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Original Article

Seasonal variation of zooplankton abundance, composition and biomass in the Chabahar Bay, Oman Sea

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Abstract: Temporal and spatial variation of zooplankton abundance, composition and biomass were examined on the Chabahar Bay, Oman Sea. The Chabahar Bay, a subtropical and semi-enclosed bay, provides an ideal breeding ground for many fish and shellfish. Five stations were investigated along the Bay. This area is under the influence of the Indian Ocean seasonal monsoons. Zooplankton was collected with vertical plankton tows using 100 µm mesh nets. Copepods dominated the zooplankton community followed by larvacea, cladocera and chaetognatha. Fifteen taxa of zooplankton were identified. *Oithona nana* and *Euterpina acutifrons* were dominated in the whole year and Larvacea showed a bloom in Northeast Monsoon. A Two-way ANOVA indicated that there were differences in abundance and biomass between sampling periods and between stations were significant. The peak zooplankton abundance in NE Monsoon could be due to winter cooling, with entrainment of nutrients into the upper layer producing phytoplankton blooms. The decline of zooplankton abundance and biomass in South West Monsoon and post-monsoon could be explained by decrease in chlorophyll a concentrations. The present result showed the composition and distribution of zooplankton differed between the monsoon seasons, resulted from changes in hydrographic conditions.

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Introduction

The Chabahar Bay is a small semi-enclosed bay on the southeastern coasts of Iran (25° 17' 45"N - 60° 37' 45" E). The Bay is connected to the Indian Ocean through Oman Sea. The effect of Indian monsoonal winds on this area is remarkable (Fazeli and Zare, 2011). This bay is one of the five major ports in Oman Sea and provides an ideal breeding ground for many fish and shell fish (Wilson, 2000). The bay is located between Chabahar and Konarak. It is 14 km wide and has a surface area of 290 km^2.The average depth of the bay is 12 m (ranging from 8-22 m) (Fazeli and Zare, 2011).

Oman Sea is located in the northwest of the Arabian Sea. The continental shelf of the region is widest off the northwest coast of India, which also experiences wind-induced upwelling. The Asia monsoon in Oman Sea is characterized by two distinct seasons separated by two transition (inter-monsoon) periods: the Southwest (SW) Monsoon from June through September and the Northeast Monsoon (NE) from December through March with the spring transition (pre-monsoon) occurs in April and May and the fall transition (post-monsoon) occurs in October and November, respectively. Southwesterly flow has a direct effect on the Arabian Sea, coast of Oman, Oman Sea, the Arabian Sea, coast of Iran, southern Pakistan, and India (Caulfield, 1990).

Although the information of the Chabahar Bay is rare, the effect of monsoon has been studied well in the region. In SW Monsoon, a peak in chlorophyll a biomass dominates in the Indian Ocean (Yoder et al.,

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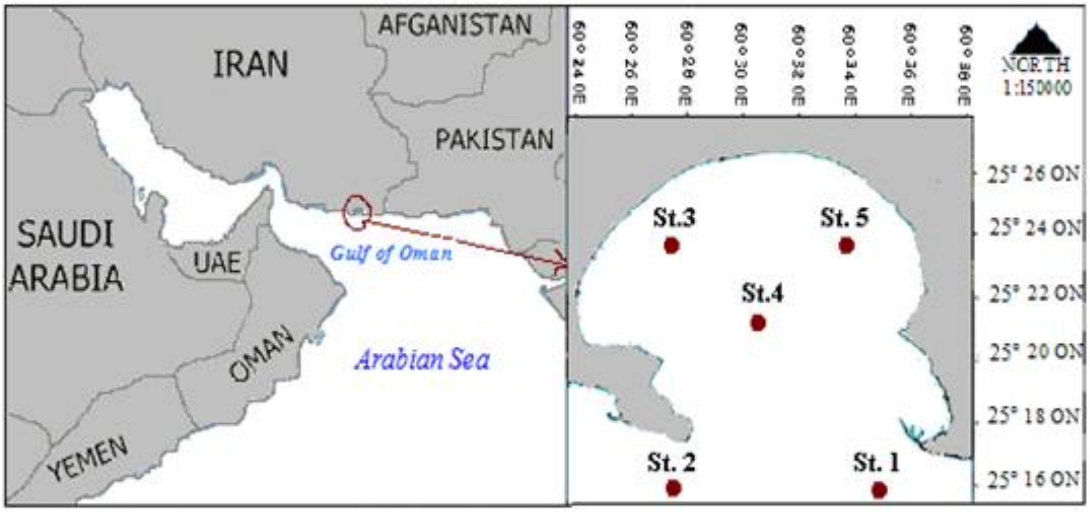

Figure 1. Map of sampling stations in the Chabahar Bay.

