SEASONAL CHANGES IN THE ABUNDANCE AND BIOMASS OF ZOOPLANKTON FROM SHALLOW MUDFLAT RIVER-ESTUARINE SYSTEM IN PERSIAN GULF

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ABSTRACT

Farhadian, O. & Pouladi, M. (2014) Seasonal Changes in the abundance and biomass of zooplankton from shallow mudflat river-estuarine system in Persian Gulf . Braz. J. Aquat. Sci. Technol. 18(2):19-29. eISSN 1983-9057. DOI: 10.14210/bjast.v18n2.p19-29 The present study was designed to investigate the seasonal changes in the abundance and biomass of zooplankton and their relationships with water quality parameters in mudflat shallow estuary, Helleh River (HR), Persian Gulf (Iran). The zooplankton consisted of *Acartia*, *Euterpina*, *Oithona*, *Oncaea*, *Paracalanus*, *Corycaeus*, *Labidocera*, *Macrosetella*, *Microsetella*, *Temora*, copepod copepodid, copepod nauplii, Barnacle, Polychaeta, Conchoecia (Ostracoda), Hyperid, Decapoda (zoea and megalopa), Actinula, Echinopluteus, Mollusca, *Tintinnopsis*, *Boliopsis*, *Discorbis*, *Diastylis*, Siphonophora and Phialidium, *Pratylenchus*, *Oikopleura*, fish eggs and fish larvae. The maximum biomass was estimated at estuary mouth in all seasons, the highest values in autumn (97.8-255.6mg/m^3) and the lowest in winter (5.5-68.2mg/m^3). The seasonal abundance (density) of zooplankton was 21,237±2,419, 45,739±6,053, 5,242±648, and 12,905±1,867ind./m^3 in summer, autumn, winter and spring, respectively. There was a significant correlation ($P<0.01$) between zooplankton abundance as well as biomass with salinity, dissolved oxygen and chlorophyll *a*. Based on PCA (Principal Component Analysis), the most important factors in mudflat shallow river–estuarine system that could describe most changes of biomass and abundance of zooplankton were salinity, chlorophyll *a*, temperature and pH, respectively.

Keywords: Plankton; Estuary; Distribution; Temporal varation; Coastal waters.

INTRODUCTION

Estuaries are one of the high productive ecosystems (Mann, 2000; Miller Jr. & Spoolman, 2012) that are important both ecologically and economically. They are the appropriate places for spawning, and feeding of many aquatic larvae, including fish and shrimp (Ross & Epperly, 1985; Deegan & Day, 1985); they are also the protected area for wildlife such as migratory birds (Miller Jr & Spoolman, 2012). Estuaries are places for human activities such as navigation, shipping, urban, industrial wastes (Carlberg, 1980; Chau, 1999; Kress et al., 2002), and human settlements around them (Chi-Fang et al., 2004), fishing, aquaculture (Jennerjahn et al., 2004) and the resorts activities (Baird et al., 1986; Costanza et al., 1989). Furthermore, other activities such as deforestation, intensive farming, raising livestock, sand mining, river diversion, and conversion of mangrove forests into shrimp/fish ponds may change estuaries and the marine environments (Morton & Blackmore, 2001; Jennerjahan et al., 2004).

Estuaries are extremely variable in their physical (e.g. salinity, light, temperature and tide), chemical (e.g. NO_3, PO_4, dissolved oxygen and silicon) and biological parameters (Suthers & Rissik, 2009). These physico-chemical characteristics are the important factors that affect abundance, biomass, and population growth of zooplankton in estuaries (Joseph & Yamakanamardi, 2011). Zooplankton populations are highly sensitive to environmental variation. Therefore, changes in their abundance, biomass and diversity can clearly show that they are ecologically important (Jayansinghe, 2004; Suthers & Rissik, 2009). Their reproductive cycles, growth, reproduction and survival rates are all important factors that affect fish resources (Harris et al., 2000). On the other hand, zooplankton assemblages were used to monitor certain aspects of the environment including hydrographic events, eutrophication, pollution, global warming and environmental problems in terms of long-term changes (Omori & Ikeda, 1984). Since the composition and abundance of zooplankton are different at various aquatic environments, their biomass is ecologically very important.

