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SOME TRAITS OF ZOOPLANKTON IN THE WAVE-BREAKING REGION OF ROCKY AND SANDY SHORES OF THE EASTERN LIBYAN MEDITERRANEAN SEA

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ABSTRACT: *Zooplankton in seawater samples collected from two wave-breaking regions at the rocky shores of Al-Satah and Al-Warsh, and the shore of a brackish lagoon (Um-Hufayan) devoid of strong waves, during summer, fall, winter, and spring 2019/2020, and filtered through 600µ. 300µ. 75µ, and 40µ sieves stacked on top of each other, were investigated qualitatively and quantitatively. The repeated bombardment of waves on rocky shores of Al-Satah, Al-Warsh, that normally continue for days, had no deleterious effect on plankton. Altogether, 45 zooplankton species or lower-taxa were encountered during the study, the overall concentration of zooplankton was 23199 to 23764 individuals per m^3. Zooplankton diversity indices by major-group or major-taxon, species or lower-taxa, site, season, and sieve mesh were established and discussed in terms of salinity, runoff regime, type of bottom substratum and hydrographic conditions of waves and winds. In general, the descending order of zooplankton richness by the number of species per major-groups or major-taxa was Arthropoda, Protozoa, Chordata, Coelenterata (Cnidaria and Ctenophora), Mollusca, Annelida, Gelatinous species, Rotifera, Nematoda, Chaetognatha, and Echinodermata. Abundance by the number of individuals per major-groups or major-taxa was of the order Arthropoda, Protozoa, Mollusca, Annelida, Chordata, Platyhelminthes, Coelenterata, Nematoda, Rotifera, Chaetognatha, Echinodermata, and Gelatinous species.*

KEYWORDS: zooplankton, phytoplankton, micro-plastics, wave-breaking, surf, Mediterranean Sea.

INTRODUCTION

Plankton are microscopic plants (phytoplankton) and animals (zooplankton) that inhabit the euphotic zone of aquatic systems; bacterio-plankton is often considered a component of the plankton. Few plankters are fairly large, e.g. the sunfish *Mola mola* and the jellyfish scyphozoa. Phytoplankton, and the autotrophic component of the bacterio-plankton, are the main primary producers of aquatic systems, and provide half the global available oxygen; zooplankton are the primary consumers. Plankton keep themselves in the euphotic zoon by reducing their settlement rate by increasing their relative surface area and reducing their specific gravity through various adaptations (the small size, projecting spines or appendages, air bubbles, etc.).

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Vertically, plankton abundance and diversity decrease on moving down the photic zone. Horizontally, plankton abundance and diversity are maximum in coastal waters, especially in upwelling areas, and decrease on moving toward the open sea. Species diversity is maximum in the tropics and decreases in upper latitudes. Protozoan forms, arthropod crustaceans, and Meroplanktonic larvae are the main constituents of zooplankton.

Marine-phytoplankton density has declined by 40% since 1950, a rate roughly equivalent to 1% decline per year, possibly due to global pollution and climate change (Boyce *et al*., 2010; Behrenfeld *et al*., 2006 and Morello, 2010); a consequent decline in zooplankton, though yet to be documented, is expected. Such a drop will inevitably affect global fisheries, hence, all studies on lankton are important.

The objective of the present work is to establish the main traits of zooplankton of the two wind-exposed wave-braking regions (Al-Satah, Al-Warsh) and a protected coastal brackish lagoon devoid of strong waves, eastern Libya Mediterranean Sea. Only a few studies tackled aspects of plankton in wave-braking regions (e.g. Campbell and Bate, 1988; Gayoso and Muglia, 1991; Kahn and Cahoon, 2012; Morgan *et al.* 2018).

Procedures and methods

The study sites

The seawater samples used for studying contained zooplankton were collected from three sites:

- **Site (1): Um-Hufayan** (Fig. 1), a brackish lagoon and wetland with shores well protected from winds, strong waves are absent; the lagoon, being an estuary of a temporal stream, is partially connected to sea; the bottom substratum is silty/sandy. The area adjoining the lagoon is sparsely populated, anthropogenic activity is meager, and the lagoon is unpolluted.
- **Site (2): Al-Warsh** (Fig. 2), the shore is rocky and highly energetic, been exposed to strong winds, waves crash violently on the rocky shore at the wave-breaking region most of the day. Al-Warsh is a polluted site, it is located about 100m to the west of a point of discharge of municipal waste of Al-Haneah, a small nearby town, to sea.
- **Site (3): Al-Satah** (Fig. 2), very similar to site 2 except that it is unpolluted, being located about 3.03km to the southwest of a Municipality waste discharge point.

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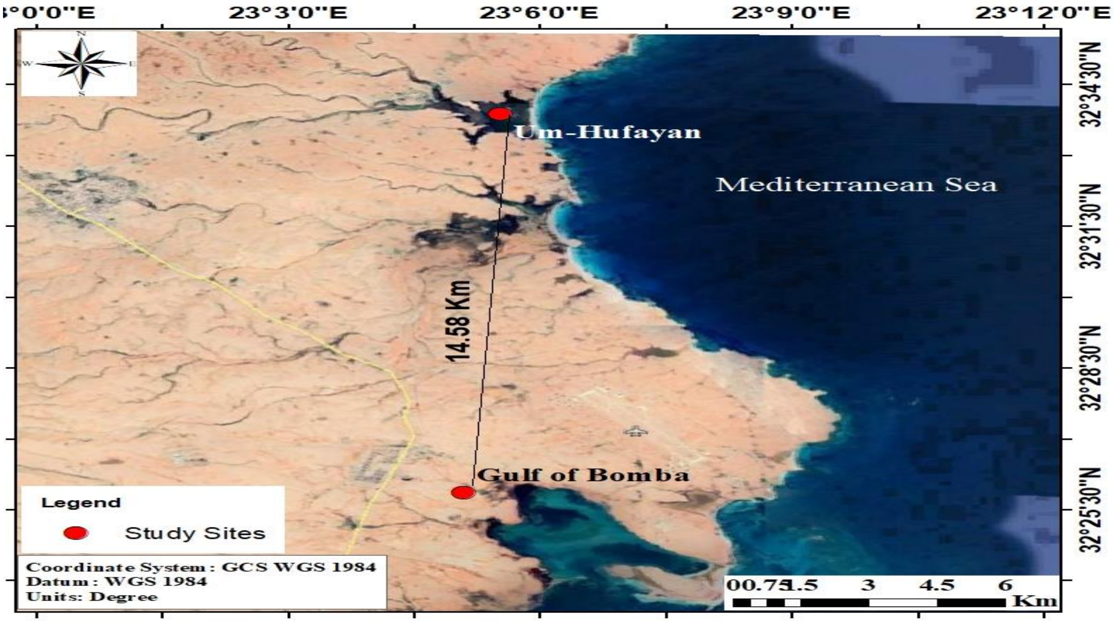

Fig. 1. Site (1): Um-Hufayan lagoon, near the Gulf of Bomba (reconstructed from Google earth map).