1993). Lower salinity water reach the sea surface in coastal upwelling that occurs in this season along the coast of Oman (Morrision et al., 1998). Prominent features along the Oman coast generated during the SW Monsoon tend to linger in place during the fall transition. During the autumnal inter-monsoon, water temperatures decreases slowly. Average sea temperatures decreases from 28 and 29 °C in October to 27 °C in November (Caulfield, 1990). Oligotrophic conditions return slowly, but during the northeast monsoon winter cooling may imply the entrainment of new nutrients into the upper layer during windy periods, resulting blooms of phytoplankton (Baars, 1998). The cool, dry northeasterly winds that characterize the NE Monsoon result in a typical winter time convection/nutrient enrichment scenario in the northern Arabian Sea (Banse and McClain, 1986; Madhupratap et al., 1996). Evaporative cooling increases the salinity of the surface waters, which further promotes the convective mixing (Wiggert et al., 2000). Donguy and Meyers (1996) defined a surface water mass with a salinity between 35.5-36.5 ppt and temperatures greater than in the 22 °C in the Arabian Sea Waters. The productivity observed during the NE Monsoon was much higher than anticipated (Mahdupratap et al., 1996b). Convective mixing during the NE Monsoon (Weller et al., 1998; Wiggert et al., 2000) turned out to be an important source of nutrients. Water temperatures decreases from 25 °C in December to 21 °C in February, then rise to 23 °C in March (Caulfield, 1990). After the termination of winter cooling and subsequent warming during the spring inter-monsoon, when primary production drops, bacteria and microzooplankton proliferate. This suggests that the organisms of the microbial loop may be an important food source that sustains mesozooplanktons throughout this period (Madhupratap et al., 1996), when water temperatures ranges from 25 °C in April to 29 °C in May (Caulfield, 1990).

Importance of zooplankton in marine pelagic food webs as food for larval fish (Jitlang et al., 2007) and as a good indicator of changes in water quality (Gannon and Stemberger, 1978). Many studies have described zooplankton and copepod community structure in many parts of Indian Ocean, Arabian Sea and the Persian Gulf (Madhupratap, 1987; Smith, 1995; Baars, 1998; Savari et al., 2004; Madhu et al., 2007) but there is little published information on them in the Chabahar Bay (Wilson, 2000). The propose of the present investigation is to describe the zooplankton community in the Chabahar Bay - Oman Sea, and provide an estimation of abundance, composition, biomass and their distribution influenced by monsoons.

Materials and methods

Sampling was performed in August 2007 (South West Monsoon), November 2007 (post-monsoon),

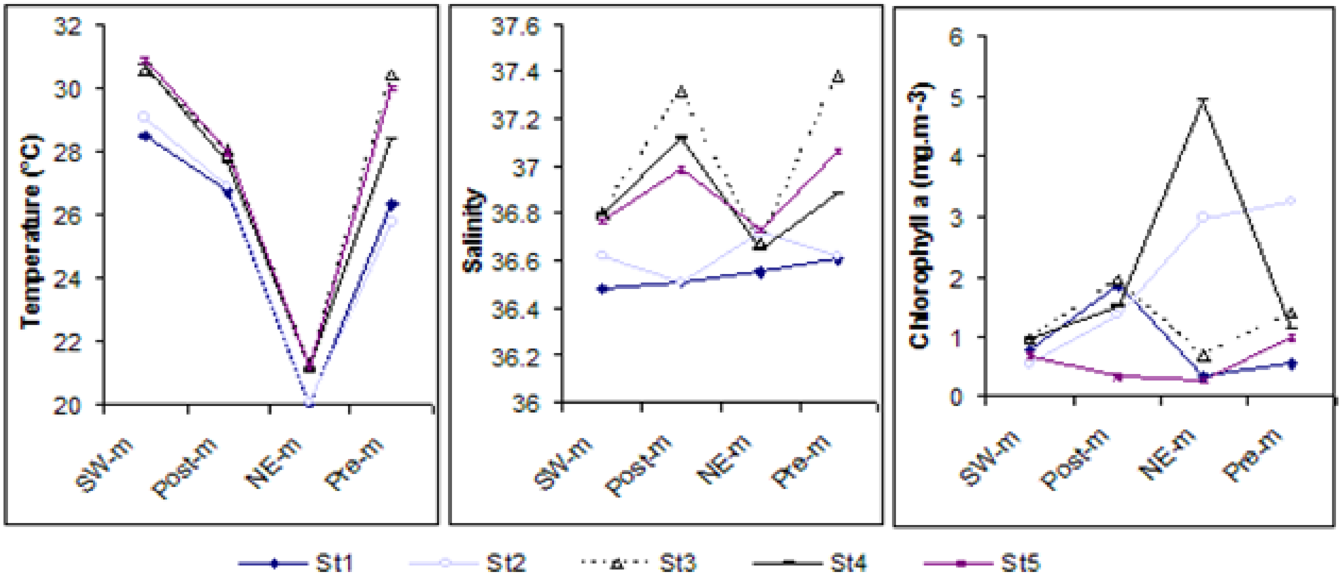

Figure 2. Seasonal variation of major environmental parameters in the Chabahar Bay (x axis as seasons and Y axis as environmental parameters) (SW-m=SW Monsoon, post-m=post-monsoon, NE-m=NE Monsoon, pre-m=pre-monsoon).

