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ORIGINAL PAPER

Influence of upwelling on the chaetognath community along the Southeastern Arabian Sea

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Abstract Community structure and distribution of chaetognaths were investigated along the upwelled and non-upwelled waters of Southeastern Arabian Sea (SEAS) from the coastal, shelf and open ocean regions. With the onset of monsoon, intense upwelling along the southern part of SEAS (8° 28′ N) and a weak coastal upwelling along the northern counterpart (15° 30′ N) was evident. Zooplankton biomass was observed to be high in the upwelled waters with the dominance of copepods. Chaetognaths were also observed in significant numbers all along the SEAS, however maximum numerical abundance was observed in the southern upwelled waters. Chaetognaths belonging to 10 genera were identified of which genus *Flaccisagitta* (54%) made the most dominant group along the entire study area followed, in order of abundance, by *Serratosagitta* (20%), *Mesosagitta* (18.2%), *Sagitta* (12.3%), *Ferosagitta* (11%) and *Krohnitta* (6.4%). *Flaccisagitta* were observed to be abundant in the upwelled waters along with *Pterosagitta, Serratosagitta, Sagitta, Krohnitta* and *Ferosagitta* whereas genus *Mesosagitta* dominated the non-upwelled waters of northern transects.

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Introduction

Biological production in the Arabian Sea is governed by physicochemical processes that alter with biannually reversing monsoon forcing (Qasim 1982; Krey and Babenerd 1976). Seasonality in the Arabian Sea is defined and divided into Southwest Monsoon (SWM), Fall Inter-monsoon (FIM), Northeast Monsoon (NEM) and Spring Inter-monsoon (SIM) respectively. SWM characterized by strong westerly winds instigates coastal and open ocean upwelling (Brock et al. 1991) which along with wind-driven mixing (McCreary et al. 1996; Lee et al. 2000) and lateral advection (Young and Kindle 1994; Prasannakumar et al. 2001) initiates high primary productivity in the Arabian Sea. However, this phenomenon is more prominent along the southern part of eastern Arabian Sea (below 15° N latitude) or the South eastern Arabian Sea (SEAS). On the other hand, the region north of 15° N (Northeastern Arabian Sea or NEAS) experiences high primary productivity during the northeast monsoon. The cold and dry northeast winds cause the densification and sinking of surface water resulting in convective mixing (Madhupratap et al.

1996; Prasannakumar and Prasad 1996) and nutrient enrichment triggering high phytoplankton production.

Secondary production in the marine ecosystem is mainly contributed by the zooplankton community. Being an essential component of the pelagic food web, they play a dual role as phytoplankton consumers and contributors to the higher trophic level (Goswami et al. 1992; Atkinson 1996; Pitchaikani and Lipton 2015). Understanding on the distribution pattern and community compositions of zooplankton of Arabian Sea come from three significant expeditions: John Murray Expedition (JME, 1933–1934), International Indian Ocean Expedition (IIOE, 1959–1965) and Indian Ocean Experiment (IOE, 1979). Data from the previous studies of IIOE include copepod (Panikkar 1970), chaetognath (Nair 1969; Nair and Rao 1973), ostracod (George1969), amphipod (Nair et al. 1973), euphausiids (Brinton and Gopalakrishnan 1973; Gopalakrishnan and Brinton 1969), polychaete worms (Peter 1969a), fish larvae (Peter 1969b) and cephalopod juveniles (Aravindakshan and Sakthivel 1973) as the major zooplankton group of the basin. Mesozooplankton biomass in the Arabian Sea remains constant throughout the year irrespective of the seasons, which is referred to as the 'Arabian sea paradox' (Madhupratap et al. 1996). During summer and winter monsoon, upwelling and convective mixing respectively, result in high productivity and hence high zooplankton biomass. However, during inter-monsoon, primary productivity declines with constant zooplankton biomass through 'microbial loop' (Azam et al. 1983), which prevails during this period. Hence the secondary production in the Arabian Sea remains constant all-round the year (Madhupratap et al. 2004).

