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DISTRIBUTION AND DIVERSITY OF GELATINOUS ZOOPLANKTON IN THE SOUTH EASTERN ARABIAN SEA, KANYAKUMARI TO OFF KOLLAM

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Distribution and Diversity of Gelatinous Zooplankton in the South Eastern Arabian Sea, Kanyakumari to off Kollam. Peter, S., Manojkumar, B., Pillai, D., Velusamy, A., Kamarudeen, B., Sreeparvathy, P., Agnes, F. — An attempt was made out to study the distribution and diversity of gelatinous zooplankton in the South Eastern Arabian Sea in the region Kanyakumari to off Kollam. A total of 19 species belonging to 8 groups such as chaetognaths, siphonophores, Hydrozoa and Scyphozoa of the phylum Cnidaria, ctenophores, appendicularians, doliolids and salps were recorded. Chaetognaths were not only predominant group, but also the most numerous. *Sagitta enflata* was the most widely distributed chaetognath species from most of the stations studied. The siphonophores were the second most abundant group. Shannon-Weaver species diversity index (H′), Margalef's species diversity index (D) and Pielou's species evenness (J′) of gelatinous zooplankton were found to be higher from the offshore, Kollam (Station 10) and minimum from the inshore, the Kanyakumari (Cape) West (Station 1). Diversity of gelatinous zooplankton was found to be positively correlated with atmospheric temperature, sea surface temperature and pH. A continuous seasonal study should be conducted to understand the clear impact of physical and chemical factors on the distribution and diversity of gelatinous zooplankton along this region.
Key words: gelatinous zooplankton, distribution, diversity, South Eastern Arabian Sea, Kerala, Indian Ocean.

Introduction

Gelatinous zooplankton are found in all oceans of the world from tropics to polar regions ranging from surface to great depths and in sizes from microns to meters. They are the least understood of planktonic groups as they are fragile animals with delicate bodies that are easily damaged or destroyed, limiting the capture of intact specimens (Raskoff et al., 2003). Gelatinous zooplankton is a taxonomically diverse group of organisms with jelly-like tissue containing high percentage of water. They include medusae, siphonophores, ctenophores, chaetognaths, pteropods, heteropods, appendicularians, salps, doliolids and pyrosomes (Madin et al., 2001).

Efficient feeding capacity, growth and reproduction allows the gelatinous species to outcompete other types of zooplankton and form dense populations over large areas leading to considerable impact on the ecosystem (Madin et al., 2001). Therefore, knowledge of species composition and distribution of gelatinous zooplankton is always considered to be of great significance in marine ecological and fishery management exercises. Strong and sustained increments of gelatinous organism populations have been recorded in different geographic marine areas (Mills, 2001; Brodeur et al., 2002). Among these groups, chaetognaths, medusae, siphonophores and ctenophores are very abundant and dense aggregates have been recorded from various settings of the world oceans (Palma & Rosales, 1995; Palma & Apablaza, 2004).

Considerable amount of work has been done to understand zooplankton populations in Indian waters. These studies have tended to focus mainly on copepods, the major zooplankton component. The other groups being of secondary importance, in terms of distribution and diversity, their distributional pattern and seasonal variation have not been studied in detail. Until recently, there were only a few recorded studies on gelatinous zooplankton along the Kerala Coast. Hence, the present study focuses on the distribution and diversity of gelatinous zooplankton in the South Eastern Arabian Sea, Kanyakumari to off Kollam.