February 2008 (North East Monsoon), and May 2008 (pre-monsoon). Five stations were selected in the Chabahar Bay (Fig. 1): two stations (Stations 1 and 2) were located far from shore waters (22 m depth), while the other two (Stations 3 and 5) were near the shore (6 m depth), and the final station (Station 4) was located in the middle of the bay (12 m depth).

Quadruple plankton samples were collected vertically at each station using a simple net (with a mouth diameter of 30 cm and a mesh size of 100 µm), with a Hydrobios flow meter mounted in the center of the net opening to estimate volume of the water, from the quadruple samples, two were used for counting and the other two for biomass measurement. The samples were immediately preserved in 4-5% formalin, buffered to a pH of 8 with sodium tetra borate (Borax), and identified to the lowest taxa possible. Zooplankton abundance was expressed as individuals m^{-3} (Somoue et al., 2005). At each station, prior to taking a plankton sample, the environmental parameters were recorded using CTD profiler lowered from the sea surface to near the bottom. Zooplankton was identified to species level using the keys of Chen et al. (1965), Nishida (1985), Krishnapillai (1986) and Conway et al. (2003).

Dry weight was calculated after drying organisms for 20 hours at 60 °C (Edmondson and Winberg, 1971). Weights were estimated using a microbalance Mettler MT5. Single large organisms > 1 cm (fish, large crustaceans and medusae) were weighed separately and were not included in the biomass data (Böttger-Schnack, 1990).

The Pearson correlation was performed to determine the significant relationship between environmental parameters and zooplankton abundance and biomass. Species diversity was calculated using Shannon–Weaver diversity index (Shannon and Weaver, 1949) and species richness (Margalef, 1968). The data were further subjected to hierarchical clustering analysis to identify the similarity between stations based on the composition of zooplankton. Using Bray-Curtis similarity index with log10 (x+1) data transformation using PRIMER version 5.2.8 (Clarke and Warwick, 1994).

Results

Environmental variables: Seasonal changes in environmental parameters are shown in Figure 2. The mean of water temperature varied from (20.52 ± 0.20 °C) in NE Monsoon to (29.92 ± 0.05 °C in SW Monsoon. The mean of salinity ranged from (36.70 ± 0.06) in SW Monsoon