Chaetognath, a major zooplankton taxon, commonly called "arrow worms" includes about 209 species recorded in the World Ocean (Bieri 1991; Vega-Perez and Schinke 2011). They have a wide range of distribution in estuaries, open oceans, tide pools, polar waters, marine caves, coastal lagoons and the deep sea. The biomass of chaetognath is considered to be 10–30% of that of entire copepod in world oceans and often rank second in abundance after copepods in the marine pelagic environments (Feigenbaum and Maris 1984; Shannon and Pillar 1986; Gibbons 1992). Being exclusively carnivorous, chaetognath plays a significant role in energy transfer from copepods to higher trophic level and thus, form a vital component of the food web in upwelling region (Giesecke and Gonzalez 2004; Ulloa et al. 2004). They prey upon pelagic organisms mainly copepods, fish larvae (Pearre 1982), polychaete (Giesecke and González 2004), euphausiids and their own kind (Gray 1961). Thus, chaetognath predation impacts the zooplankton and icthyoplankton communities of the world oceans (Casanova and Nair 1999). The close relationship of chaetognath with certain environmental variables and their species-specific horizontal and vertical distribution make them excellent indicators of water masses (Bieri 1959; Cheney 1985; Terazaki 1989) and their distribution pattern is associated with hydrographic phenomena such as upwelling event. The classic work on chaetognaths was done by Russell (1935 and 1939). Chaetognaths of Indian waters were studied by John (1933 and 1937), Varadarajan and Chacko (1943) and Chacko (1950). Works on the systematics of chaetognaths of Indian coastal waters were carried out by George (1952), Ganapati and Rao (1954), Rao (1958a, b) and Rao and Ganapati (1958). Nair et al. (2002) studied the abundance and community structure of chaetognaths in the northern Indian Ocean. Later, Kusum (2012), Kusum et al. (2014) and Nair et al. (2015) reported on the distribution of chaetognaths in the Indian EEZ (Exclusive Economic Zone). However, the present study attempts to understand the community composition of zooplankton and chaetognath along the southeastern Arabian sea during summer monsoon upwelling and to delineate the difference in community structure of chaetognaths between the upwelled and non-upwelled waters during the season.

Materials and methods

Samples were collected onboard research vessel *FORV Sagar Sampada* during the summer monsoon season (13th–31st July, 2017) along the coastal and open ocean regions of South Eastern Arabian sea. Four latitudinal transects, viz, Off Thiruvananthapuram (T1; 8° 28′ N), Off Kochi (T2; 9° 56′ N), Off Calicut (T3; 11° 21′ N) and Off Goa (T4; 15° 30′ N) were surveyed at the coastal, shelf and open ocean regions (Fig. 1). Vertical profiling of physical and chemical parameters such as temperature, salinity, dissolved oxygen and density was obtained using Conductivity-Temperature-Depth profiler (CTD, Sea-Bird Electronics model 911 series, Sea-Bird Inc.). Chlorophyll