The zooplankton density and biomass vary in different regions of the world. For instance, the zooplankton density ranged 15,000-255,000ind./m^3 in Cuba Bay (Zaballa & Gaudy, 1996), 45,261ind./m^3 in Bahuda estuary (Mishra & Panigrahy, 1999), 12, 918 ind./m^3 (adult copepod density of 2,927ind./m^3) from Straits of Malacca, Malaysia (Rezaei-Marnani, 2002), and 16,040 to 119,810ind./m^3 in Langat river estuary, Malaysia (Jayasinghe, 2004). Similarly, zooplankton biomass can greatly vary among estuaries, from time to time and place to place within an estuary (Knox, 1986). Srinivasan & Santhanam (1991) recorded a dry biomass of 738mg/m^3 for zooplankton of Pullavazhi, southeast coast of India. Jayasinghe (2004) stated dry biomass from 10.7 to 950.8mg/m^3 in the Langat river estuary, Malaysia. Rezaei-Marnani (2002) reported zooplankton biomass of 48.5 to 122.6mg dry weight/m^3 during different cruises in Straits of Malacca, Malaysia.

Zooplankton studies have been carried out in different parts of Persian Gulf (Grice & Gibson, 1978; Savari, 1982; Michel & Herring, 1984; Khodaddi, 1990; ROPME, 2003; Rabbanih *et al*., 2011). Michel & Herring (1984) estimated density of 45,000ind./m^3 for total zooplankton and 27,779 ind./m^3 for copepods from northern parts of Persian Gulf. Rabbanih *et al*. (2010) reported density of 1,470.5ind./m^3 at warm seasons (spring and summer) and 611.1ind./m^3 at cold seasons (autumn and winter) by using a 100µm plankton net from different stations of the northern part of Persian Gulf, Busheher waters. ROPME (2003) reported that the highest concentration of nutrients (NO_3, PO_4 and SiO_4) came to Persian Gulf from Iranian coastal waters. Therefore, proper management of nutrients loaded from rivers to Persian Gulf, and determination of the biomass and composition of planktonic assemblages at different parts of estuarine rivers, especially at estuarine waters, are essential to assess environmental conditions.

Helleh River (HR) is a permanent river with 170 km length that is discharged to the Persian Gulf at 54 km far from Busheher. The HR originates from southern part of Zagros Mountains, Iran. This river receives the Dalaki and Shapur rivers at the west of Shiraz, Fars province. The HR basin has an ecological importance for migratory birds, wildlife and aquatic organisms, especially fish. The ichthyofauna of HR basin was studied by Teimori et al. (2010). The HR estuary consists of brackish and freshwater lagoons with different depths (Table 1) throughout the year. Therefore, research on abundance, biomass, and composition of zooplankton is important for fishery management at HR estuary.

The main objective of this study was to determine zooplankton abundance, biomass and their possible ecological relationships with water quality parameters in HR estuary, Boushehr, the northern part of Persian Gulf, Iran.

MATERIALS AND METHODS

Study area and sampling

The study area was located in the HR estuary (28º20'N 51º30'E), in the southwestern part of Busheher province, north of Persian Gulf, Iran (Fig. 1). Along HR estuary, five sampling stations (Figure 1, Table 1) were determined based on environmental gradients of flow dynamics and mixing of fresh and costal water, depth, tides, river flow and geomorphological features.

Seasonal samplings were carried out in the middle of each season for a one-year period from August 2011 to April 2012. Measurements were made of water temperature, Secchi depth, dissolved oxygen (YSI 51 Oxygenmeter, OH, USA), pH (WTW 330 pHmeter, Weilheium, Germany) and salinity in situ. For measur-