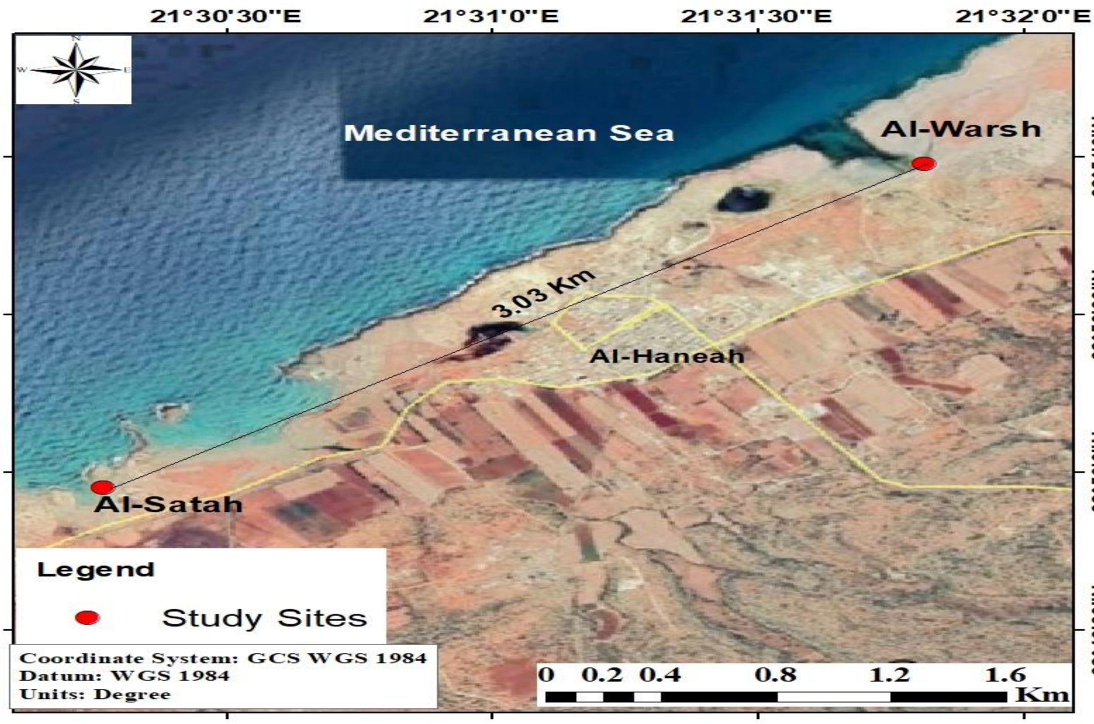

Fig. 2. Site (2) and Site (3): Al-Warsh and Al-Satah near Al-Haneah town.

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Measuring phisico-chemical parameters of the study sites and collecting plankton samples from them.

The wave breaking regions of Al-Warsh and Al-Satah, and Um-Hufayan shore were visited at midday during summer, fall, winter and spring of September 2019 - March 2020 where:

- Surface water temperature, salinity and dissolved oxygen were measured (Fig. 3).
- Two hundred and forty liters of seawater collected from each site at each season by buckets were filtered slowly through 600µ. 300µ. 75µ and 40µ sieves stacked on top of each other (Fig. 3). Plankton retained by each sieve was stored in labeled glass bottles to which buffered formalin preservative was added.

In the laboratory, the bottles were kept still for 10 hours to allow contained plankton to settle down, then the excess water above the plankton was carefully siphoned out so that, in each bottle, the settled plankton was contained in 10ml of seawater. By this process, the plankton extracted from the 240 l seawater samples by each sieve, from each site, at each season, was concentrated in 10ml seawater individual vials.

Microscopic examination

In the laboratory, each vial was shaken to homogenize the plankton, then depending on the density of the plankton, either ¼, ½. ¾ or 1ml of the seawater was taken with a graduated dropper and spread on glass slides, covered with glass covers and examined under low and medium power of an optical microscope. Seen zooplankton were identified to the lowest possible taxa based on online identification guides and other net resources.

Fig. 3. Measuring some physico-chemical traits of shore surface water at a study site, and sieving 240ml sea water sample gathered by a standard bucket).

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Calculating zooplankton diversity indices

Species Richness (S) (Biodiversity), Evenness (E), Shannon-Weiner index (H), Simpson's index (D), Simpson's index of diversity (1 - D), Simpson's reciprocal index (1/D) diversity indices of zooplankton by site, season and sieve were calculated with "Online VIRTUE-s Biodiversity Calculator (virtue-s@bioenv.gu.se. Copyright © 2020 University of Gothenburg)".

Berger and Parker (d), Alpha (α), Beta (β), Gamma (γ) diversity indices were calculated with a hand calculator. (See Atea (2021) for definition, formulae and significance of individual diversity indices).

RESULTS

Physico-chemical traits of surface water of the study sites

Surface water temperatures of all sites were close (Table 1), ranging from 16 to 30 ^{0}C according to season. Salinity was noticeably lower at Um Hufayan (brackish lagoon) where it ranged from 14.5 to 25.2$^o/_{oo}$, and 32.8 to 34.4. $^o/_{oo}$ in the other sites. Dissolved oxygen was relatively high in all sites, at all seasons, being slightly higher at Um Hufayan than at the two other sites.

Table 1. Physico-chemical traits of surface water of the study sites by season and site.

Seasons	Summer			Fall			Winter			Spring		
Locations	Um	Als	Alw	Um	Als	Alw	Um	Als	Alw	Um	Als	Alw
Temp. ^{0}C	21	30	25	16	17	18	18	20	18	21	21	20
Salinity $^0/_{00}$	25.2	34.4	34.0	14.5	32.8	33.2	16.5	33.8	33.4	15	33	33
D.O. mg/l	7.4	6	6.6	8.5	7.6	7.5	8.2	7.1	7.5	7.9	7.1	7

D.O.: Dissolved oxygen; **Um:** Um-Hufayan; **Als:** Al-Satah; **Alw:** Al-Warsh;

Diversity of zooplankton collected during the study.

The descending order of richness by major-group or major-taxon (number of zooplankton species or minor-taxon per major-group or major-taxon) encountered during the study was Arthropoda, Protozoa, Chordata, Coelenterata (Cnidaria and Ctenophora), Mollusca, Annelida, gelatinous species, Rotifera, Nematoda, Chaetognatha and Echinodermata (Fig. 4). Abundance by major-group or major taxon (number of individuals per major-group or major taxon), the order was Arthropoda, Protozoa, Mollusca, Annelida, Chordata, Platyhelminthes, Coelenterata, Nematoda, Rotifera, Chaetognatha, Echinodermata and gelatinous species (Fig. 5).

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The species richness index, (S) shown in Fig. 6 indicates that 45 zooplankton species or minor-taxa were encountered during the study. Evenness (E) was high (0.708), D, the Simpson index measure of dominance, was very low, indicating that dominance was weak, and hence biodiversity was high. This was also reflected by the high value of the Simpson index of diversity (1-D) of 0.902, and the Simpson reciprocal index (1/D) of 10.204; the Shannon and Weaner index (H) was 2.697, indicating high diversity. Berger and Parker's index (d) showed that copepods contributed most to zooplankton (0.104 or 10.4% copepods relative to all individuals of zooplankton).