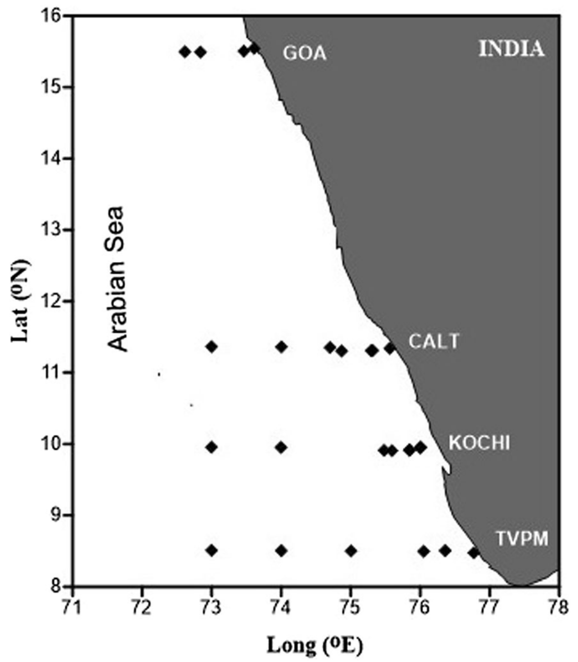

Fig. 1 Study area and sampling stations along the Southeastern Arabian Sea

a was measured spectrophotometrically using a Hitachi U-2900 UV/Visible spectrophotometer following 90% acetone extraction (Parsons et al. 1984). Major nutrients such as nitrate, phosphate, and silicate were estimated using standard procedures (Zhang and Fischer 2006; Grasshoff et al. 1983).

Zooplankton samples were collected using a standard zooplankton Bongo net by oblique hauls. Samples collected and biomass was estimated following the displacement volume method (Harris et al. 2000). Samples were preserved in 5% formaldehyde for later enumeration and identification. The sample was then sorted to group level based on standard keys, and the faunal composition and relative abundance of different zooplankton taxa were obtained. Chaetognath was sorted out from the mesozooplankton sample and identified to genus level based on identification keys (Tokioka 1965; Bieri 1991). Univariate and multivariate statistical analysis and plotting of data were carried out using statistical software like PRIMER V 6, Origin Pro 8.5 and SPSS.

Results

The South Eastern Arabian Sea is unique in its hydrographic features and is characterized by the phenomenon of coastal upwelling that influences the physicochemical and biological attributes of the region. During the present study sea surface temperature (SST) varied from 24.5 to 27.8 °C with an increasing trend from south to north along the coastal waters and with higher temperature along the offshore waters (~ 28.4 °C). Low SST (~ 25.2 °C) was observed along 8° 28′ N, 9° 56′ N and 11° 21′ N (upwelled waters) whereas towards 15°30′N (non-upwelling waters) comparatively high SST (28.4 °C) was observed (Fig. 2). Sea Surface Salinity (SSS) during the study period varied from 32.43 to 34.73 psu with higher values towards the south (8° 28′ N) as well as to the offshore waters, which further decreased towards the north. Dissolved Oxygen (DO) varied from 4.85 ml L^{-1} to 5.17 ml L^{-1} with low DO values towards the offshore waters (~ 3.9 ml L^{-1}). The surface concentration of nitrate, phosphate and silicate along the study area were on an average of 2.69 µmol L^{-1}, 0.8 µmol L^{-1} and 12.2 µmol L^{-1} respectively. The southern upwelled waters and the northern non-upwelled waters showed very slight variations in the concentration of nitrate, phosphate and silicate during the study period. However, nitrate concentration was comparatively high along the coastal waters of 8°28′N (~ 3.25 µmol L^{-1}) and 9° 56′ N (~ 2.88 µmol L^{-1}). Further north, in the non-upwelled waters concentration of nitrate, decreased (Fig. 3). Chlorophyll *a* concentration along the study area, varied from 0.01 to 10.84 mg m^{-3} showing a decreasing trend from south to north along the coastal waters with a highest concentration (~ 10.84 mg m^{-3}) along 8°28′N.

Upwelling signatures were prominent during the season with a moderate to intense upwelling along the nearshore waters from 9° N to 13° N (off Thiruvananthapuram to off Calicut) and further north of 13° N (off Goa) signatures of upwelling weakened. Along 8°28′N an upsloping of 24 °C isotherm from 75 m to surface coastal waters indicate intense coastal upwelling extending to the offshore waters (Fig. 2a). An upsloping of 24 °C isotherm from 75 m to subsurface (20 m) coastal region along 9° 56′ N(off Kochi) indicate coastal upwelling extending to the shelf waters (Fig. 2b), however, along 11° 21′ N, 24 °C isotherm was evident below a depth of 70 m