Methodology

A biodiversity survey of gelatinous zooplankton from surface waters in the South Eastern Arabian Sea, Kanyakumari (Cape) to off Kollam was carried out during the cruise No. 319 of the research vessel **FORV *Sagar Sampada*** from 01 October to 31 October, 2013. Specimens of zooplankton were quantitatively sampled from 11 stations. Stations 1 to 8 were inshore or coastal stations. Stations 9, 10 and 11 off Kollam were the offshore stations during this expedition (fig. 1). Bongo net of 200 µm mesh size, mouth area 0.28 m^2 was used for collection of gelatinous zooplankton. The collected specimens were preserved in 4 % formaldehyde and identified with stereo zoom microscope. The identification of gelatinous zooplankton was based on taxonomic keys (Conway et al., 2003; Todd & Laverack, 1991). Environmental parameters like salinity, sea surface temperature, dissolved oxygen, and pH were measured in situ with a HACH HQ40d Portable Multi Meter. Atmospheric temperature was measured using standard centigrade thermometer. SPSS software version 22 was used to carry out the statistical analysis. Species diversity indices i. e., Shannon-Weiner diversity index (H′), Margalef's diversity index (D), and Pielou's species evenness (J′) were also estimated.

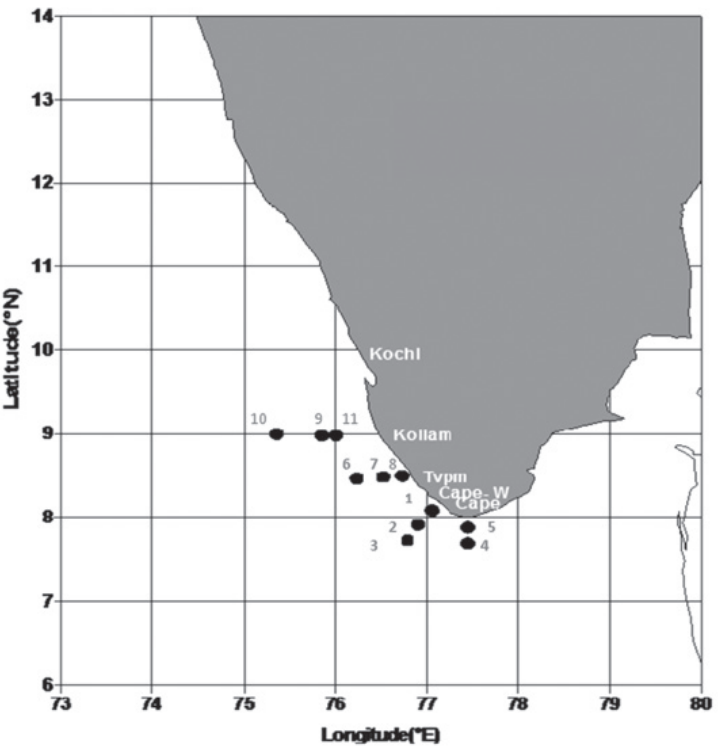

Fig.1. Location of the sampling stations during the cruise is indicated in black circles and numbers of stations are indicated in red color.

Diversity indices of gelatinous zooplankton during the period of collection were calculated using the formulae:

Shannon-Weaver species diversity (H′)

$$H' = -\Sigma\,[P\,(log_2 P)],$$ where P is the relative importance of species,

Margalef's species diversity index (D)

$$D = (S-1)/log_2 N,$$ where N is the total number of individuals in the community,

Pielou's species evenness (J′)

$J' = H'/\ log_2 S$, where S is the total number of species in a sample, across all samples in dataset.

Results

Species Distribution and Diversity

The gelatinous zooplankton, investigated in the present study, consisted of 19 species belonging to 8 groups such as chaetognaths, siphonophores, Hydrozoa and Scyphozoa of the phylum Cnidaria, ctenophores, appendicularians, doliolids and salps (figs 2 to 12). The systematic account of gelatinous zooplankton encountered during the course of study is listed in table 1. Chaetognaths remained as the predominant group from offshore stations (9, 10, and 11) studied (table 1). They were represented by seven species from the genus *Sagitta,* namely *S. enflata* Grassi, 1881*, S. ferox* Doncaster, 1902*, S. hexaptera* d'Orbigny, 1836*, S. bedoti* Béraneck, 1895*, S. bipunctata* Quoy & Gaimard, 1827*, S. robusta* Doncaster, 1902 and *S. decipiens* Fowler, 1905. Hydrozoa of the phylum Cnidaria was represented by two classes *viz.* Hydroidomedusae and Siphonophorae. Class Hydroidomedusae was represented by only one species, *Liriope tetraphylla* Chamisso & Eysenhardt, 1821 from the family Geryoniidae.