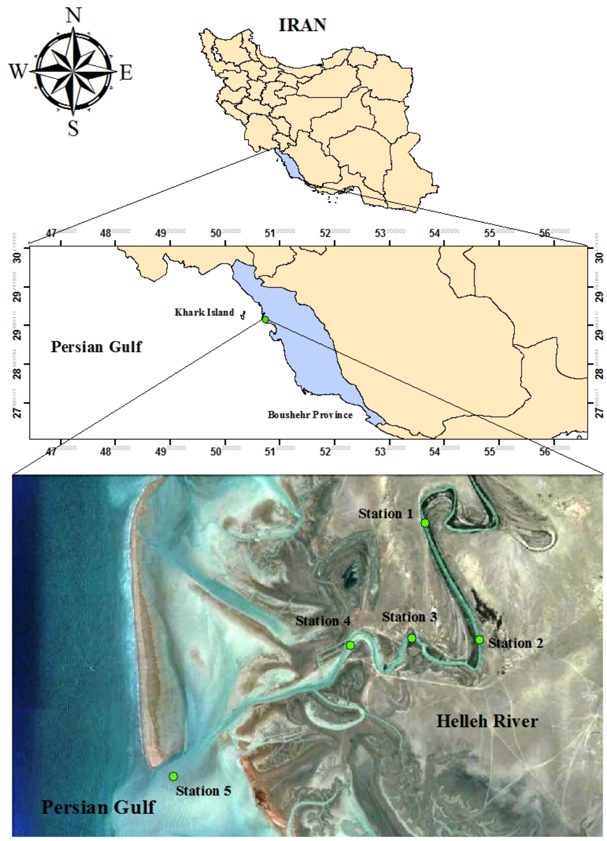

Figure 1. Stations and geographic locations in Helleh River estuary, Persian Gulf, Iran.

Table 1 - Sampling stations and their depth (m) in each season at Helleh River estuary, Persian Gulf, Iran.

Stations	Lat. N	Long. E	Depth (m)			
			Summer 2011	Autumn 2011	Winter 2012	Spring 2012
1	29° 10´ 21.9"	50° 40´ 38.5"	0.73	0.88	0.96	0.90
2	29° 09´ 37.1"	50° 41´03.2"	2.14	2.30	2.38	2.24
3	29° 09´ 36.8"	50° 40´32.9"	2.21	2.45	2.37	2.32
4	29° 09´ 35.3"	50° 40´04.9"	1.62	1.80	2.02	1.96
5	29° 08´ 39.3"	50° 38´54.1"	2.35	2.56	2.78	2.50

ing chlorophyll a, NO_3 and PO_4, three water samples of 3-L were collected from the water column at the sampling sites by a Van Dorn water sampler. The amounts of chlorophyll a, NO_3 and PO_4 were determined according to Parsons et al. (1984) in the laboratory. For phytoplankton studies, the water samples were collected from surface layer. The Lugol's iodine solution (10mL for 200mL sample) was used as the fixative of phytoplankton samples. The zooplankton samples were collected from middle of each season between 0800 and 1200 h by vertical haul using zooplankton net (bolting silk, 140μm mesh size, and diameter of 25cm) from the sampling sites with three sub-samples in the high tide of water. Zooplankton was immediately fixed in 5% formalin for the identification and quantitative estimation of relative density (abundance) of each zooplankton category.

Zooplankton

Zooplankton samples were initially put in their major taxonomic groups and enumeration was determined by using stereo microscopes (Olympus SZ6045, Japan) with the magnification of 6. Since the majority of the present study was comprised of copepods, the adult individuals were separated from the sub-samples and preserved in small glass bottles using 70% ethyl alcohol for species identification using zooplankton keys (Monchenko, 1974; Grindley, 1981; Maguire et al., 1985; Nishida, 1985, 1985; Todd & Laverack, 1991; Chihara & Murano, 1997). For the estimation of zooplankton density, each sample was kept in the measuring cylinder and adjusted to a known volume by adding distilled water, and then transferred to a wide mouth 250mL glass beaker. Next, a magnetic stirrer was set on the lowest speed for gently mixing of zooplankton sample and a sub-sample was taken using a Stemple pipette while it was mixed. The sub-samples were transferred to a zooplankton counting chamber (Bogorov's chamber) and zooplankton was counted under a dissecting microscope (Omori & Ikeda, 1984). The density of zooplankton was estimated according to formula of $D= (N/V_1) \times (V_2 \times F) /V$, where D= zooplankton density, N= sub-sample individuals, V_1= sub-sample volume, V_2 = volume of original sample, V= water filtered volume by plankton net, and F= net filtration efficiency (90%). Zooplankton dry biomass was calculated by Postel et al (2000) method through filtration and oven dried at 60°C for 24 hours.

Statistical Analysis

One-way ANOVA was performed to test significant seasonal differences in zooplankton density and water quality parameters. Data were presented as means ± standard error of means. Differences in means were compared by Duncan's Multiple Range Test. All percentage data were Arcsine-square root transformed and then tested for normal distribution and homogeneity of variance before performing ANOVA (Zar, 1984). All statistical analysis was carried out using SPSS, version 11.5. Pearson correlation was calculated for the abundance, biomass and water parameters.