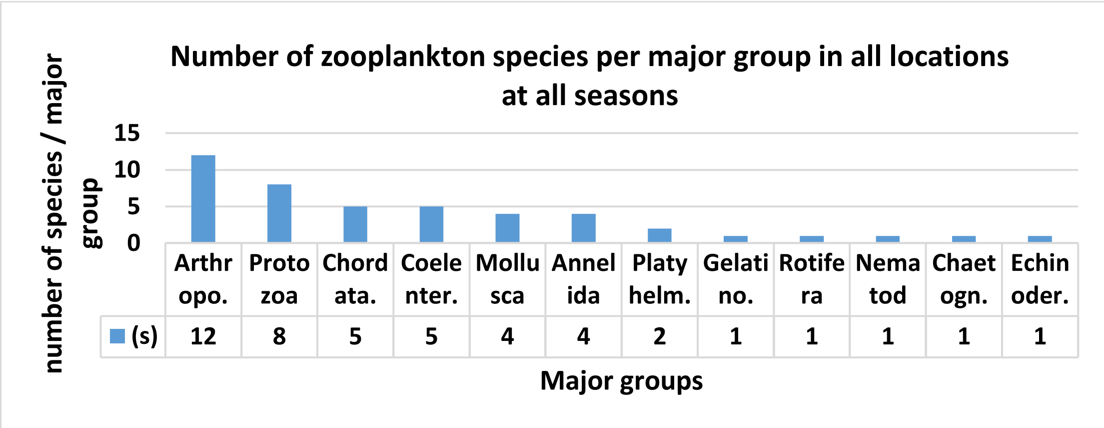

Fig. 4. Number of zooplankton species per major group or major taxon encountered during the study.

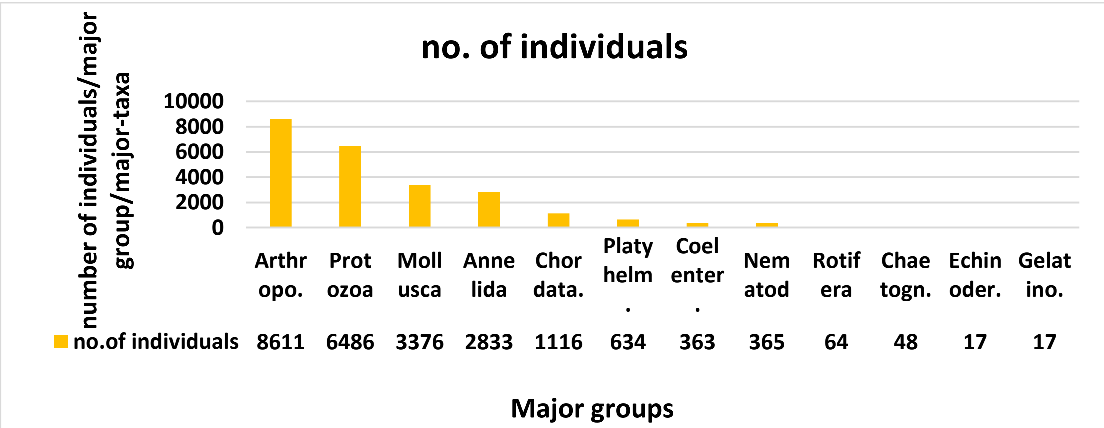

Fig. 5. Number of zooplankton individuals per major group or major taxon encountered during the study.

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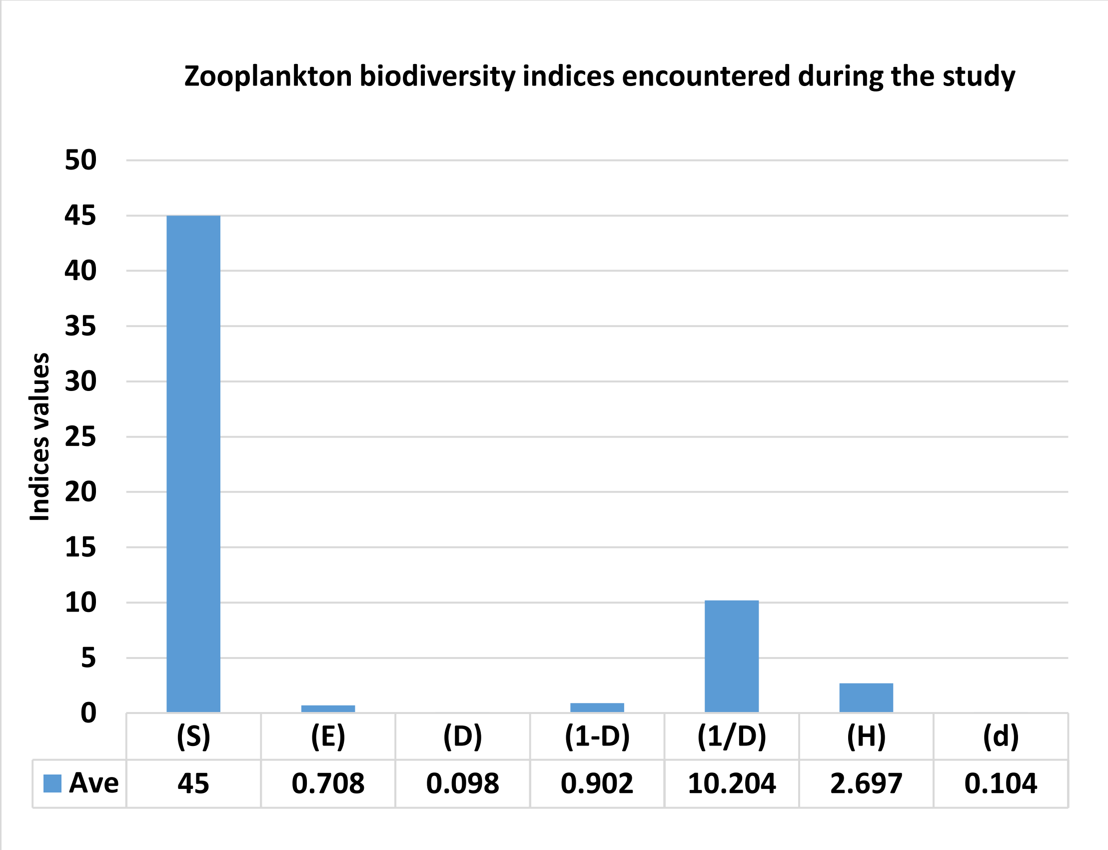

Fig. 6. Biodiversity indices of zooplankton collected during the study.

In descending order of magnitude of the number of species per major group or major taxon by site, Arthropoda, Protozoa, Chordata, Coelenterata, Mollusca, and Annelida constituted most of the zooplankton in all individual sites (Fig. 7). Lesser but significant contributions were made by gelatinous species, Rotifera, Nematoda, Chaetognatha, and Echinodermata. By the relative number of zooplankton individuals per major group or major taxon per site, the two major contributors in Um-Hufayan (Fig. 8) were Mollusca (2123) and Annelida (2101). The other major contributors were Arthropoda, Protozoa, Chordata, and Nematoda. In Al-Satah and Al-Warsh, the two major contributors were Arthropoda (3152, 3989) and Protozoa (2227, 3882) but significant contributions were made by Chordata, Mollusca, Annelida, Platyhelminthes, Nematoda, and Coelenterata.