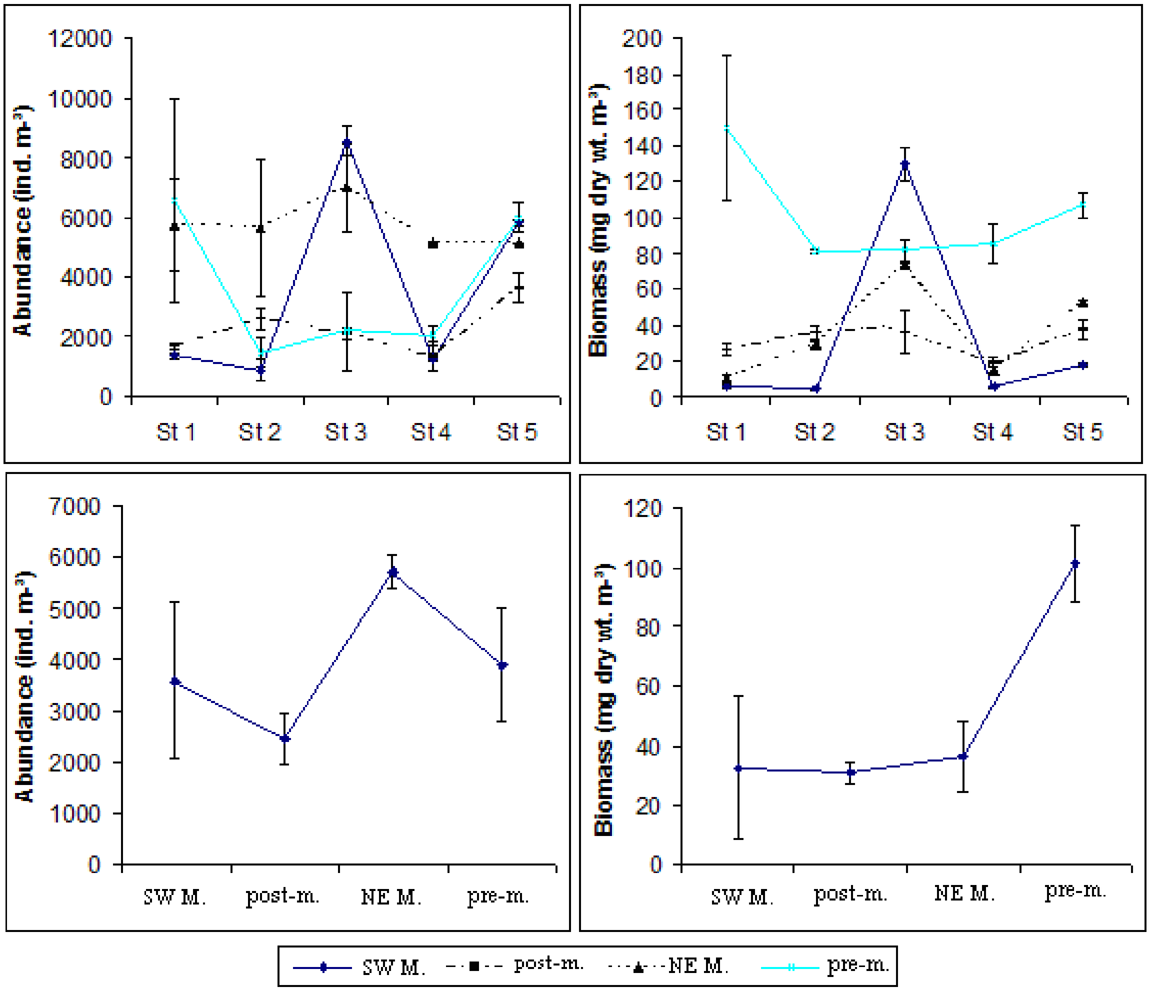

Figure 3. Temporal and spatial variation of zooplankton abundance and dry-weight in the Chabahar Bay.

to (36.91) in pre-monsoon. The minimum and maximum value of chlorophyll α concentrations were noticed (0.77 ± 0.08 mg.m^{-3}) to (1.84 ± 0.92 mg.m1^{-3}) in SW Monsoon and NE Monsoon, respectively.

Zooplankton abundance and biomass: Seasonally, mean abundance of zooplankton varied considerably (Fig. 3). The highest abundance of zooplankton was in NE Monsoon (5728 ± 337.20 individuals m^{-3}) and the lowest was in post-monsoon (2453 ± 480.14 individuals m^{-3}). Dry weight biomass was observed highest in pre-monsoon (101.10 ± 13.11 mg dry wt. m^{-3}) compared to other periods. Post-monsoon was characterized by lowest dry weight biomass value of 30.80 ± 6.54 mg dry wt. m^{-3}. Near shore stations (3 and 5) showed maximum zooplankton abundance and dry weight biomass, while offshore stations (1 and 2) showed the lowest (Fig. 3).

Taxa composition: Figure 4 shows total identified zooplankton in the Chabahar Bay. Copepods dominated the zooplankton community followed by larvacea, cladocera and chaetognatha. The other dominant groups comprised ostracoda, siphonophora, decapoda and thalliacea. Other taxa were rarely encountered.

Copepods were the dominant group during four seasons, reaching 1254 ± 302.65 individuals m^{-3} during pre-monsoon, 613 ± 326.35 individuals m^{-3} during SW Monsoon, 594 ± 54.11 individuals m^{-3} during post-monsoon and 890 ± 161.7 individuals m^{-3} in NE Monsoon.

Copepod species belonging to 18 families were recorded during the investigation period (Table 1). Some species were observed only in one season with lowest abundance (< 25 individuals m^{-3}) such as *Sapphirina gastrica*, *Sapphirina nigromoculata*,