RESULTS

Water quality

Seasonal average of temperature and dissolved oxygen and chlorophyll *a* were 32.4°C, 6.8mg/L and 110μg/L in summer; 19.2°C, 7.1mg/L and 380μg/L in autumn; 13.6°C, 11.3mg/L and 50μg/L in winter; 23°C, 8.4mg/L and 240μg/L in spring, respectively. Seasonal average of Secchi depth, salinity and pH were 44.4cm, 39.6ppt and 8.1 in summer; 48cm, 37.6ppt and 8.1 in autumn; 50cm, 17.2ppt and 8.1 in winter; 45.2cm, 27.8ppt and 8.2 in spring, respectively (Table 2). Seasonal average of PO_4 and NO_3 were 200 and 30μg/L in summer; 190 and 27μg/L in autumn; 120 and 23μg/L in winter; and 190 and 29μg/L in spring, respectively.

Zooplankton

The zooplankton consisted of *Acartia* sp., *Euterpina* sp., *Oithona* spp., *Oncaea* sp., *Paracalanus* sp., *Corycaeus* sp., *Labidocera* sp., *Macrosetella* sp., *Microsetella* sp., *Temora* sp., copepod copepodid, copepod nauplii, Barnacle larvae, Polychaeta larvae, Conchoecia sp., Hyperid larvae, Decapoda larvae (zoea and megalopa), Actinula larvae, Echinopluteus larvae, Mollusca larvae, *Tintinnopsis* sp., Ctenophora larvae (*Boliopsis* sp.), Protozoa (*Discorbis* sp.), cumacea (*Diastylis* sp.), Cnidaria larvae (Siphonophora and Phialidium), Nematoda larvae (Pratylenchus spp.), Urocordata (*Oikopleura* spp.), fish eggs and fish larvae (Tables 3-6). Among identified zooplanktons, *Acartia* sp. and copepod nauplius had highest density, respectively.

The seasonal abundance (density) of zooplankton was 21,237±2,419, 45,739±6,053, 5,242±648, and 12,905±1,867ind./m^3 in summer, autumn, winter and spring, respectively. The highest amount of zooplankton density was recorded at station 5 (estuary mouth) throughout the year (Tables 3-6). Dry biomass of zooplankton at HR estuary is presented in Tables 5-8. Amounts of dry biomass at stations of 1, 2, 3, 4, and 5 were 59.9, 69.8, 47.9, 86.8 and 99.4mg/m^3 in summer; 97.9, 146.5, 184.4, 140.7 and 255.6mg/m^3 in autumn; 11, 11.6, 8.3, 5.5 and 68.2mg/m^3 in winter; and 27.4, 28.5, 43.6, 47.6 and 102.5mg/m^3 in spring,

Table 2 - Average of water quality parameters in different seasons at Helleh River (HR) estuary.

Parameter	Summer 2011	Autumn 2011	Winter 2012	Spring 2012
Temperature (°C)	32.4 ± 1.1 ^{d}	19.2 ± 0.1 ^{b}	13.6 ± 0.2 ^{a}	23 ± 0.5 ^{c}
Salinity (ppt)	39.6 ± 1.2 ^{b}	37.6 ± 1.9 ^{b}	17.2 ± 6.3 ^{a}	27.8 ± 6.4 ^{ab}
DO (mg/L)	6.8 ± 0.1 ^{a}	7.1 ± 0.1 ^{a}	11.3 ± 0.3 ^{c}	8.4 ± 0.1 ^{b}
pH	8.1 ± 0.01 ^{a}	8.1 ± 0.03 ^{ab}	8.1 ± 0.01 ^{a}	8.2 ± 0.02 ^{b}
Secchi depth (cm)	44.4 ± 0.7 ^{a}	48 ± 0.7 ^{a}	50 ± 1.6 ^{a}	45.2 ± 1.8 ^{a}
Chlo. *a* (µg/L)	110 ± 20 ^{c}	380 ±50 ^{a}	50 ± 10 ^{d}	240 ± 10 ^{b}
PO_4 (µg/L)	200 ± 50^{a}	190 ± 30^{a}	120 ± 30 ^{a}	190 ± 30 ^{a}
NO_3(µg/L)	30 ± 7^{a}	27 ± 3^{a}	23 ± 4^{a}	29 ± 2^{a}

*Means in the same row sharing a common superscript are not significantly different (P>0.05).

Table 3 - Mean (±SE) abundance and dry biomass of zooplankton at different stations of Helleh River estuary in summer.