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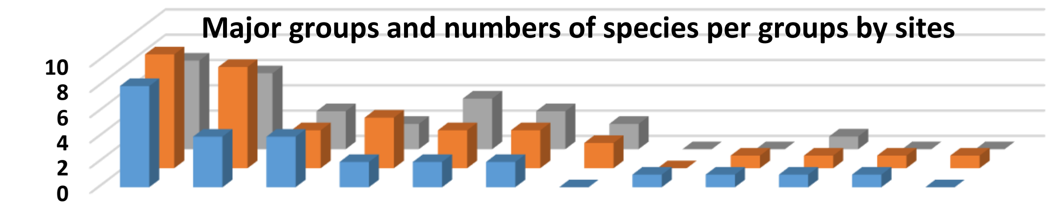
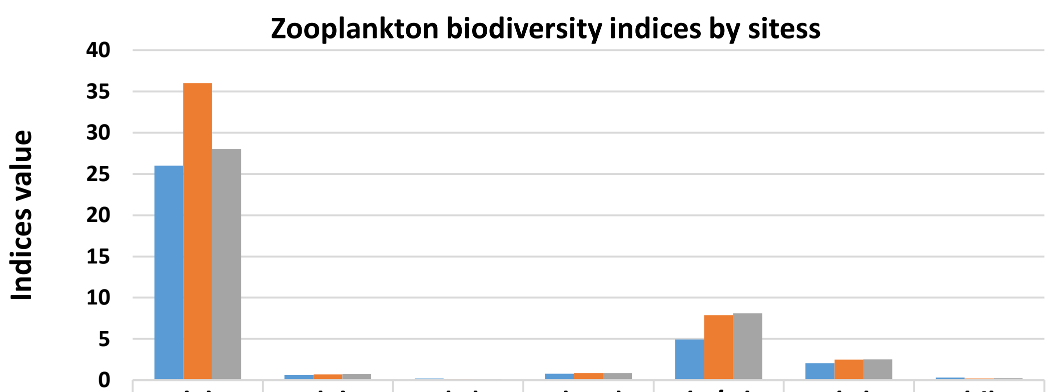
The order of species richness (Fig. 9) was Al-Satah, Al-Warsh, and Um-Hufayan (S = 36, 28, and 26 consecutively). Evenness was highest in Al-Warsh (E = 0.755) and lowest in Um-Hufayan (E = 0.636). 1-D was of the orders of Al-Warsh (0.877), Al-Satah (0.873), and Um-Hufayan (0.797)



	Arthropoda	Protozoa	Chordata	Coelentrata	Mollusca	Annelida	Platyhelminthes	Gelatinous	Rotifera	Nematoda	Chaetognatha	Echinodermata
Um-H	8	4	4	2	2	2	0	1	1	1	1	0
Al-S	9	8	3	4	3	3	2	0	1	1	1	1
Al-W	7	6	3	2	4	3	2	0	0	1	0	0

Fig. 7. Numbers of species per major group or major taxon by sites (all seasons summed together).



	(S)	(E)	(D)	(1-D)	(1/D)	(H)	(d)
Um-H	26	0.636	0.203	0.797	4.926	2.073	0.305
Al-S	36	0.698	0.127	0.873	7.874	2.501	0.197
Al-W	28	0.755	0.123	0.877	8.13	2.515	0.264

Fig. 8. Number of individuals per major group or major taxon by sites (all seasons summed together). (Um-H: Um-Hufayan; Al-S: Al-Satah; Al-Warsh)

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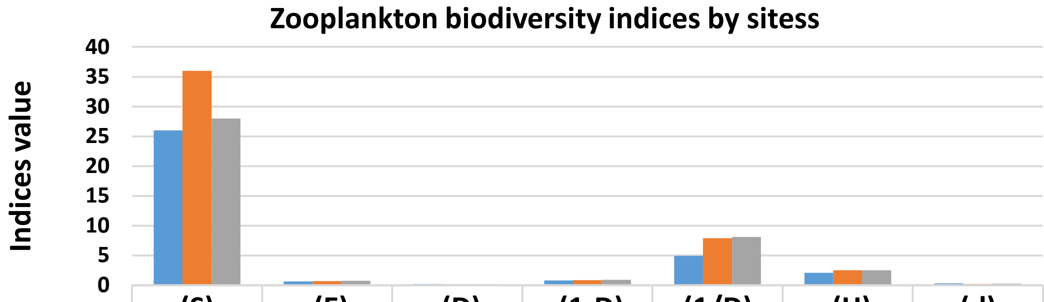

	(S)	(E)	(D)	(1-D)	(1/D)	(H)	(d)
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Al-W	28	0.755	0.123	0.877	8.13	2.515	0.264

Fig. 9. Zooplankton biodiversity indices of all sites for all seasons.

In conclusion, zooplankton biodiversity was relatively higher in Al-Satah and Al-Warsh than in Um-Hufayan. The principal component (d) in Al-Satah and Al-Warsh was nauplius larvae, and Polychaeta in Um-Hufayan. The variation of the species composition (ß diversity) was greatest between Um-Hufayan and Al-Warsh (ß = 22, Table 2), moderate between Um-Hufayan and Al-Satah (ß = 18), and lowest between Al-Satah and Al-Warsh (ß = 16); γ diversity, the measure of the overall number of zooplankton species in binary locations was 42 for Um-Hufayan and Al-Satah (Table 2), 35 for Um-Hufayan and Al-Warsh, and 39 for Al-Satah and Al-Warsh. γ was 45 for the three sites, that is to say, 45 plankton species were encountered in the present study.

Table 2. Alpha, Beta, and Gamma indices by sites.

Index	Um-H / Al-S		Um-H/ Al-W		Al-S /Al-W	
	Um-H	Al-S	Um-H	Al-W	Al-S	Al-W
α	26	36	26	28	36	28
ß	18		22		16	
γ	42		35		39	

Zooplankton biodiversity by seasons

The general distribution of zooplankton by the number of species or minor taxon per major group or major taxon was similar in all seasons (all sites summed together), Fig. 10. In descending order of the number of species per major group or major taxon, Arthropoda, followed by Protozoa, contributed most zooplankton in all seasons. These were followed by Chordata, Mollusca, Annelida, and Coelenterata, then a lesser contribution from the rest of the groups. Altogether, 35, 24, 19 and 18 species or minor

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taxa (S index) showed up in the plankton in summer, fall, winter, and spring consecutively (Fig. 10).

The overall number of individuals per season was of the order of 8605/m^3 zooplankton in spring, 7781/m^3 in fall, 4638/m^3 in summer, and 2387/m^3 in winter (Fig. 11), this contribution came from Arthropoda, Protozoa, Mollusca, Annelida, Chordata, Nematoda, and then the rest of the groups, in order. The maximum number of arthropods was in spring (4426), that of protozoa (2371), Mollusca (1802), and Annelida (1417) was in fall, that of Nematoda (131) was in summer, and that of Platyhelminthes was (550) in spring.