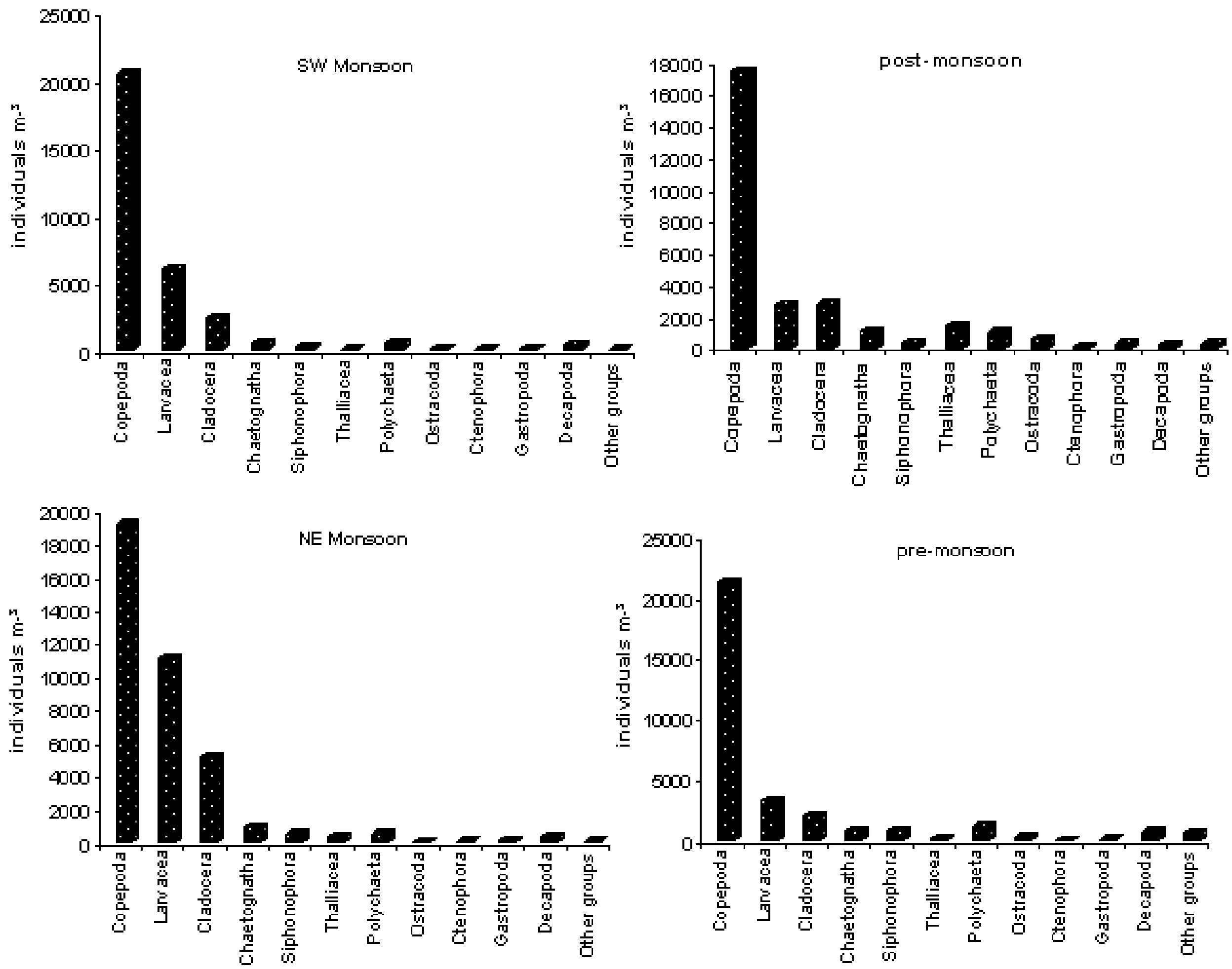

Figure 4. Relative abundance (individuals m^{-3}) of dominant groups of zooplankton in the Chabahar Bay.

Lucicutia flavicornis, *Lucicutia gaussae* that only occurred during post-monsoon. *Oithona fallax*, *Paracandacia truncata* and *Euchaeta marina* were observed only during NE Monsoon. *Bestiolina similis* and *Delibus nudus* just appeared during pre-monsoon. *Euterpina acutifrons*, *Macrosetella gracilis* and *Microsetella rosea* were observed in highest abundance during pre-monsoon. *Temora turbinata* were greater during pre-monsoon and NE Monsoon than other seasons. Moreover, *Pseudodiaptomus marinus* increased remarkably during NE Monsoon but was rarely observed in other seasons.

Larvacea: A bloom of larvacea was noticed in NE Monsoon while it completely disappeared during pre-monsoon. Among them *Oikopleura longicauda* was the most dominant species. Their abundances ranged from 1136 to 16778 individuals m^{-3}.

Cladocera: Cladocera was present all year round but in large number (5104.11 individuals m^{-3}) in NE Monsoon. The highest abundance was found in station 3 (8471.80 individuals m^{-3}). Their abundances ranged from 166 to 15389 individuals m^{-3}. *Evadne* sp. was dominant during four periods but showed highest abundance in NE Monsoon at station 3.

Chaetognatha: The most dominant chaetognatha species was *Sagitta enflata* and *Sagitta* sp. and thrived best in post-monsoon. Maximum number of chaetognatha was found at station 4 with a mean of 1349 individuals m^{-3}.

Other dominant groups: Siphonophora occurred throughout the year but were most abundant during pre-monsoon. They were represented by *Bassia bassensia*. Siphonophora abundance ranged from 1