Zooplankton		Stations				
		1	2	3	4	5
Polychaete	*Tomopteris*	0	0	333±49	113±12	226±24
	Trochophore	0	266±28	0	0	340±37
	Veliger	110±6	340 ±42	0	0	1246±137
Calanoidae	*Acartia* sp.	3000±176	2493±311	2889±430	2833±311	1473±162
	Paracalanus sp.	4444±261	6006±749	1110±165	4873±536	1813±199
	Temora sp.	333±19	680±84	0	1133±124	906±99
Cyclopoidae	*Oithona* spp.	3777±222	793±98	1777±264	113±12	4306±474
Poecilostomatoida	*Oncaea* sp.	0	113±14	444±66	266±24	0
	Corycaeus sp.	4000±235	0	0	3371±371	0
Harpacticoida	*Microsetella* sp.	0	0	444±66	680±74	0
	Macrosetella sp.	0	0	0	0	680±74
Copepoda larvae	Copepodid	444±26	4080±509	3889±579	4760±523	3966±436
	Copepoda nauplii	0	2153±268	3555±529	3060±336	9180±1010
Ostracoda	Conchoecia spp.	0	113±14	0	0	0
Decapoda (*Hyoplax frater*)	Crab zoea	0	113±14	0	0	0
	Crab egg	0	266±28	0	0	0
Cirripedia	Barnacle Cyprid larvae	0	0	222±33	0	566±62
Amphipoda	Hyperia	0	906±113	555±82	0	1360±149
Urochordata	Fish embryo	222±131	0	0	0	0
	Oikopleura sp.	0	266±28	0	0	0
Cnidaria	Actinula larva	0	113±14	0	0	
Echinodermata	Echinopluteus larvae	110±16	680±84	0	0	113±12
Mollusca	Cephalopoda larvae	0	1020±127	666±99	793±87	0
	Gasteropod larvae	222±131	0	222±33	113±12	906±99
Protozoa	Globigerinid	222±131	0	0	0	0
Unidentified invertebrate eggs		333±19	1360±169	666±99	453±49	793±87
Total abundance (ind./m^3)		17217±1373	21761±2694	16772±2494	22561±2471	27874±3061
Seasonal abundance (ind./m^3)				21237±2419		
Dry biomass (mg/m3)		59.5	69.8	47.9	86.8	99.3
Seasonal mean dry biomass (mg/m3)				72.7±10.3		

Table 4 - Mean (±SE) abundance and dry biomass of zooplankton at different stations of Helleh River estuary in autumn.

Zooplankton		Stations				
		1	2	3	4	5
Polychaete	*Tomopteris*	181±25	0	0	0	0
	Trochophore	181±25	0	370±47	0	726±101
	Veliger	181±25	362±55	0	384±39	0
Calanoidae	*Acartia* sp.	4717±656	3084±469	1295±167	2269±276	10525±1462
	Paracalanus sp.	0	181±27	0	0	0
	Labidocera sp.	0	0	2777±360	192±19	1088±151
Cyclopoidae	*Oithona* spp.	1814±252	0	10184±1320	578±59	0
Poecilostomatoida	*Corycaeus* sp.	181±25	1088±165	55±72	192±19	362±50
Harpacticoida	*Microsetella* sp.	0	181±27	185±23	0	0
Copepod larvae	Copepodid	2359±328	544±82	2407±312	770±79	1633±277
	Copepoda nauplii	10707±1490	29215±4442	25182±3264	31004±3183	34663±4824
Ostracoda	*Conchoecia* spp.	363±50	362±55	185±23	192±19	362 ±50
Decapoda(*Hyoplax frater*)	Crab zoea	2540±353	362±55	185±23	192±19	362±50
	Crab megalopa	0	0	370±47	0	0
	Crab egg	0	907±137	0	192±19	0
Cirripedia	Barnacle nauplii	1814±252	3629±551	2036±264	384±39	9255±1288
	Barnacle Cyprid larvae	0	0	0	192±19	0
Amphipoda	Hyperia	0	0	0	192±19	0
Urochordata	Fish embryo	0	0	555±71	384±39	0
Cnidaria	Actinula larvae	0	0	185±23	0	0
Echinodermata	Echinopluteus larvae	0	0	0	0	181±25
Mollusca	Cephalopoda larvae	181±25	0	0	0	181±25
	Gasteropod larvae	544±75	2177±331	1851±240	1540±158	1269±176
Protozoa	*Tintinnopsis* sp.	0	362±55	185±23	192±19	726±101
Unidentified invertebrate eggs		3810±530	181±27	2036±264	2269±276	3991±555
Total abundance (ind./m^3)		29573±4111	42635±6478	50043±6543	41118 ±4300	65324±8835
Seasonal abundance (ind./m^3)				45739±6053		
Dry biomass (mg/m^3)		97.8	146.5	184.4	140.7	255.6
Seasonal mean dry biomass (mg/m^3)				165.0±29.0		

