dissolved oxygen and the water depth along the first axis. It is obvious that pH is more correlated with the second axis. The variables that was associated with the axis 1 (the salinity, pH and the temperature) indicate a severe environmental conditions gradient, and the analysis clearly illustrates the tendency of shelter shallow lagoon habitats (L1, L2, and L3) and coral reef stations C2 and C3 towards the overexposure affectedness by the environmental changes (Fig. 4).

Axis 2 was correlated with pH (Hydrologically linked factor). CCA ordination of the data according to the four habitats distributed in 12 stations indicates water quality differences between the different habitats and the sampling stations. All the sampling sites were well distinguished according to each habitat. Deep open-water habitat stations (O1, O2, and O3) were clearly characterized by being higher in the dissolved oxygen content and deeper and this reflects the more stable environmental conditions in this habitat. It was clear that the stations which represent the Seagrass habitat were negatively correlated with pH values and characterized by lower dissolved oxygen content (Fig. 5).

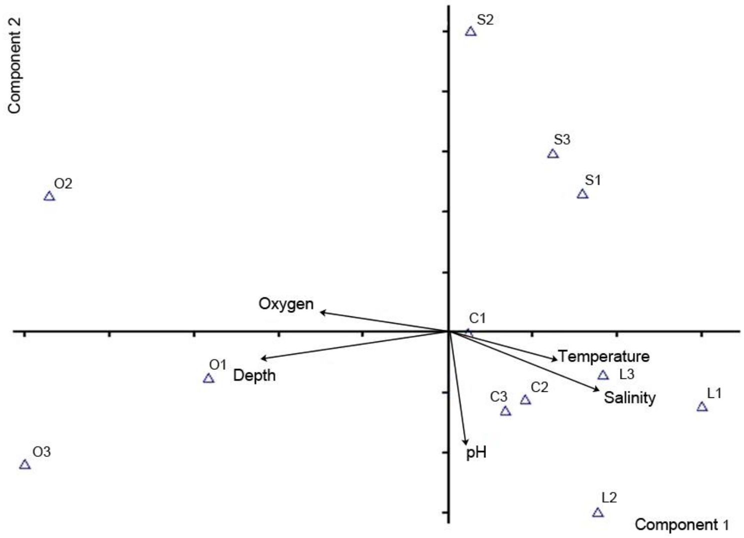


Fig. 5: CCA components projection on the Axis 1 and Axis 2 showing the distribution of the stations based on the prevailing environmental condition during summer.

DISCUSSION

The Red Sea is an oligotrophic enclosed sea and can be considered as an extreme environment for marine organisms owing to its lack of any fresh water supply, or any connection with open oceans, except at the far south. This causes high salinity, high evaporation rate, and hence have very stable physical characteristics (Edwards, 1987; Weikert, 1987). The hydro-physical and chemical characteristics of the Red Sea water depend also on its dynamics as well as on the geographical location (Abdelmongy and El-Moselhy, 2015).

Surface water temperature showed an 8.5°C differences between the minimum value in winter and the maximum in summer and it was mostly influenced by air temperature. Salinity was usually high reflecting the unique character of the Red Sea as the most saline body of water in the world oceans. Salinity increases considerably from south (about 37) to north (>40) (Morcos, 1970). The present samples exhibited a wide variation of 9.2, the fluctuation in the salinity values was very obvious in the shelter shallow lagoon habitats where it is recorded their minimum values during winter (35.2) when the rains were more frequent and abundant and the maximum recorded reading (40) during summer. These differences are reflected on the zooplankton abundance and diversity especially in such habitat, as they generally decreases to the north of the Red Sea as a result of the changing environmental conditions (Halim, 1969; Beckmann, 1984; Weikert, 1987).