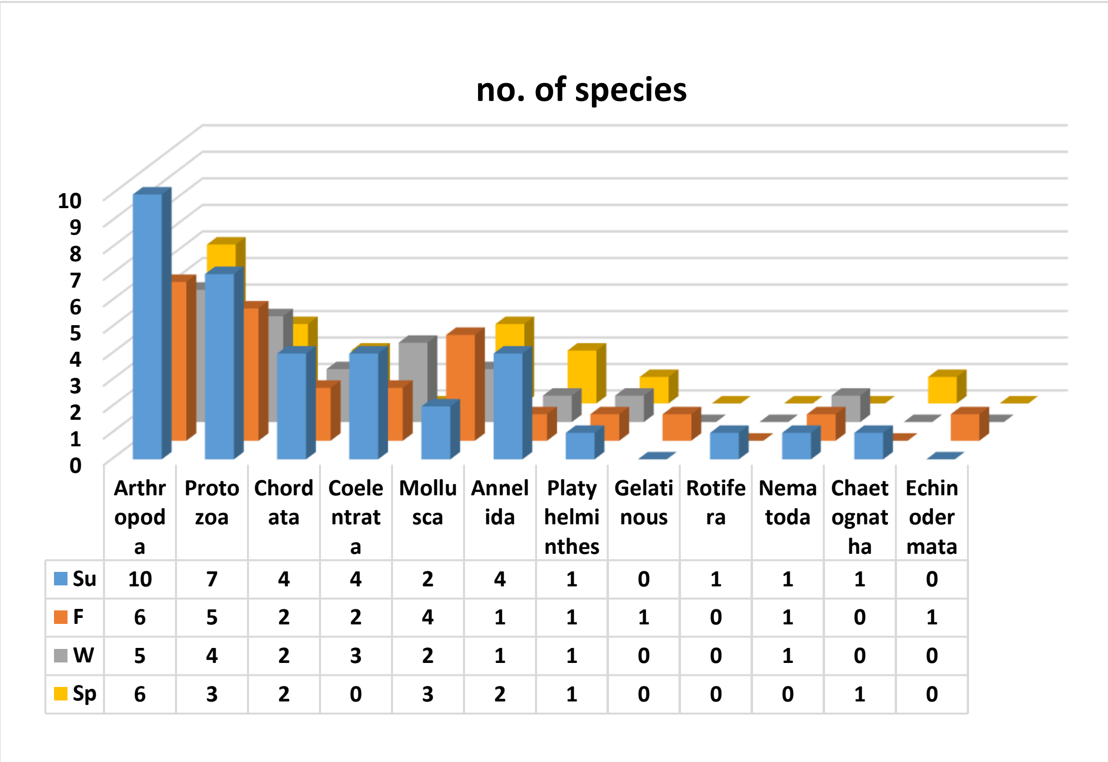

Fig. 10. Number of zooplankton species or minor taxon per major group or taxon by seasons (Su: summer, F: fall; W: winter; Sp: spring).

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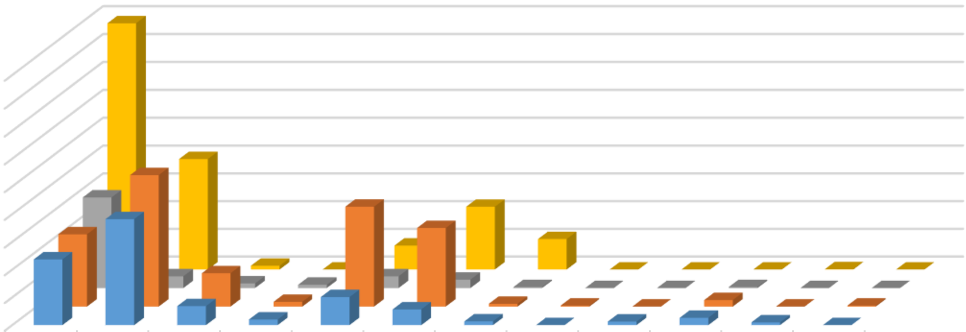

	Arthropoda	Protozoa	Chordata	Coelentrata	Mollusca	Annelida	Platyhelminthes	Gelatinous	Rotifera	Nematoda	Chaetognatha	Echinodermata
Su	1186	1911	342	101	505	283	67	0	64	131	48	0
F	1304	2371	601	85	1802	1417	50	17	0	117	0	17
W	1634	212	84	60	212	151	17	0	0	17	0	0
Sp	4426	1992	68	0	432	1132	550	0	0	0	5	0

Fig. 11. Number of zooplankton individuals per major group or major taxon by seasons.

Evenness (E) and (1-D) indices were high in all seasons (Fig. 12), being highest in summer (0.808 for the former and 0.918 for the latter). Values of the (H) index by seasons were comparable: from2.059 to 2.871, Nauplius larvae contributed 43.8% of the zooplankton population by number in winter and 29.8% in spring, bivalves contributed 21.2% in fall, and Euglena 17.9% in summer.

The ß and γ indices (Table 3) were lowest for the fall/winter and winter/spring combinations (13 and 26), and highest for the summer/fall combination (31 and 43)

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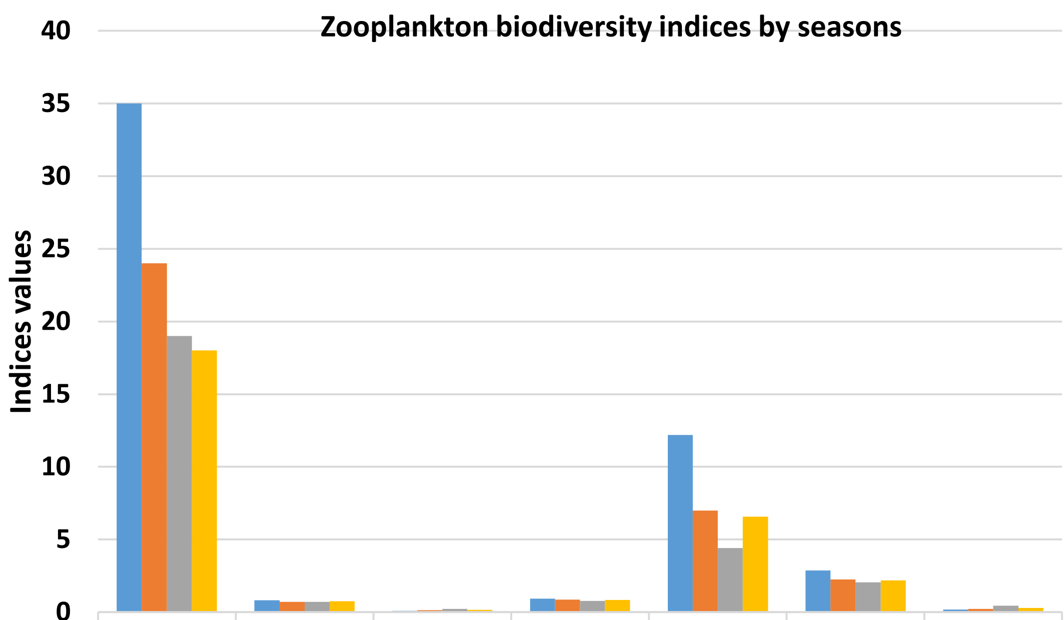
A detailed tabulation of zooplankton biodiversity indices by site, and season, is given in Fig. 13.



	(S)	(E)	(D)	(1-D)	(1/D)	(H)	(d)
Su	35	0.808	0.082	0.918	12.195	2.871	0.179
F	24	0.706	0.143	0.857	6.993	2.243	0.216
W	19	0.699	0.227	0.773	4.405	2.059	0.438
Sp	18	0.754	0.152	0.848	6.579	2.179	0.298

Fig. 12. Zooplankton biodiversity indices by seasons.

Table 3. Alpha, Beta, and Gamma indices by seasons

Biol	Su /F		Su/ W		Su/ Sp		F/W		F/Sp		W/Sp	
	Su	F	Su	W	Su	Sp	F	W	F	Sp	W	Sp
α	35	24	35	19	35	18	24	19	24	18	19	18
ß	31		31		23		13		18		15	
γ	43		40		38		28		29		26	