Oithona spp= *O. oculata, O. nana, O. frigida, O. brevicornis, O. fallax*

respectively. Results also indicated that the mouth of the estuary procured the highest zooplankton biomass.

Zooplankton and water quality relationships

The correlation between water parameters and zooplankton is presented in Table 7. Results showed that there was a significant correlation ($P<0.05$) between zooplankton abundance and salinity ($r=0.68$), biomass and salinity ($r=0.67$), abundance and dissolved oxygen ($r=-0.59$) and biomass and dissolved oxygen ($r=-0.54$), abundance and chlorophyll *a* ($r=0.71$), biomass and chlorophyll *a* ($r=0.68$). Principle component analysis (PCA) showed that chlorophyll *a* and salinity had the highest positive correlation while dissolved oxygen had a negative correlation that could describe changes of zooplankton density and biomass in different seasons (Table 8).

DISCUSSION

Plankton is important for sustainable fisheries management based on biological, ecological, and economical aspects. Evaluation of zooplankton biomass in the estuarine systems for better management of fish and shrimp stocks is essential. There are seasonal variations in biomass and abundance of zooplankton in the estuaries that vary significantly according to the changing water quality, tides and other important factors such as phytoplankton and zooplankton community structures. The biomass and abundance of zooplankton in the present study were the highest in autumn at mouth of HR estuary (station 5). The zooplankton biomass values obtained in HR estuary were among the highest in the literature within Persian Gulf waters. This was due to high thermal tolerance, environmental and reproductive conditions of zooplankton living (Xuelu et al., 2011). In contrary, the reduction of dry biomass and abundance of zooplankton in winter

Table 5 - Mean (±SE) abundance and dry biomass of zooplankton at different stations of Helleh River estuary in winter.

Zooplankton		Stations				
		1	2	3	4	5
Calanoidae	*Acartia* sp.	0	0	0	113±14	0
	Labidocera sp.	0	0	0	0	793±87
Poecilostomatoida	*Oncaea* sp.	0	0	0	0	340±37
	Corycaeus sp.	0	108±16	210±34	0	0
Copepod larvae	Copepoda nauplii	555±72	980±149	632±103	113±14	4646±511
Ostracoda	Conchoecia spp.	222±28	218±33	0	0	906±99
Amphipoda	Hyperia	0	108±16	0	0	0
Urochordata	*Oikopleura* sp.	0	0	0	0	266±24
Cnidaria	Siphonophora	0	108±16	104±17	0	0
	Phialidium	0	0	0	0	2946±324
Ctenophora	*Boliopsis* sp.	333±43	0	0	0	0
Mollusca	Cephalopoda larvae	0	326±49	206±37	0	340±37
	Gasteropod larvae	0	108±16	207±73	113±14	266±24
Nematod	*Pratylenchus* spp.	1444±187	326±49	210±34	906±113	113±11
Protozoa	*Discorbis* sp.	0	326±49	0	113±14	0
Unidentified invertebrate eggs		333±43	544±82	737±120	113±14	5780±636
Total abundance (ind./m^3)		2887±373	3152±475	2306±418	1471±183	16396±1790
Seasonal abundance (ind./m^3)				5242±648		
Dry biomass (mg/m3)		11.0	11.6	8.3	5.5	68.2
Seasonal mean dry biomass (mg/m3)				20.9±13.3		

can be related to low water temperatures, poor living conditions and reduction of photosynthetic primary production and chlorophyll *a* (Omori & Ikeda, 1984; Day et al., 1989). In addition to the relative small mesh sized net (140 μm) employed, some of the smaller zooplankton components were caught, which, in turn, might have increased the biomass values as reported by Morioka et al. (1990) and Nakashima et al. (1992). The depth of sampling in different sampling stations in HR was almost less than 2.5 m, indicating that the shorter distance of vertical haul might have also given the larger component of phytoplankton in the net collection.