A marked decrease of copepod diversity was observed in the Northern part of the Red Sea. It was 300 calanoid species in the Arabian Sea (Grice and Hülseman, 1967), 107 copepod species through the open Red Sea (Delalo, 1966) and 65 copepod species in the Gulf of Suez (Halim, 1969). Al-Najjar (2002) recorded 55 copepod species in the Gulf of Aqaba, a great drop noticed in mangrove Safaga area to reach 26 species (Obuid Allah *et al.*, 2005), and only 23 copepod species were identified by Abdel-Rahman (1997) in the Suez Canal. Finally, copepod diversity was reached to 69 species in the present study. The gradual decrease in the number of species may be attributed to the increase of water temperature and salinity, the factors that are considered to be important in controlling the abundance of zooplankton as mentioned by Goldman and Horne (1983), Marinone (2012) and Soria *et al.* (2012). The present results revealed that temperature and salinity are the primary factors influencing copepod densities and diversity and the numbers of nauplius larvae.

A total of 69 species of copepods were encountered in the study area, with highest diversity (58 species) identified in the deep open water habitat and lowest in the seagrass habitat (27 species). Coral reef and shallow sheltered lagoon habitats exhibited 55 and 45 species, respectively. The species number of calanoid copepods (38 species) was near to that recorded by Böttger-Schnack *et al.* (2001) who recorded 35 calanoid species and by Al-Najjar (2002) (34 species) in the Gulf of Aqaba. While in the southern Red Sea Delalo (1966), Almeida Prado-Por (1983) and Sheppard *et al.* (1992) recorded 60 species of calanoid copepods and about 46 in the north. However, the decrease in the species numbers at the northern part than the southern was seemed to be ascribable to the extreme environmental conditions in the north of Red Sea (Böttger-Schnack, 1996) in addition to the huge human activities which in the study area.

The most widely distributed copepod species in Hurghada waters were: *Clausocalanus* sp., *Oithona nana*, *Oithona plumifera*, *Paracalanus* sp., *Oncaea scottodicarloi*, *Microsetella* spp., *Corycaeus* sp., *Oncaea* spp. and *Pontellina plumata*. These species were more or less similar to those recorded in other regions of northern Red Sea (Abdel-Rahman, 1997; El-Sherbiny, 1997; Khalil and Abdel-Rahman, 1997; Cornils *et al.* 2005; Aamer *et al.* 2007). The above cited copepod genera are generally found in the oligotrophic subtropical water of the Atlantic Ocean (Fernández de Puelles and Braun, 1996; Hernandez-Leon, 1998; Kovalev, 2006) and mainly related to the amount and quality of the food.

Seagrass and coral reef attract dense populations of aquatic organisms from the different levels. Seagrass is the preferable substrate for the fish larvae and the juveniles more than any other habitat, they encountered in large numbers especially on the seagrass-replete reef (Beck *et al.*, 2001 and Shibuno *et al.*, 2008), and on the other hand many offshore fishes actively seek for such habitats and select it as a nursery ground (Nakamura *et al.*, 2009). Several studies on the stomach content of the seagrass and coral reef fishes and larvae indicated that copepods configured the main bulk of their food items. Withal, zooplanktivores intensely grazes on zooplankton organisms (Glynn 1973; Johannes and Gerber, 1974; Hamner *et al.*, 1988 and Williams *et al.*, 1988) especially the large size preys including calanoid and cyclopoid copepods (El-Serehy and Abdel-Rahman, 2004); this may explain why calanoids and cyclopoid recorded their minimum densities at these two habitats (Table 4) and the minimum diversity (Table 3). No doubt that the impact of the sever environmental conditions in the sheltered shallow lagoons which considered semienclosed areas are very obvious and reflected on the inhabitant organisms, as a result the minimum diversity was recorded at this habitat.

Poecilostomatoid copepods play an important role in the copepod composition and comprising more than 32% and 45% of the total adult copepod in the seagrass habitat during winter and summer respectively, also this order represented by considerable percentage (36.2%) where it considered the most dominant order in shallow shelter lagoons during winter and forming 27.1% during summer. This agree with Böttger (1987) who studied it in samples collected from the central Red Sea and found that the genus *Oncaea* hold a key position in the community structure of the Red Sea plankton. The species inhabits different habitats from shallow areas to the deep sea (e.g. Turner and Dagg, 1983; Nishida, 1985; Schnack *et al.*, 1985; Bottger-Schnack, 1990 and Paffenhofer, 1993). The family Oncaeidae is an ideal food for fish larvae, planktonic predators, small carnivorous or omnivorous organisms (Kellerman, 1987; Oresland and Ward, 1993; Metz and Schnack-Schiel, 1995). Two species were dominant (*Oncaea bispinosa* and *O. scottodicarloi*) and showed their maximum densities during summer.