Siphonophores appeared as the second most abundant group from the stations studied. A total of five species from three genera were present. Among these, *Diphyes chamissonis* Huxley, 1859 appeared as the most dominant species. The ctenophore population was represented by only one species, *Pleurobrachia pileus* O. F. Müller, 1776 of the class Tentaculata, and planktonic chordates of the region were represented by *Oikopleura dioica* Fol, 1872. Two species of salps (*Salpa fusiformis* Cuvier, 1804 and *Thalia democratica* Forskål, 1775) and one species of doliolids *Doliolum gegenbauri* Uljanin, 1884 were found during the expedition along this region.

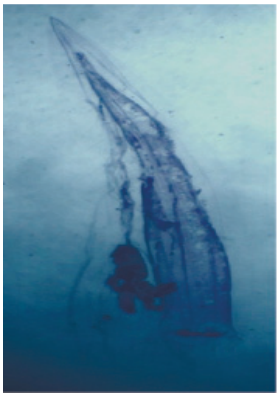

Fig. 2. *Diphyes bojani.*

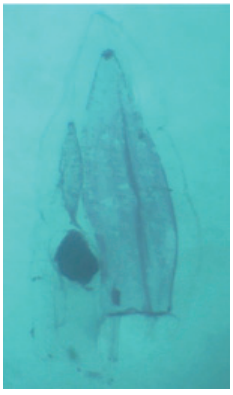

Fig. 3. *Diphyes chamissonis.*

Fig. 4. *Diphyes dispar.*

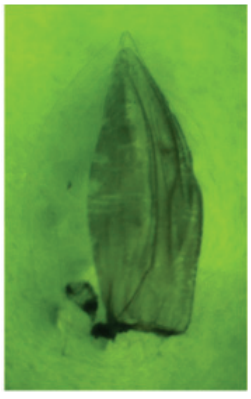

Fig. 5. *Lensia subtiloides.*

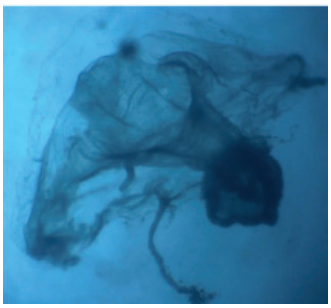

Fig. 6. *Liriope tetraphylla.*

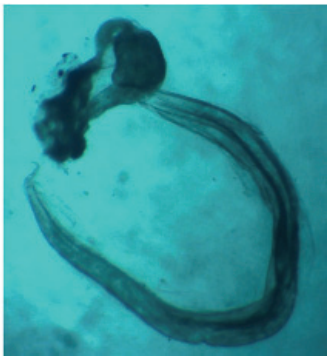

Fig. 7. *Oikopleura dioica*

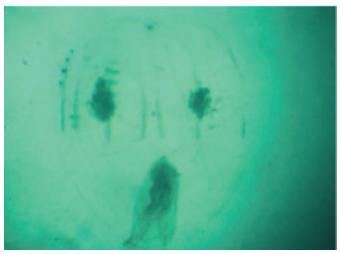

Fig. 8. *Pleurobrachia pileus.*

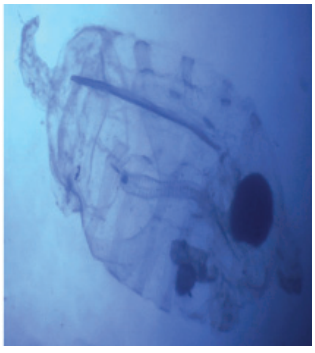

Fig. 9. *Salpa fusiformis.*

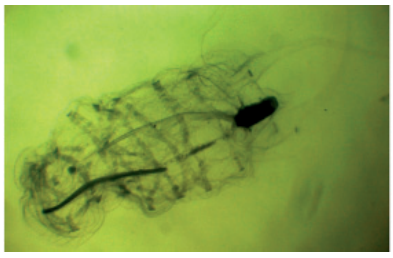

Fig. 10. *Thalia democratica.*

Fig. 11. *Eudoxoides mitra.*

Fig. 12. *Doliolum gegenbauri.*

Variations in the distribution of gelatinous zooplankton taxa were observed from the stations studied (table 1). Station 10, the more offshore station to Kollam was represented by higher number of taxa (6) while, the least (2) were represented from station 1. Chaetognaths were found in copious amounts in station 10 (off Kollam). All the seven species reported in this exploration were identified from there (table 1). *S. enflata* was the most widely distributed chaetognaths species from majority of the stations; whereas, *S. bedoti* was found to be least in distribution and was represented only from station 10. The most dominant siphonophore species encountered was *D. chamissonis,* which was distributed in 7 out of 11 stations. The hydromedusae population was represented by *L. tetraphylla,* the maximum number being recorded from Station 5 (Kanyakumari East). Like chaetognaths, distribution of *O.dioica* was also found to be higher in Kollam station, yet from a different coordinate (Lat 09 °.00.452 N and Long 75 °. 26.26 E). Other groups, like salps and doliolids, were found in lesser numbers. The distribution of gelatinous zooplankton from various stations is indicated in table 1.

Statistical Analysis

In the present study, Shannon-Weaver diversity index (H′), Margalef's diversity index (D) and Pielou's species evenness (J′) were used to describe the underlying changes in physical and chemical properties of gelatinous zooplankton species. Among the stations, species diversity, richness (Margalef's species diversity index), and evenness of gelatinous zooplankton were found to be higher from the more offshore, Kollam (Station 10) and minimum from the inshore, the Kanyakumari West (Station 1). The detailed values of the different diversity indices are depicted in table 3.

Table 1. GPS locations of the sampling stations studied

Stations	Latitude, N	Longitude, E
1	08°.15.041	76°.57.085
2	08°.04.480	76°.44.470
3	07°.59.664	76°.41.639
4	07°.11.185	77°.30.352
5	07°.48.108	77°.30.703
6	07°.59.077	77°.34.201
7	08°.28.436	76°.45.866
8	08°.28.155	76°.23.127
9	09°.00.452	75°.26.260
10	08°.59.857	75°.59.699
11	09°.00.000	76°.22.670

Discussion

Chaetognaths not only remained as the most dominant group but also appeared in large numbers. The dominance of chaetognaths over other groups could be due to their continuous breeding and adaptation to wide range of environmental conditions (Oresland, 1987). As mentioned in earlier studies (Liang, 1995 & 2001), number of species obtained from the inshore waters was found to be less compared to the offshore stations (9, 10 and 11). *S. enflata* remained as the most dominant species during our study, which was