Different groups of zooplankton were identified in this estuary. The copepod, mostly calanoid, was the dominant assemblage in HR estuary. Similar zooplankton groups were common in other estuaries (Tiwari and Nair, 1993; Wooldridge and Callahan, 2000; Primo et al., 2009; Hwang et al., 2010; Xuelu et al., 2011). In fact, distribution of zooplankton populations is mostly governed by various behavioral and physiological adaptations to ever changing hydrographical conditions (Mohan et al., 1999). It depends on the regime of individual estuaries which varies according to climate and the catchments area of its feeder river. Furthermore, Vucetic (1973) maintains that the geographic distribution of zooplankton depends on the different conditions for feeding and reproduction in various biotopes. The mudflats biotope of HR estuary makes water rich in some important nutrients from bottom into the water column and increases the primary production and chlorophyll *a* (Chua, 1970).

The various features of estuarine ecosystems stem from salinity gradient along estuary. This is mainly due to the strength of diurnal tidal current, which comes from the sea and the volume of freshwater flow from the upstream. In this study, salinity had a positive correlation (Table 7) and it was an effective factor (Table 8) on abundance and biomass of zooplankton, especially at mouth of estuary. Salinity affects the overall composition of the zooplankton community and also, the individual species at different stages of their life cycle (Day et al., 1989). In addition, salinity is the most important factor influencing the community structure of zooplankton populations in tropical and subtropical estuaries (Lee and Olsen, 1985; Mitral et al., 1990; Lopes, 1994, Nasser et al., 1998; Hwang et al., 2010) as well as zooplankton density (Fernandex de Puelles et al., 2003; Hwang et al., 2010). Moreover, Mishara and Panigrahy (1999) noted salinity as the most important factor in the distribution of zooplankton (specifically copepods) in the estuaries. They reported that freshwater flowing into estuaries decreased the zooplankton densities.

In some cases, other physico-chemical parameters such as Secchi disk and chlorophyll *a* have some

Table 6 - Mean (±SE) abundance and dry biomass of zooplankton at different stations of Helleh River estuary in spring.

Zooplankton		Stations 1	2	3	4	5
Polychaete	*Tomopteris*	0	362±63	0	370±47	740±110
	Trochophore	0	0	533±85	370±47	370±55
	Veliger	0	1269±222	711±113	0	370±55
Calanoidae	*Acartia* sp.	544±75	0	177±28	925±120	925±137
	Paracalanus sp.	0	0	711±113	0	370±55
Cyclopoidae	*Oithona* spp.	362±50	362±63	177±28	555±72	370±55
Poecilostomatoida	*Oncaea* sp.	181±25	0	355±56	370±47	555±82
Harpacticoida	*Euterpina* sp.	181±25	0	0	0	370±55
	Microsetella sp.	0	0	355±56	370±47	370±55
Copepod larvae	Copepodid	362±50	0	355±56	0	740±110
	Copepoda nauplii	1814±252	1452±254	1244±198	4259±552	6110±910
Ostracoda	Conchoecia spp.	0	1088±190	355±56	370±47	555±82
Cumacea	Diastylis sp.	0	0	177±28	0	0
Decapoda (*Hyoplax frater*)	Crab zoea	181±25	0	177±28	0	370±55
Cirripedia	Barnacle nauplii	362±50	0	0	0	1110±165
(*Balanus improvisus*)	Barnacle Cyprid larvae	0	0	0	185±23	0
Amphipoda	Hyperia	0	0	0	0	185±27
Aschelminthes	*Brachionus* plicatilis	362±50	0	355±56	0	740±110
Urochordata	Fish embryo	726±101	0	0	0	555±82
	Oikopleura sp.	0	0	177±28	555±72	2407±358
Cnidaria	Siphonophora	0	0	355±56	0	555±82
Mollusca	Cephalopoda larvae	362±50	362±63	1244±198	555±72	370±55
	Gasteropod larvae	0	1269±222	1955±311	925±120	1259±193
Nematod	*Pratylenchus* spp.	544±75	726±127	533±85	555±72	925±137
Protozoa	*Tintinnopsis* sp.	181±25	0	0	555±72	370±55
Unidentified invertebrate eggs		1814±252	907±158	1600±254	1150±111	4259±634
Total abundance (ind./m^3)		7976±1105	7797±1362	11546±1607	12069±1521	24950±3741
Seasonal abundance (ind./m^3)				12905±1867		
Dry biomass (mg/m^3)		27.4	28.5	43.6	47.6	102.5
Seasonal mean dry biomass (mg/m^3)				49.9±15.4		

Oithona spp= *O. oculata, O. nana, O. frigida, O. brevicornis, O. fallax*

Table 7 - Pearson correlation coefficients between some of the properties of water with abundance and biomass of zooplankton biomass in Helleh River estuary.