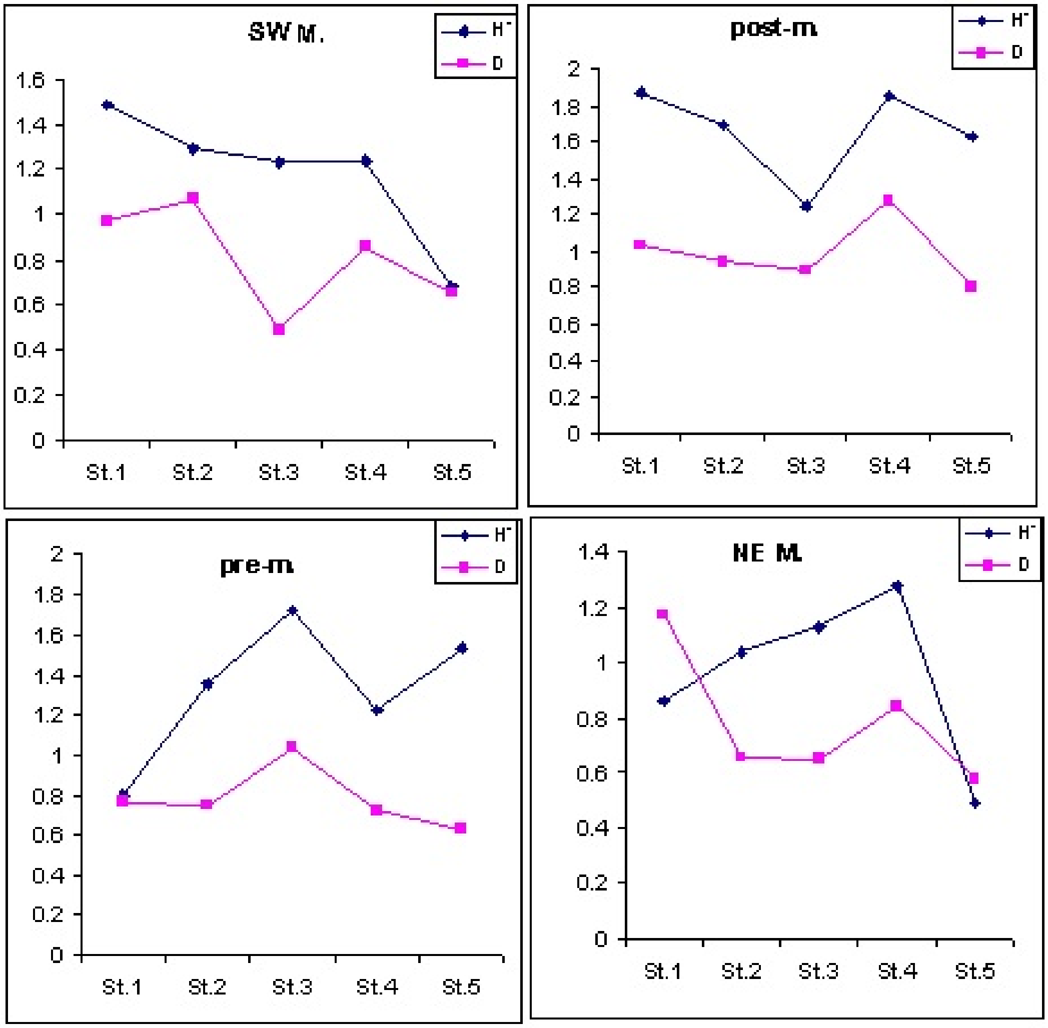

Figure 5. Diversity indices (H') and species richness (D) of zooplankton (SW M=SW Monsoon, post-m=post-monsoon, NE M=NE Monsoon, pre-m=pre-monsoon).

to 2653 individuals m^{-3}; the maximum value was found at station 5 with an average of 1124 individuals m^{-3}. Ctenophora was rare and present in low number ranging from 0 to 60 individuals m^{-3}. They were completely absent in pre-monsoon. Ctenophora was not observed at station 5.

Among thaliaceans, *Doliolum* sp. was common in distribution. The maximum number of thaliaceans was found at station 5 (mean of 957 individuals m^{-3}). Their abundances ranged from 45 to 2653 individuals m^{-3}.

Polychaete larvae ranged from 1 to 3301 individuals m^{-3}, and reached to the highest abundance in pre-monsoon (average of 1084 individuals m^{-3}).

Ostracoda showed highest abundance (472 individuals m^{-3}) in post-monsoon and disappeared in NE Monsoon. The lowest abundance was observed at station 4 (25 individuals m^{-3}) and completely absent at station 5.

Amongst mollusks, the most dominant gastropoda were *Atlanta helicinoides*. *Pterotrachea hippocampus* was oly observed in station 4 and only during pre-monsoon.

Crustacea (copepods, decapods, ostracods and euphausids) were highly encountered in pre-monsoon as compared to other periods. They comprised ~80% of the zooplankton community in this season. Echinodermata were rare in distribution and consisted of Auricularia larvae and Ophiopluteus larvae.

Zooplankton diversity and composition: Zooplankton species showed wide variations in diversity (0.49–1.87) and richness (0.49–1.27). Highest diversity and richness values were observed at Stations 1 and 2 (off shore stations) compared to the other stations. Peak diversity occurred in post-monsoon and the lowest was in NE Monsoon. The highest and lowest richness was observed in post-monsoon and pre-monsoon respectively (Fig. 5).

The cluster analyses indicated a relatively high degree of homogeneity in the zooplankton composition between stations 2 and 4 during a year (Fig. 6). The similarity was lowest between stations 2-4 and station 5.

Environmental parameters and zooplankton: It seems chlorophyll α, temperature and depth are major factors controlling distribution of zooplankton in the Chabahar Bay. Pearson correlation showed a positive relationship between chlorophyll α value and zooplankton and copepod abundance (Table 2). Total zooplankton abundance and copepod indicated a positive relation with dry weight biomass. Among zooplankton groups, a negative relationship was observed between larvacea and temperature, and between ctenophora and biomass. Siphonophora negatively related to depth. Also, a positive relationship was observed between depth and abundance of ostracoda.