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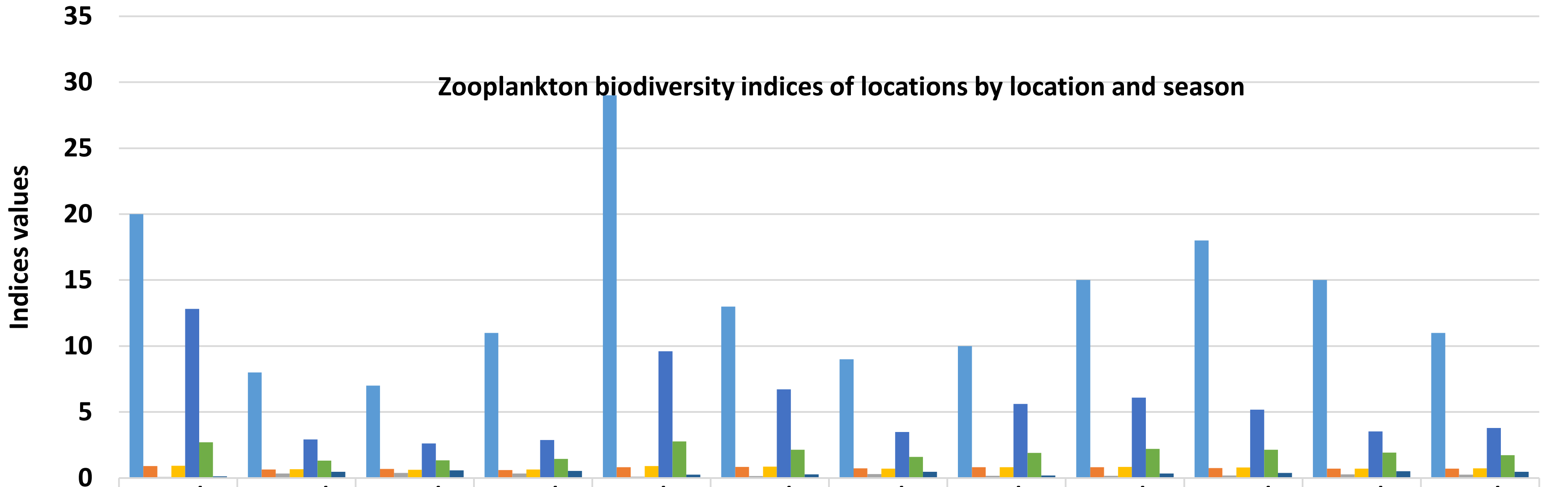

	Um-H/Su	Um-H/F	Um-H/W	Um-H/Sp	Al-S/Su	Al-S/F	Al-S/W	Al-S/Sp	Al-W/Su	Al-W/F	Al-W/W	Al-W/Sp
(S)	20	8	7	11	29	13	9	10	15	18	15	11
(E)	0.9	0.636	0.691	0.605	0.822	0.835	0.728	0.823	0.818	0.744	0.707	0.718
(D)	0.078	0.342	0.381	0.346	0.104	0.149	0.287	0.178	0.164	0.193	0.284	0.264
(1-D)	0.922	0.658	0.619	0.654	0.896	0.851	0.713	0.822	0.836	0.807	0.716	0.736
(1/D)	12.821	2.924	2.625	2.89	9.615	6.711	3.484	5.618	6.098	5.181	3.521	3.788
(H)	2.697	1.323	1.344	1.451	2.767	2.142	1.599	1.895	2.216	2.152	1.916	1.721
(d)	0.124	0.461	0.583	0.544	0.249	0.277	0.481	0.194	0.342	0.391	0.512	0.461

Fig. 13. Zooplankton biodiversity indices by site and season.

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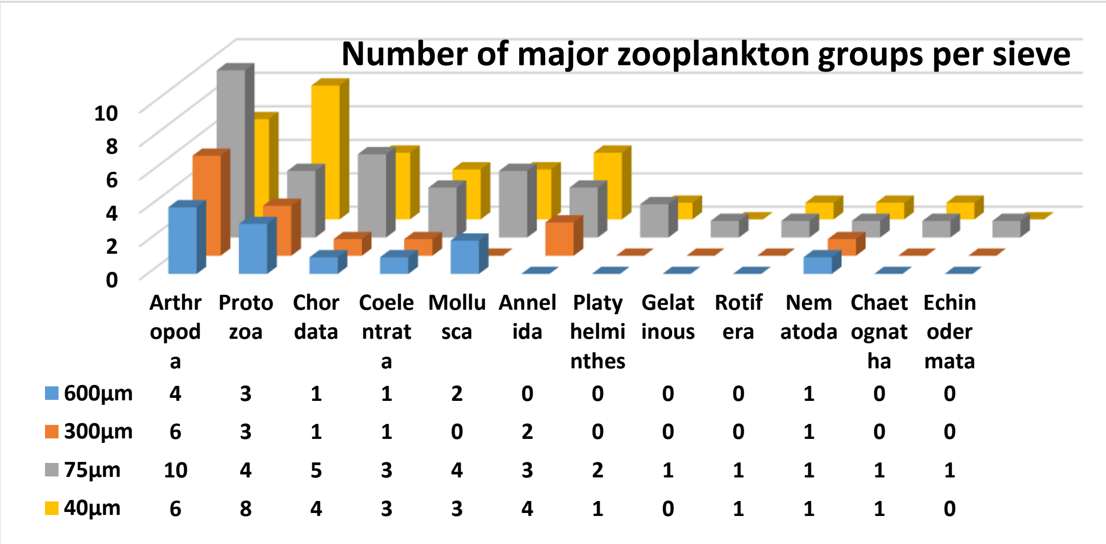
Zooplankton biodiversity by sieves

In general, the 75µ sieve collected more zooplankton, followed by the 40µ sieve, and then the 300 and 600µ sieves (Figs. 14, 15, 16); for example, the 75µ sieve collected a total of 36 species (Fig. 14) distributed on Arthropoda, Protozoa, Chordata, Coelenterata, Mollusca, Annelida, gelatinous species, Rotifera, Nematoda, Chaetognatha and Echinodermata, the 40µ sieve was next: it collected 34 species, the 300µ sieve collected 14 species, and the 600µ collected only 12 species. Number wise, most zooplankton were collected by the 40µ and 75µ sieves, for example these two collected 3723 and 4257 Arthropods, and 4515 and 703 protozoans, in order (Fig. 15), while the 300µ and 600µ sieves collected 206 and 141 Arthropods, and 181 and 894 protozoans.

Species diversity (S) of zooplankton by the 600, 300, 75 and 40µ sieves were 12, 14, 36 and 32 (Fig. 16), evenness (E) was highest for the 300µ sieve zooplankton (E = 0.804) and lowest for the 600µ sieve zooplankton (E = 0.563), the Simpson index of diversity (1-D) was high for the 75, 40 and 300µ sieves (0.867, 0.859 and 0.841), and moderate for the 600µ sieve (0.568), Shannon and Weiner index (H) followed the same trend: it was high for the 75 and 40 sieves (H= 2.424 and 2.423), moderate for the 300µ sieve (2.123) and low for the 600µ sieve (1.398), Berger and Parker index of dominance indicated high dominance by of Euglena (d= 0.642) in the 600µ sieve and low for the other sieves (d= 0.216 to 0.244, (Radiolaria, bivalves and Nauplius larvae).

The ß index for possible sieves pairs ranged from 10 to 28 (Table 4), in descending order of magnitudes they were: 600/75, 300/75, 300/40, 600/40, 75/40 and 600/300µ;



the γ index ranged from 18 to 46 (Table 4), (these pairs were: 75/40, 300/75, 600/75, 300/40, 600/40 and 600/300µ.

Fig. 14. Number of major zooplankton groups or taxa per sieve (all sites at all seasons summed together).