Table 2. Distribution of gelatinous zooplankton in different sampling stations

Species	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7	Stn 8	Stn 9	Stn 10	Stn 11
Chaetognaths											
Sagitta enflata	–	+	+	–	+	+	–	+	+	+	+
Sagitta ferox	–	–	+	+	–	+	–	–	+	+	–
Sagitta hexaptera	+	–	–	–	–	–	–	–	+	+	–
Sagitta bedoti	–	–	–	–	–	–	–	–	–	+	–
Sagitta bipunctata	–	–	–	–	–	–	–	–	–	+	+
Sagitta robusta	–	+	–	–	+	–	+	+	+	+	+
Sagitta decipiens	–	–	–	–	–	–	–	–	+	+	+
Siphonophores											
Diphyes chamissonis	+	+	–	–	+	+	+	+	–	+	–
Lensia subtiloides	–	+	–	–	+	+	–	+	–	+	–
Eudoxoides mitra	–	–	–	–	+	–	–	–	–	+	–
Diphyes bojani	–	+	–	–	+	–	–	–	–	+	–
Diphyes dispar	–	–	–	–	–	+	–	+	–	+	–
Hydrozoa											
Liriope tetraphylla	–	+	–	–	+	+	+	–	–	+	+
Scyphozoa											
Aurelia sp.	–	–	–	–	–	–	–	+	–	+	–
Ctenophores											
Pleurobrachia pileus	–	+	–	–	–	–	–	–	–	–	–
Tunicates											
Oikopleura dioica	–	–	–	+	–	–	–	–	+	+	–
Doliolids											
Doliolum gegenbauri	–	–	+	+	–	–	–	+	+	+	–
Salps											
Salpa fusiformis	–	+	–	+	+	–	–	–	–	–	–
Thalia democratica	–	+	–	+	+	–	–	–	–	–	–

Abbreviations: '+' — sign indicates present; '–' — sign indicates absent; 'Stn' — denotes Station.

comparable to many other observations reported earlier (Nair et al., 2002; Balamurugan, 2011).

During this study, hydromedusae were found abundantly from the inshore stations studied and were represented by only one species, viz., *Liriope tetraphylla*. A similar study conducted by Santhakumari & Nair (1999) in the waters of south-east coast of India, and Zakaria (2004) from the waters of the western part of the Egyptian Mediterranean Coast were in agreement with these findings. In the group of scyphomedusae, only one species from the genus *Aurelia* was collected and their size was found to be larger compared to other groups of gelatinous zooplankton. The samples were collected from the shoreward of Station 8 (Trivandrum) and station 10 (off Kollam).

Siphonophores occupy the fourth or fifth place in the order of abundance in the tropical zooplankton community (Yamazi, 1971).They are abundant in the Indian seas and constitute an important part of the marine zooplankton (Venkataraman, 2005). In the present investigation, siphonophores were the second abundant group and were mainly represented by *D. chamissonis.* A study conducted by Rengarajan (1975) in the waters of south-west coast of India was in agreement with this finding. *Lensia subtiloides* Lens & van Riemsdijk, 1908*, Eudoxoides mitra* Huxley, 1859*, Diphyes bojani* Eschscholtz, 1825 and *Diphyes dispar* Chamisso & Eysenhardt, 1821 were the other species in the order of their numerical abundance.

Phylum Ctenophora consisting of gelatinous marine carnivores were found from the surface to several thousand meters deep. Ctenophores have been known to occur throughout the year along east coast of India (Iyyapparajanarasimapallavan et al., 2013). *Pleurobrachia pileus,* during the present investigation, was restricted to the coastal waters of Kanyakumari West (Station 2). Tunicates, the major components of herbivorous zooplankton, remain as a mass in the upper layers of tropical seas and are able to colonize easily when the conditions are suitable. Tunicates are subdivided into two groups: appendicularians encompassing fritillarians and oikopleurids and thaliaceans that included both doliolids and salps (Stemmann et al., 2008). Doliolids and salps appear to be abundant close to the increasing concentrations of chlorophyll a (Chl a) from the shoreward's of northern part of the Levantine Sea (Weikert & Godeaux, 2008), Japan Sea (Iguchi & Kidokoro, 2006) and in the northern Arabian Sea (Naqvi et al., 2002). In accordance with these findings, the distribution of salps during the investigation was also found merely from the inshore stations (2, 4 & 5). They occur regularly in upwelling waters, rich in phytoplankton and nutrients (Deibel & Pafenhöffer, 2009). In the present study, the enrichment of inshore waters from rivers during the North-East monsoon season might have generated enough food sources for these organisms. Menard et al. (1994) and Laval (1997) stated that the blooming of *Salpa fusiformis* is generally observed when the phytoplankton is productive. *Salpa*