During the study period, small cyclopoid ranked the second in the density after the calanoids, it composed a mean of 26.12% to the total adult copepods density and represented the main order in the deep open-water habitat during winter and summer (35.5% and 45.6% of the total adult density) (Table 4). For the other habitats, it ranged between 7.8 and 28.8%. In the present work the order Cyclopoida represented by seven species, 6 were under the genus *Oithona,* additionally *Oithona nana* was the most dominant species. This can explained by the fact that the genus *Oithona* has been described as the most ubiquitous and abundant copepod in the world’s oceans (Gallienne and Robins, 2001).

Because of copepods are known to be the most important group of the mesozooplankton in the world wide oceans (cf. Mauchline, 1998), its densities or community structures must be evaluated accurately in addition to the mesh net sizes and the methods of counting must be estimated (Hwang *et al.*, 2007; Tseng *et al.*, 2011), and therefore the present study based on sampling with fine-mesh nets (55 µm). The estimation methods for copepod density in many previous works are relatively not accurate because samples were often collected by nets with 200 µm mesh size or more, and the researchers have commented on losses of smaller organisms such as *Oithona* and *Oncaea*, as well as juvenile forms of larger copepods, from these nets, that the nets mesh size is the main factor affecting the quantitative and qualitative accuracy (Unesco, 1968). Most coastal copepod communities are composed of small-size species, as well as larvae or juvenile copepods (Turner, 2004). Consequently, in the present data the outnumbering of copepod stages (Nauplii and copepodites) than the adults in the different habitats (more than 70 %) may be related to the use of fine mesh net (55 µm) and almost the small nauplii forms were quantitatively sampled, and/or the breeding season of most species occurred all the year round in the warm seas (Raymont, 1983). nauplii reached their maximum abundance during summer (76.2 %) which agrees with Vervoort (1965) and Atkinson and Sinclair (2000). El-Sherbiny *et al.*, 2007 found that adult copepods constituted only 22.3% of total copepods, in Sharm El-Sheikh, Northern Red Sea with net mesh size 100 µm.

The mean density of copepods (685.75 ind.m^{-3}) was much lower than that recorded in previous studies on the northern region of the Red Sea. The total copepods count 1291.13 ind.m^{-3} was estimated by Obuid Allah *et al.* (2005); 2112 ind.m^{-3} by Dorgham *et al.* (2012b); 1206 ind.m^{-3} by Cornils, *et al.* (2007); 1840 ind.m^{-3} by El-Sherbiny *et al.* (2007) and 3186 ind.m^{-3} by El-Serehy *et al.* (2013). These studies were sampled by nets of mesh size > 100-333 µm, but the factor that may be responsible for the reduction of the copepods density at the present study is the migration vertically from the surface to the deeper layer during daytime to avoid the predation (Ricardo *et al.*, 2013).

The community structure and copepod densities in the different habitats are likely to be affected by different factors; one of the most important factors is the extensive feeding on endemic copepods by aquatic organisms (Abou Zaid *et al.*, 2014). Seagrass habitats are used as food, nursery ground and shelter against strong current for many fishes and other invertebrate fauna (Fortes, 1990). The increased predation in seagrass habitat may explain the reduction in both copepod diversity and density compared with the other habitats. Coral reefs harbored high numbers of copepod species (53) as compared with the other habitats, this agree with Roberts *et al.*(2002) who found that coral reefs are known for harboring high biodiversity of benthic fauna and fish. Copepod diversity and density were higher in the open deep water habitat (55 species, 695.9 ind.m^{-3}); this may be due to the aggregation of deep-sea and surface copepods beside the less effect of predation by other marine organisms.

Species diversity of copepods was higher in winter than in summer. This is comparable with Halim (1969) and El-Sherbiny (1997) who mentioned that the population reaches its maximum diversity in winter and the lowest in May-June. Weikert (1980) showed that most of copepod species migrate seasonally to cool water layer, avoiding rising surface temperature during summer.