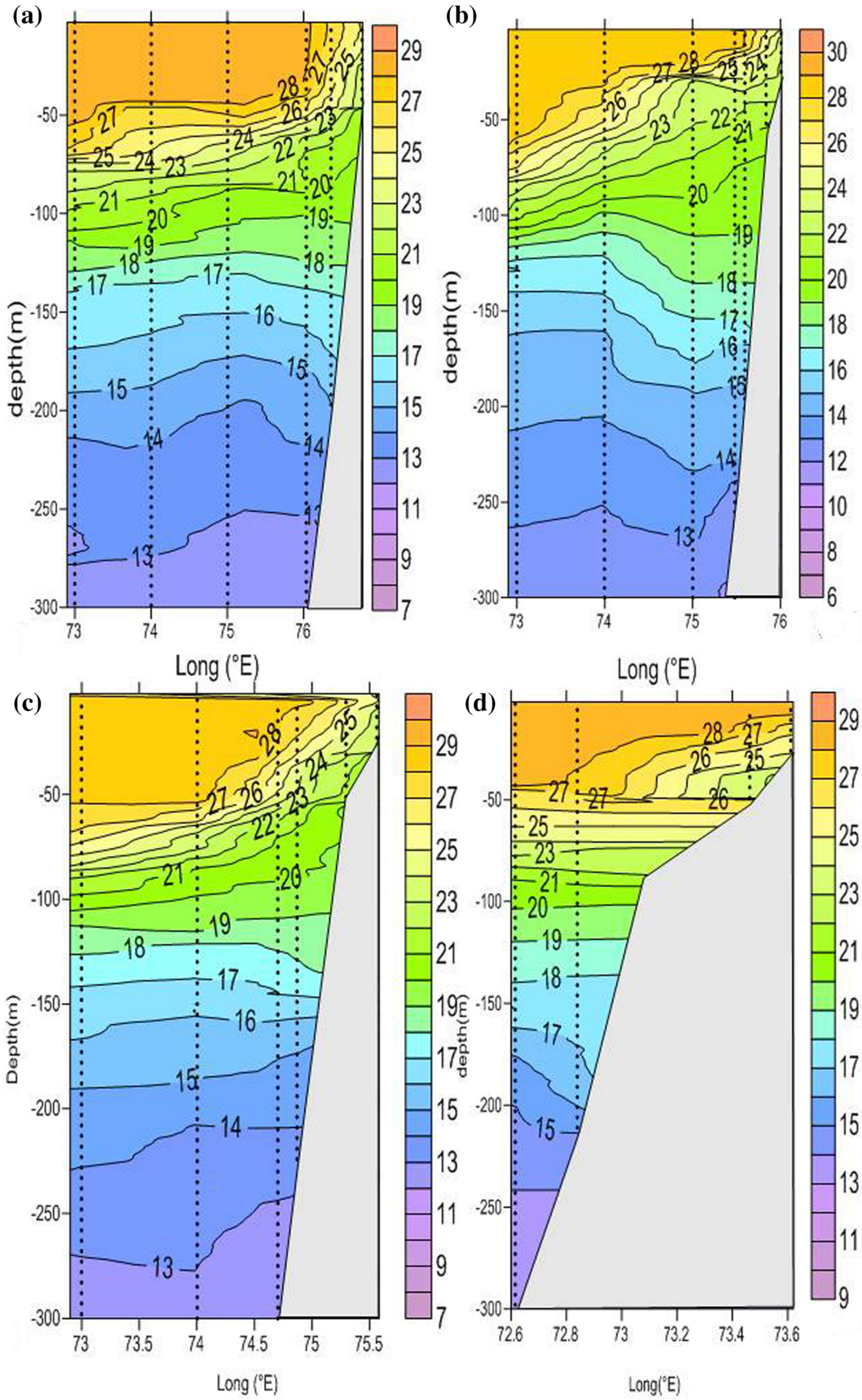

Fig. 2 Vertical distribution of temperature along different transects of SEAS during the summer monsoon **a** off Thiruvananthapuram (8°28′N) **b** off Kochi (9°56′N) **c** off Calicut (11°21′N) and **d** off Goa (15°30′N)