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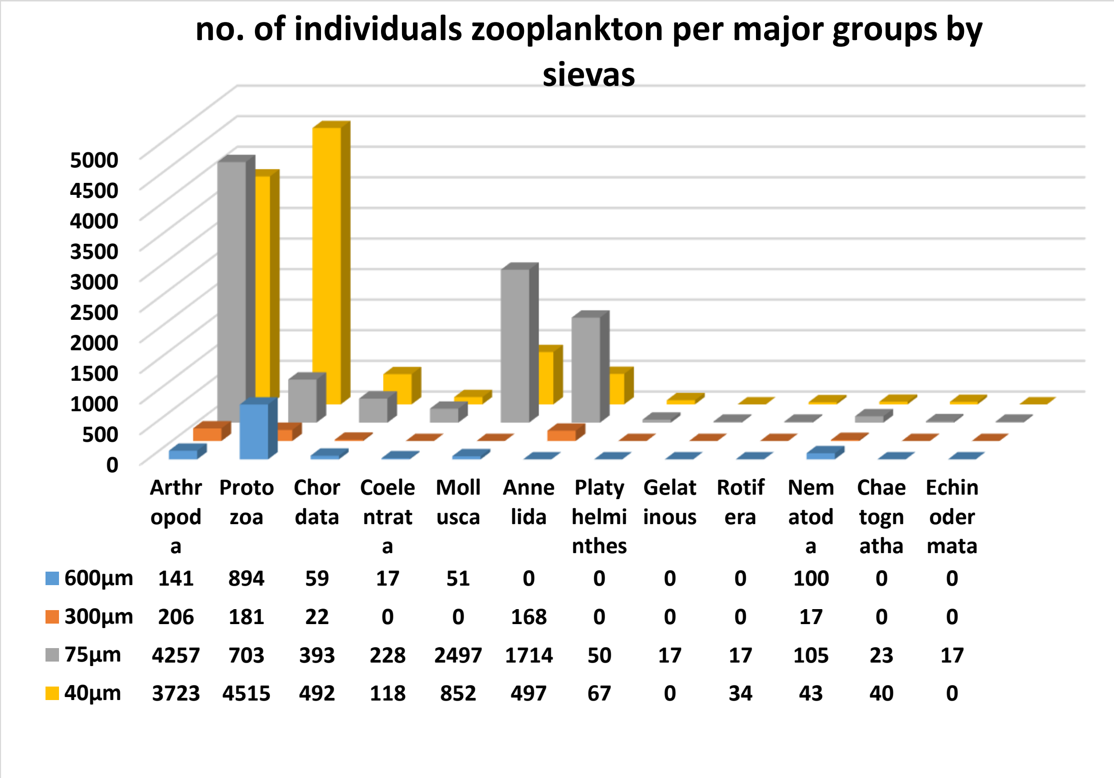

Fig. 15. Number of zooplankton individuals per major group or taxon by sieves (all sites and seasons summed together).

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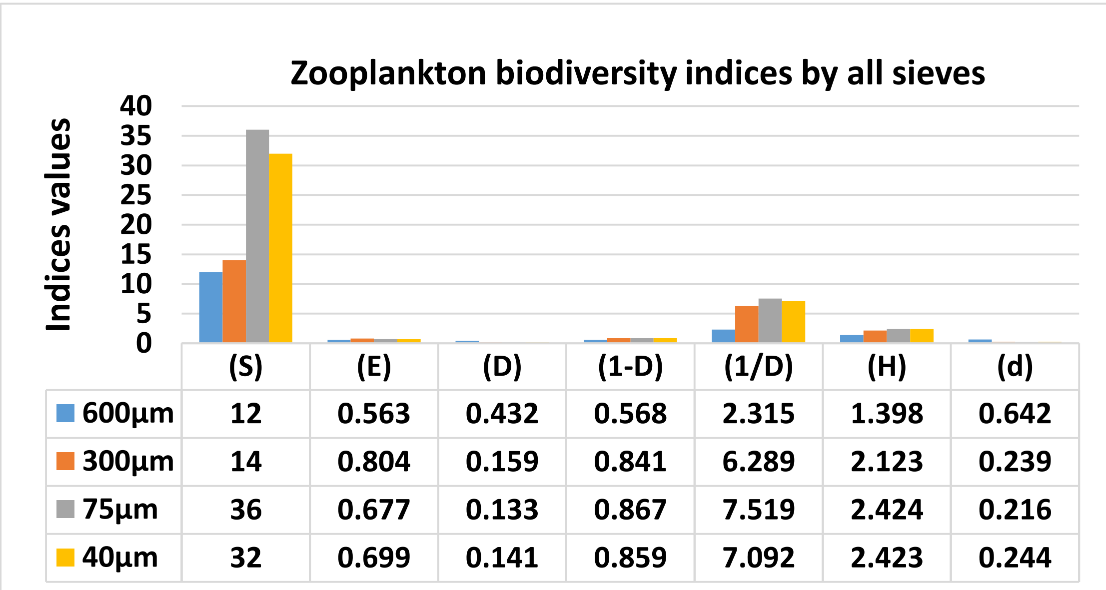

Fig. 16. Zooplankton biodiversity indices by sieves.

Print ISSN: ISSN 2053-4108(Print)
Online ISSN: ISSN 2053-4116(Online)

Table 4. Alpha, Beta and Gamma indices by sieves.

Biol	600/300		600/75		600/40		300/75		300/40		75/40	
	600	300	600	75	600	40	300	75	300	40	75	40
α	12	14	12	36	12	32	14	36	16	32	36	32
ß	10		28		20		26		24		19	
γ	18		37		34		38		36		46	

The phytoplankton component of the zooplankton

During the course of the microscopic analysis of the plankton samples, it was observed that most phytoplankton were collected by the 40µ sieve, and then the 74µ sieve, the 600µ sieve didn't collect any phytoplankton. Phytoplankton were more abundant in Um-Hufayan than in the other sites, especially during summer. The most abundant groups of phytoplankton were centric and pinnate diatoms, followed by filamentous algae.

Micro-plastics among plankton

Microscopic examination of collected plankton samples revieled frequent presence of micro-plastics in form of fine fibers (few millimeters long) that were often brightly colored. It seems that these fibers were remnants of fishing nets and synthetic ropes that were used for setting, mooring and hauling nets, and anchoring boats.

DISCUSSION

Microscopic examination of live plankton samples immediately after collection from Al-Satah and Al-Warsh wave-break zones had shown that contained zooplankton were all intact, healthy and active, despite of the strong turbulence and friction created by repeated violent crashing of waves, wave after wave, hour after hour, and day after day, on the rocky shores, and the back currents as they reseed to sea through very rough and irregular meandering channels dug in shore rocks; this observation was confirmed later in the laboratory during microscopic examination of the fixed plankton samples.

Species richness and abundance are two common parameters used to characterize biodiversity. In the present study, altogether 45 species or lower taxa were encountered; richness by major group was Arthropoda, Protozoa, Chordata, Coelenterata (Cnidaria and Ctenophora), Mollusca, Annelida, gelatinous species, Rotifera, Nematoda, Chaetognatha, and Echinodermata. By the abundance of the number of individuals per major-groups or major-taxa, the order was Arthropoda, Protozoa, Mollusca, Annelida, Chordata, Platyhelminthes, Coelenterata, Nematoda, Rotifera, Chaetognatha, Echinodermata, and gelatinous species; the overall mean concentration of zooplankton in the study area was 23199 to 23764 individuals per m^3. The dominance of Arthropods and protozoa in marine plankton has been well documented (Gómez, 2012; Mollo and Noury, 2013; Dawson and Paredez, 2013); studies that did not report the dominance of

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protozoa generally used plankton nets with large mesh-size. For example, Mantha *et al*. (2019) reported that in the Gulf of Aqaba and the northern Red Sea, the most abundant taxa were Copepoda, Gastropoda, Bivalvia, Chaetognatha, Tunicata, and Ostracoda; altogether, 30 taxa covering 10 phyla were recorded. However, the total concertation of zooplankton was only 617.83 ± 201.84 individuals per m^3 compared to the 23764 ind. per m^3 of the present study. The disagreement may be due to a difference in the mesh size of their plankton net and the sieves we used, and because they collected the zooplankton from a depth of 200 m to the surface, while only surface zooplankton was collected in the present study. Zooplankton abundance generally decreases with depth (Longhurst, 1995); Fernández de Puelles (2019) mentioned that the zooplankton abundance in open sea epipelagic was usually >200 ind·m−3, 100 ind·m^{-3} in the mesopelagic layer, and < 3 ind·m^{-3} in the bathypelagic zone. However, Nowaczyk *et al*. (2011) using 120 µm mesh size bongo net and Niskin bottles found that zooplankton abundance across the epipelagic Mediterranean Sea varied from 872 ± 93 to 1407±687 ind.m^3. Heneash (2014) recorded 106 zooplankton species in the south-eastern Mediterranean Sea, Egypt; the average zooplankton population was 24×103 individuals m^{-3}, which is very close to the value obtained in the present study.