It is worth mentioning that some of the copepods in the present study are bathypelagic, usually being found below 200 m depth (Weikert 1982), as *Phaenna spinifera* Claus, 1863 that recorded in the present study from the coral reefs and the deep open-water habitats and *Mecynocera clausi* Thompson I.C., 1888 (Dorgham *et al.* 2012b), which encountered in the shallow sheltered lagoon and the deep open-water habitats, this can explain why these two species appeared in low densities in such habitats. Furthermore, *Acartia danae* and *Clytemnestra scutellata* are new records for the Northern Red Sea, appeared only in shallow sheltered lagoon and deep open water habitats, indicating their northward migration, as they had previously been confined to the main basin of the Red Sea.

CONCLUSION

The present data provides basic information about the copepod community and diversity in the surface waters of different habitats of Hurghada, Northwestern the Red Sea. The results indicated a considerable reduction in abundance and species diversity. It can be concluded that, the community of copepods changes depending upon the habitat; calanoid copepods dominate the shallow sheltered lagoon and the coral reef habitats, while cyclopoids predominate the deep open water, but Harpacticoida and Poecilostomatoida species in the seagrass habitat. This supports the argument that there is influence of the local geographic habitats on the spatial variability of copepod abundance and community structure. It is necessary to use fine-mesh size nets (<100 µm) to evaluate accurate abundance of small copepods. Therefore, there is a necessity to perform a long-term and permanent monitoring on the copepod community at the different Red Sea habitats.

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ARABIC SUMMARY

التوزيع الموسمى لمجدافيات الأرجل المتواجدة بالنطاق البحري العلوي فى البيئات المختلفة شمال غرب البحر الأحمر، مصر.

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أُجرِيت الدراسة الحالية لطبقة المياه العلوية في الجزء الشمالي الغربي للبحر الأحمر المصري خلال رحلتان بحريتان (شتاء وصيف، 2017). تم تجميع العينات من 12 موقع يمثلوا أربعة بيئات بحرية مختلفة. وتهدف الدراسة الحالية إلى التوصل إلى فهم أفضل للتركيب النوعى والكثافة العددية لمجتمعات مجدافيات الأرجل في البيئات المائية المختلفة وتحديد العوامل البيئية التى تتحكم فى توزيع وتركيب تلك الكائنات. أظهرت النتائج زيادة فى قيم الملوحة في البيئات المائية الضحلة المحمية مما ميَّزها بطبيعةٍ خاصة خلال موسم الصيف. بعد الفحص والدراسة تأكد وجود 67 نوعاً من مجدافيات الأرجل تنتمي إلى 35 جنس موزعة ضمن 23 عائلة تنتمى إلى أربع مجموعات وذلك بالإضافة إلى المراحل غير الناضجة. لوحظ وجود إختلافات كبيرة في بنية مجتمعات مجدافيات الأرجل وتنوعها باختلاف المواسم والبيئات. ولقد سُجِّل أكبر عدد من الأنواع (55 نوع) فى البيئات المائية المفتوحة ذات الأعماق الكبيرة، في حين لوحظ أقل تنوع (24 نوع) في بيئات الحشائش البحرية. وبالنظر إلى مجموعات الكوبيبودا، كانت الـ calanoids هى الأكثر وفرة وتقطن جميع البيئات، وتشكل متوسط قدره 49,2٪ من إجمالي المجدافيات الناضجة، كما أنها كانت المجموعة الأكثر تنوعًا حيث مُثِّلت بــ 38 نوعًا. ولقد سُجِّلت أعلى كثافات لمجدافيات الأرجل فى بيئات الشعاب المرجانية (856 فرد/م^3)، بينما كانت وفرة مجدافيات الأرجل ضعيفة في بيئات الأعشاب البحرية (572 فرد/م^3). وأخيرًا، فإن التغير الملحوظ في كثافة وتنوع مجدافيات الأرجل بين البيئات المختلفة يعكس مدى أهمية النظام البيئي كعامل يؤثر في بنية المجتمعات الحية.