Table 3. Diversity indices of gelatinous zooplankton during the study

Station No: & Transect		Shannon-Weaver species diversity index, H′ (bits/individual)	Margalef's species diversity index, D	Pielou's species evenness, J′
S1	Kanyakumari West	0.0320	0.1146	0.0461
S2		0.5518	0.5548	0.2511
S3		0.0412	0.2256	0.3670
S4	Kanyakumari East	0.5297	0.4560	0.5251
S5		1.0164	0.3025	0.5223
S6	Trivandrum	1.0228	0.3034	0.5708
S7		0.0893	0.1848	0.1288
S8		0.1897	0.4610	0.0912
S9	Kollam	0.2920	0.3058	0.1705
S10		1.2592	0.6289	0.7642
S11		0.4880	0.1569	0.7040

fusiformis and *Thalia democratica* were the two species reported from this group during the current study.

Larvaceans also contribute significantly to planktonic biomass (Uye & Ichino, 1995; Hopcroft et al., 1998). They live in open-ocean and near the shore in surface waters and in middle depths. Nevertheless, they rarely dominate numerically; and are believed to be minor components of the gelatinous zooplankton community (Hopcroft et al., 1998). *Oikopleura dioica* was the only one species reported from the present study. Santhanam & Perumal (2003) reported the incidence of this species from the coastal waters of Parangipettai in the south-east coast of India.

Diversity indices are considered based on two assumptions: (a) stable communities have a high diversity value and unstable ones have a low diversity (b) stability in diversity is an index of environmental integrity and wellbeing (Magurran, 1988). In reality, the diversity value decreases with environmental degradation and it may function as a sensitive indicator for pollution (Klemm et al., 1990). In the present study, Shannon-Weaver species diversity index (H′), Margalef's species diversity index (D) and Pielou's species evenness (J′) were found to be higher in Station 10 (off Kollam), than the other stations. Analysis of the geographical location showed that Station 10 was located more offshore to the other stations. The greater diversity indices from this station means larger food chain, more cases of inter-specific interactions and greater possibilities for negative feedback control like fresh water inflow which reduces oscillations and consequently increases the stability of the community (Ludwig & Reynold, 1988).

Yet again, the period of study was in October, which marks the end of the south-west monsoon and beginning of the north-east rains in Kerala. The low diversity indices and evenness of the more inshore station, viz. Station 1 (Kanyakumari West), might be due to the high freshwater inflow from rivers which in turn affect the distribution and diversity of gelatinous zooplankton, that live in the water column in the ocean. Relatively low zooplankton density in the near shore stations compared to offshore may be attributed to earlier works of Asha et al. (2002) and Robin et al. (2003). During the monsoon period, the rivers bring large quantities of fresh water into the Arabian Sea, altering the physico-chemical properties of the water column (de Souza et al., 1996). As a result, change in their diversity and abundance or community composition can provide important indications of environmental change or disturbance (Varadharajan & Soundarapandian, 2013). During this study, species diversity of gelatinous zooplankton was found positively correlated with AT, SST and pH (table 4). Diversity and abundance of the gelatinous zooplankton are highly influenced by the various physico-chemical parameters prevailing in the study area. Earlier studies have reported that the maximum zooplankton density requires optimal nutrient along with favorable temperature conditions (Saxena, 1982; Padmanabha et al., 2006). In conformity with these findings, a study from coastal waters of Tamil Nadu revealed a positive correlation between the diversity and AT, SST, pH and salinity examined (Iyyapparajanarasimapallavan et al., 2013).