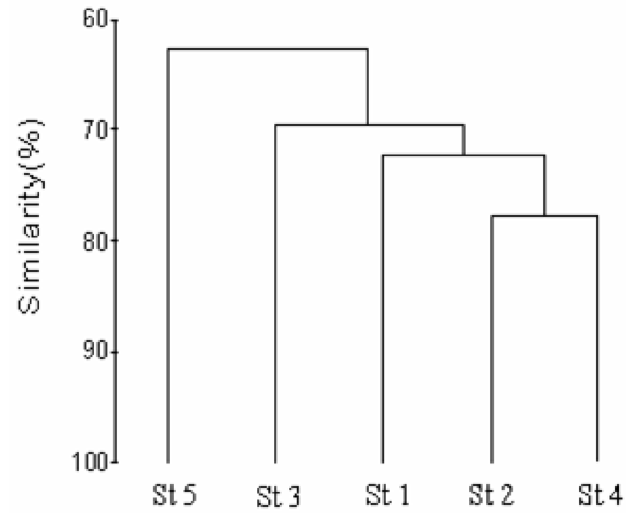

Figure 6. Cluster analyses showing similarity of stations based on zooplankton composition during the whole year.

Discussion

The first objective of this study was to document seasonal and spatial variation of marine condition in the Chabahar Bay. We found temperature and Chlorophyll α in the Bay were seasonally structured. NE Monsoon generally consists of moderate wind-driven mixing, a net flux of heat from the ocean to the atmosphere, and elevated evaporation (Wiggert et al., 2000). Thus, it appears nutrients transported via this wintertime mixing fuel the subsequent spring phytoplankton bloom as defined by the appearance chlorophyll α in Chabahar Bay which confirmed the record of Kumar and Prasad (1999) in the Arabian Sea. High temperature was observed in SW Monsoon resulted in high sunlight. In post-monsoon and NE Monsoon temperature showed decreasing trend through the Bay by decreasing in sunlight. Salinity did not vary significantly during warm and cold season as evaporation is high during cold season (Wiggert et al., 2000). Our findings in water temperature, chlorophyll α and salinity in the Chabahar Bay were similar to the record of Caulfield (l990) in Oman Sea and Arabian Sea.

The second objective of this study was to understand zooplankton link to the changing environmental parameters affected by monsoon in the Chabahar Bay. In NE Monsoon, high zooplankton abundance occurred in the Chabahar Bay. Positive relationship between chlorophyll α value and zooplankton abundance suggests that the abundance is regulated by food availability (e.g. phytoplankton) similar to other tropical waters (Yoshida et al., 2006; Mahdu, 2007). Baars (1998) stated that entrainment of nutrients into the upper layer by winter cooling caused producing phytoplankton blooms. Furthermore, temperature fluctuations are good indicators of the variability of nutrient input. Several days after a decrease in temperature, the enrichment of water lead to intensive primary and secondary production (Roy, 1992). Thus, the population rises to a higher level in the winter as a result of favorable environmental conditions, including temperature, dissolved oxygen and the availability of abundant food in the form of bacteria, nanoplankton and suspended detritus (Salve and Hiware, 2010). Surprisingly, biomass of zooplankton in this season

Table 1. List of zooplankton species collected in the Chabahar Bay.

Siphonophora	**Copepoda**
Family Proboscidactyla	**Family Paracalanidae**
Proboscidactyla stellata	*Parvocalanus crassirostris*
Fmily Diphyidae	*P.elegans*
Diphyes spp.	*Paracalanus parvus*
Family Abylidae	*Acrocalanus longicornis*
Enneagonum hyalinum	*A.gracilis*
Bassia bassensia	*A.monachus*
Ctenophora	*A.gibber*
Family Pleurobranchiidae	*Paracalanus aculeatus*
Pleurobranchia sp.	*Bestiolina similis*
Family Bolinopsidae	*Delibus nudus*
Bolinopsis	**Family Acartiidae**
Appendicularia	*Acartia pacifica*
Family Fritillaridae	*A. erythraea*
.*Fritillaria* sp	*A. longiremis*
Family Oikopleuridae	**Family Candaciidae**
Oikopleura longicauda	*Paracandacia truncata*
Decapoda	**Family Clausocalanoidea**
Family Luciferidae	*Clausocalanus furcatus*
Lusifer typus	*C. gracilis*
L. sp.	*C. minor*
Thaliacea	**Family Calocalanidae**
Family Salpidae	*Calocalanus plumulosus*
Salpa sp.	**Family Centropagidae**
Family Doliolidae	*Centropages tenuiremis*
Doliolum sp.	**Family Pseudodiaptomidae**
Bivalvia	*Pseudodiaptomus marinus*
Brachiopod larvae	**Family Oncaeidae**
Polychaeta	*Oncaea media*
Family Tomoperidae	*O. venusta*
Tomopteris sp.	*O. clevei*
Family Lopadorhynchidae	**Family Sapphirinidae**
Maupasia gracilis	*Sapphirina gastrica*
Cladocera	*S.nigromoculata*
Family Podonidae	**Family Ectinosomatidae**
Evadne sp.	*Microsetella rosea*
Podon sp.	*Subeucalanus crassus*
Echinodermata	*Subeucalanus monachus*
Auricularia larvae	*Pareucalanus attenuatus*
Ophioplutes larvae	**Family Lucicutiidae**
Cephalochordata	*Lucicutia flavicornis*
Branchiostoma sp.	*L. gaussae*
Family Euphausiidae	**Family Euchaetidae**
Nematoscelis sp.	*Euchaeta marina*
Euphausia sp.	**Family Oithonidae**
Vertebrata	*Dioithona aculata*
Fish larvae	*Oithona attenuata*
Ostracoda	*O. nana*
Family Halocypridae	*O. brevicornis*
Conchoecia sp.	*O. simplex*
Chaetognatha	*O. plumifera*
Family Sagittidae	*O. fallax*
Sagitta enflata	**Family Corycaeidae**
S. sp.	*Corycaeus pacificus*
Gastropoda	*C. andrewsi*
Family Atlantidae	*C. asiaticus*
Atlanta helicinoides	*C. affinis*
Munthaea sp.	*C. dahlia*
	Family Euterpinidae
	Euterpina acutifrons
	Family Miraciidae
	Macrosetella gracilis
	Family Clytemnestridae
	Clytemnestra scutellata