Parameter	Abundance	Biomass
Temperature	0.113 (0.634)	0.075 (0.754)
Salinity	0.677 ** (0.001)	0.671 **(0.001)
Dissolved oxygen	-0.589 **(0.006)	-0.537 **(0.015)
pH	0.121(0.612)	0.184 (0.438)
Secchi depth	-0.240 (0.921)	0.004 (0.988)
Chlorophyll *a*	0.708 **(0.001)	0.682 **(0.001)
PO_4	0.411 (0.072)	0.443 (0.051)
NO_3	-0.041 (0.864)	-0.070 (0.771)

**: Significant correlation in 0.01 level. Data in parenthesis are F-values.

Table 8 - Seasonal PCA analysis of zooplankton abundance, biomass and water quality parameters at Helleh River estuary.

	Components		
Parameters	1	2	3
Temperature	0.785	0.228	-0.424
Salinity	0.822	0.000	0.045
Dissolved oxygen	-0.881	0.344	0.223
pH	0.168	0.347	0.719
Secchi depth	-0.394	0.653	0.179
Abundance	0.841	0.476	-0.164
Biomass	0.822	0.517	-0.095
Chlorophyll *a*	0.655	0.425	-0.195
PO_4	0.573	-0.067	0.581
NO_3	0.298	-0.527	0.272
Percent of variance	41.76	21.54	10.91

effects on zooplankton biomass. According to Nair et al (1981), zooplankton biomass was declined with the increase of turbidity of water in an Indian estuary. On the other hand, density of copepod Acartidae had a positive correlation with chlorophyll *a* in La Habana (Cuba) (Lee and Olsen, 1985; Zaballa and Gaudy, 1996). In the current study, chlorophyll *a* had a positive correlation and also, it was effective factor (based on PCA analysis) on zooplankton density and biomass at sampling locations (stations), especially at the mouth of estuary. However, this significance correlation indicated that zooplankton biomass was regulated mostly by food supply and quality of food (Verity, 1987). The availability of food items is one of the major factors determining the zooplankton distribution (Cox and Wiebe, 1979; Mitra et al., 1990; Park and Marshall; 2000).

In this study, temperature had a poor correlation with the density and biomass of zooplankton. Although several authors (Madhupratap, 1987; Mishra and Panigrahy, 1999) showed that temperature had an insignificant effect on tropical zooplankton populations, some available literature (Osore, 1992; Lopes, 1994; Nasser et al., 1998) noted temperature as an important factor affecting the abundance and distribution of zooplankton populations. According to Day et al (1989), the main factors of temperature, food supply and predation controlled zooplankton distribution in estuarine ecosystems.

The seasonal study in HR estuary showed that dissolved oxygen had a negative correlation with density and biomass. In addition, dissolved oxygen is the other critical variable that should be considered in evaluating the water quality in estuaries. The low dissolved oxygen concentration of a water body directly affects the survival of aquatic organisms, thereby altering estuarine healthy ecological balance (Zheng et al., 2004). Frequent occurrences of hypoxia due to the sudden decrease of dissolved oxygen caused the significant reduction of fishery harvests, toxic algal blooms and the loss of biotic diversity (Pearl, 1988; Howarth et al., 2000). The variances of dissolved oxygen in estuaries were controlled by physical and biochemical processes (Ambrose et al., 1993; Chen 2003). According to Upadhyay (1988), the high concentration of dissolved oxygen was also correlated with high pH. In all seasons, pH was in alkaline range and based on PCA analysis, it was a very effective factor on stations with the highest density and biomass. Alkaline pH usually provides the best conditions for the growth of zooplankton (Arnott and Vanni, 1993; Bhuiyan and Nessa, 1998).

To conclude, this research showed that the highest density and biomass of zooplankton was at mouth area of estuary in all seasons which had a positive significant correlation with salinity and chlorophyll *a* in HR estuary, Persian Gulf.

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