In the present study, variations in both atmospheric and sea surface temperatures were observed. Temperature variations between the stations could be ascribed to atmospheric conditions; rainfall and time of sample collection (Srichandan et al., 2015). AT and SST were found to be positively correlated ($r = 0.608$, $P = 0.04$) during this exploration (table 4). Annual and seasonal study for a period of 40 years (1961–2000) over the Arabian Sea and Indian Ocean region was in agreement with this finding where, a positive correlation was obtained between these two parameters inspected (Jaswal et al., 2012). A significant variation in AT and SST was also reported by Iyyapparajanarasimapallavan et al. (2013) from the coastal waters of Tamil Nadu, east-coast of India during the summer and winter seasons of year 2008.

Salinity acts as a major ecological factor in the distribution of living organisms and its variation caused by dilution and evaporation is most likely to influence the faunal dis-

tribution of aquatic organisms (Chandrasekaran, 2000). Currently, both AT (r =0 .611; P = 0.045) and SST (r = 0.692; P = 0.018) showed positive correlation (r = 0.692; P = 0.018) with salinity indicating their strong affinity (table 4).The Arabian Sea is found to be a highly evaporative basin and temperature is assumed to have a dominant control of the salinity structure (Joseph & Freeland, 2005). However, in the present study, not much variation was observed in salinity from the stations studied. In near shore stations salinity was found to be moderately less due to the fresh water input and the species diversity in these stations was relatively low compared to the other off stations studied. A similar type of variation in salinity was observed in coastal waters of Kalpakkam in the east coast of India (Satpathy & Biswas, 2014).

pH in surface waters remained alkaline throughout the investigation. Since the study was in October, the higher values (7.7 to 8.2) could be due to the high photosynthetic activity as observed by Subramanian & Mahadevan (1999) along the Chennai coast and Srichandan et al. (2015) from the North-Western Bay of Bengal. According to Hen & Durbin (1994), the variation in pH of marine water appears to be correlated with change in temperature, dissolved oxygen and phytoplankton production. At this point, this is confirmed by the significant negative correlation with dissolved oxygen(r = –0.647; P = 0.03) (table 4).

Analysis of the results showed that temperature affects the dissolved oxygen (DO) level in water. The amount of oxygen that dissolves in water can vary in daily and seasonal patterns, and decreases with higher temperature, increased biological activity, respiration of organisms and the increased rate of decomposition of organic matter (http://www.ramp-alberta.org). In the present study, AT and DO were inversely proportional and the relationship was found to be significant (table 4). This is well explained by the significant negative correlation of dissolved oxygen with salinity and temperature by Rai & Rajashekhar (2014) from the Arabian Sea waters of Kerala, south-west coast of India.

Conclusion

A total of 19 species from 8 groups were observed during the present study. Species diversity of gelatinous zooplankton was found positively correlated with atmospheric temperature, sea surface temperature and pH ($p < 0.050$). Since, the gelatinous zooplankton community is highly sensitive to environmental variation, changes in their distribution and diversity can provide important indications of environmental change or disturbance. Hence, they are of ecological importance. Future studies on these systems should be focused on detailed checklists of gelatinous zooplankton composition so as to elucidate the existence of bio-geographic regions along the South Eastern Arabian Sea. A continuous seasonal study should also be conducted to understand the clear impact of

Table 4. Correlation matrix between various parameters and species diversity

	AT	SST	PH	Salinity	DO	Species Diversity
AT	1					
SST	0.608*	1				
PH	–0.284	–0.141	1			
Salinity	0.611*	0.692*	0.017	1		
DO	–0.629*	–0.165	–0.647*	–0.366	1	
Species Diversity	0.727*	0.652*	0.646*	–0.587	0.166	1

* Correlation is significant at the $p < 0.05$ level (2-tailed).

Abbreviations: AT— Atmospheric Temperature; SST — Sea Surface Temperature; DO — Dissolved Oxygen.

physical and chemical factors on the distribution and diversity of gelatinous zooplankton along this region.

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