Table 2. Pearson correlation of environmental parameters and abundance of major zooplankton and biomass.

Variables	Chl- a (mg m-3)	Temperature (°C)	Salinity (ppt)	Depth (m)	Zoo.biomass (mg dry wt. m-3)
Zooplankton	0.44*	-0.31	-0.12	-0.15	0.52*
Copepoda	0.46*	-0.06	-0.00	-0.02	0.79*
Larvacea	0.03	-0.56*	-0.24	-0.25	-0.14
Cladocera	0.43	-0.17	0.17	-0.21	0.29
Chaetognatha	0.15	-0.15	-0.15	-0.26	-0.20
Siphonophora	0.07	0.02	0.26	-0.47*	0.13
Thalliacea	0.20	0.02	0.17	-0.24	-0.07
Polychaeta	-0.23	-0.05	-0.13	0.18	0.10
Ostracoda	0.02	0.13	-0.22	0.55*	-0.08
Ctenophora	-0.15	0.18	0.20	-0.03	-0.47*
Gastropoda	0.04	0.30	0.10	-0.18	-0.29
Decapoda	-0.37	0.04	0.00	0.01	-0.23

was not high as much as expected. A bloom of larvacea, which is not unexpected in Indian Ocean region (Tsujimoto et al., 2006), noticed in this season and increased abundance of zooplankton but had insignificant effect on biomass.

In pre-monsoon, abundance of zooplankton was lower than NE Monsoon while biomass was higher. The reason could be explained by the high abundance of crustacea which comprised ~80% of the zooplankton community in this season. Furthermore, Madhupratap and Haridas (1990) stated that biomass is elevated by the presence of siphonophorea and medusa in Indian Ocean.

The decline of zooplankton abundance and biomass in SW Monsoon and post-monsoon may be explained by decrease in chlorophyll α concentrations. Similar to the present result, Ashjiana et al. (2002) reported highest biomass during pre-monsoon and NE Monsoon, and the lowest during the SW Monsoon and post-monsoon in Arabian Sea.

In the present study, near shore stations showed higher abundance and biomass of zooplankton which confirmed the record of Madhupratap and Haridas (1990) and Padmavati et al. (998), who reported a sharp decline in zooplankton abundance and biomass with depth. However, station 1 (an offshore station) was different from other stations based on several characteristics. The offshore currents could be responsible for an unexpected high abundance and biomass as it has been reported in Omani coastal region and northern Somalia by Smith and Bottero (1977) and Smith and Codispoti (1980).

The third objective of this study was to understand seasonal succession of zooplankton in the Chabahar Bay. The variation of dominant zooplankton among four sampling seasons is apparently influenced by monsoon (Chen, 1992). In SW Monsoon, the summer population of total zooplankton falls due to a dilution effect that confirmed the record of Salve and Hiware (2010). However, high abundance of larvacea and calanoid copepod was remarkable. During autumn, by the prevailing post-monsoon chaetognatha and ostracoda were observed dominant.

In NE Monsoon, many organisms were increased in number such as copepods (*Oithona nana*, *Temora turbinata*, *Centropages tenuiremis*), larvacea and cladocera. Similarity, the NE Monsoon is characterized by increased number of *Oithona* as Smith et al. (1998) mentioned, *Temora turbinata* as Madhupratap (1987) observed and cladocera as Sharma and Cyril (2007) reported.

In pre-monsoon, harpacticoid copepod, decapods, ostracods, euphausids, siphonophors, gastropoda and polychaeta larvae were dominant which was similar to the record of Geetha et al. (1997).

In post-monsoon, species richness of zooplankton increased with increasing population density. High diversity in this season reflected higher structured communities. The lowest richness was observed in NE Monsoon that could be due to dominance of larvacea.

Spatially, mean zooplankton diversity and richness were found to be inversely related to zooplankton abundance. Higher diversity value in offshore stations could be due to stable environmental conditions prevailing there which permitted plankton community to diversify (Goswami et al., 1992). The swarming of zooplankton in coastal waters resulted in low diversity but high biomass community (Madhupratap, 1987).

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