Even though 45 species/taxa were identified under the terms of the present study, the actual number of taxa or species present in sea at the study sites must have been several times higher. First, it is not possible to collect the tiniest zooplankton with sieves. The sieve with the smallest aperture we used was 40µ but a significant portion of the zooplankton is smaller than that. Second, it is extremely difficult, if not impossible, to identify zooplankton down to the species level. Aboul Ezz *et al*. (2014) found that the zooplankton community of Matrouh beach, in the south-eastern Mediterranean Sea, was characterized by low diversity and high variability due to seasonal changes in water temperature and salinity, among others, twenty-two protozoa and 14 copepods constituted 49 species; the average zooplankton abundance was 36.0×103 ind.m^3, (copepods 72.4%, protozoa 11.7%). Moore and Sander (1979) identified 87 species of zooplankters from oceanic, 84 from the shelf, 77 from the harbor mouth, and 66 from the harbor basin waters of the Caribbean Sea off Jamaica. Lue and Webber (2014) studied zooplankton from oceanic, shelf, and harbor waters, south-east coast, Jamaica by conducting vertical hauls with 64, 200, and 600µm mesh size-nets (compared to 40, 75, 300, and 600µm in the present study); in 106–114 taxa, the abundance of zooplankton ranged from 5,858.5 to 2,124.2 individuals/m3 (mean = 47). Leitao et al. (2019) studied connectivity between coastal and oceanic zooplankton from Rio Grande do Norte, tropical Western Atlantic, using 64, 120, and 300µm. They identified 199 taxa, 88 of them in the microzooplankton fraction, 115 in the mesozooplankton fraction, and 102 in the macrozooplankton fraction.

As it can be seen from the above discussion, recorded zooplankton biodiversity and abundance, among other factors, is a function of the mesh size of the net and the amount of water sieved. The smaller the mesh, the more plankton is collected. Therefore, zooplankton estimates given in the present work must be viewed as a comparative study

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involving sites and seasons and not an absolute measure of total zooplankton biodiversity.

Temporal and spatial variations in zooplankton diversity are a function of abiotic and biotic traits of the habitat that affect phytoplankton abundance, grazing by predators, patchiness, diel vertical migrations, the mesh-size of the collecting gear, and the amount of water sieved. Given this, in the present study, the difficulty of interpreting spatial (the three study sites) and temporal (the four seasons of the study period) variation in composition (types of taxa and species) and abundance (number of individuals per taxa or species) of zooplankton plankton must be obvious. Dissolved oxygen at the three study sites by season was relatively high and comparable. The same thing applies to the surface water temperature. The salinity of Um-Hufayan lagoon was, however, significantly lower than that of the other two sites. Al-Satah and Al-Warsh are close sites. The main difference is that Al-Haneah, a nearby small city, discharges its municipal wastewater directly into the Al-Warsh shore water, whereas the Al-Satah shore is clean. The bottom substratum of Um-Hufayan lagoon is soft, silty or sandy. The lagoon itself, being protected from winds, was generally calm and devoid of strong waves. On the other hand, the shores of Al-Satah and Al-Warsh were exposed and rocky; strong winds and waves prevailed all through the year. Um-Hufayan lagoon receives an appreciable amount of runoff during the fall in the form of temporary streams. The other two sites receive only the normal runoff expected for the eastern Libyan Mediterranean Sea coast. It, therefore, seems that differences in salinity, runoff regime, type of bottom substratum, and hydrographic conditions of waves and winds are the major determinants of the spatial and temporal differences in zooplankton diversity encountered within the three sites of the present study.

In the present study, the 40, and then the 74µ sieves collected most phytoplankton, while the 600µ sieve didn't collect any phytoplankton. The 75µ sieve collected most of the zooplankton, followed by the 40µ sieve, and then the 300 and 600µ sieves. This appeared to be a direct consequence of the smaller size of phytoplankton compared to zooplankton. The mesh size of plankton nets usually varies from 50 µm to 300 µm (University of Tasmania, 2013), depending on the size of the target organisms. In the present study, the most abundant groups of phytoplankton were centric and pinnate diatoms, followed by filamentous algae. It is commonly agreed among scientists that diatoms are the most abundant phytoplankton group in the sea.

In the present study, the presence of micro-plastics in the form of fine fibers, presumably remnants of fishing nets and boat anchoring ropes, was occasionally seen among the examined plankton of all sites, at all seasons, even though fishing activities were very moderate. Therefore, it seems that these micro-plastics have been accumulating for a long time. According to Marc (2015) plastic debris is a highly persistent material that is not biodegradable and thus tends to accumulate in the marine environment, where it is protected from UV, the major degradable factor on land (Hidalgo-Ruz *et al*., 2012).

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Implication to research and practice

Plankton in wave-breaking zones hasn't been examined thoroughly enough to draw broad conclusions regarding their characteristics and how they're influenced by wave activity and beach morphology. The current study concluded that high energy at wave-breaking zones is not harmful to plankton, but it was unable to provide light on the adaptations that allow plankton to do so.

When comparing regional and/or temporal plankton diversity (in all of its forms), the mesh size of the collecting device, as well as the amount of water sieved by it, must be considered; absolute diversity cannot be established.

CONCLUSIONS

- The violent bumping of waves on rocky shores does not harm plankton
- The descending order of zooplankton richness by the number of species per major-group/taxa was Arthropoda, Protozoa, Chordata, Coelenterata (Cnidaria and Ctenophora), Mollusca, Annelida, Platyhelminthes, Gelatinous species, Rotifera, Nematoda, Chaetognatha, and Echinodermata.
- Abundance by the number of individuals per major-group/taxa was of the order: Arthropoda, Protozoa, Mollusca, Annelida, Chordata, Platyhelminthes, Coelenterata, Nematoda, Rotifera, Chaetognatha, Echinodermata, and gelatinous species.
- The overall number of individuals per season was of the order of $8605m^{-1}$ zooplankton in spring, $7781m^{-1}$ in fall, $4638m^{-1}$ in summer, and $2367m^{-1}$ in winter.
- Altogether, 45 zooplankton species/taxa were encountered during the study. The Simpson index of dominance indicated that biodiversity was high.
- The order of species richness (S) was Al-Satah > Al-Warsh > Um-Hufayan. Evenness was highest in Al-Warsh and lowest in Um-Hufayan.
- Species diversity in ascending order by sieve was 40, 75, 300, and 600µm.
- Most phytoplankton were collected by the 40µ sieve, followed by the 74µ sieve.
- Encountered spatial and temporal differences in zooplankton diversity and abundance were probably due to differences in salinity, runoff regime, type of bottom substratum, and hydrographic conditions of winds and waves at sites during seasons.

Future research

The scientific community is encouraged to study plankton in the wave-breaking zone for the purpose of finding out how they avoid mechanical damage by wave action.

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