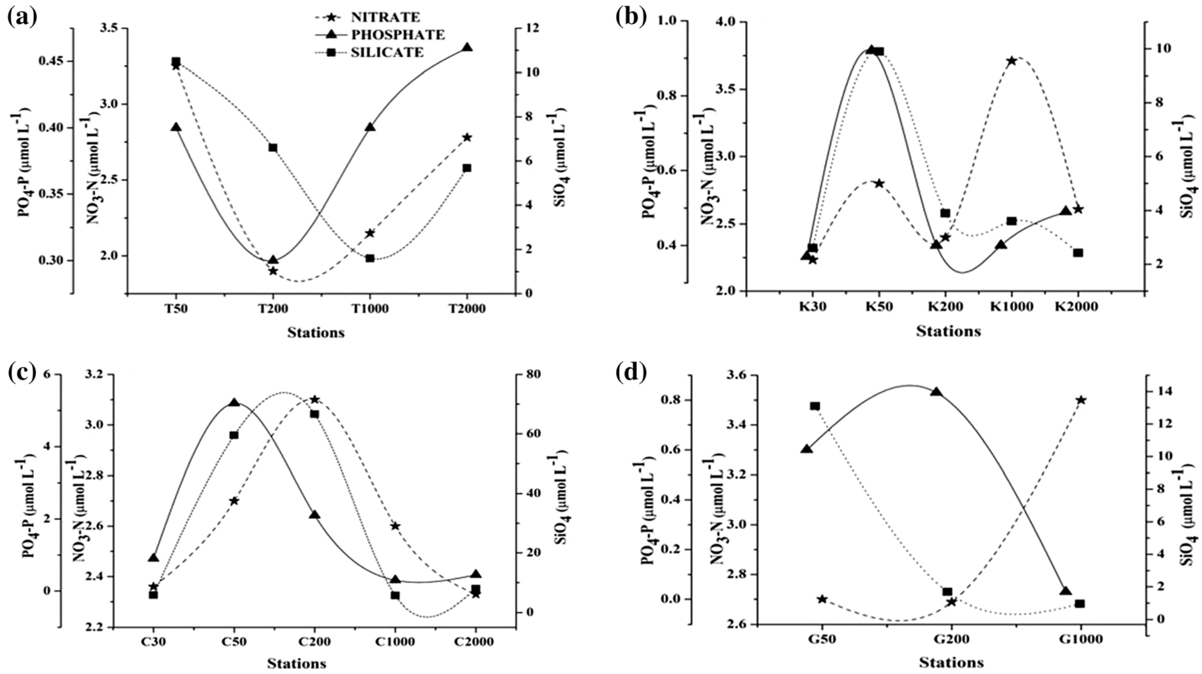

Fig. 3 Spatial variability in the surface nutrient pattern along the various transects **a** off Thiruvananthapuram (8°28′N) **b** off Kochi (9°56′N) **c** off Calicut (11°21′N) and **d** off Goa (15°30′N)

signifying weak coastal upwelling (Fig. 2c). The signatures of upwelling was almost absent along the northern transect (15°30′N) (Fig. 2d).

Mesozooplankton community structure

Mesozooplankton biomass along the study area varied from 0.05 to 0.77 ml m^{-3} with maximum along the shelf waters of 8° 28′ N and minimum along offshore waters of 15° 30′ N (Fig. 4). In general zooplankton biomass decreased from coast to open ocean regions and also from southern transects to north. Analysis of variance (ANOVA) of zooplankton biomass showed a significant variation between the upwelled and non-upwelled waters (Global R: 0.896; p: 0.2%). Zooplankton biomass was higher along the southern upwelled waters (0.38 ml m^{-3}) (Fig. 4a–c) while it decreased towards the non-upwelling regions (0.1 ml m^{-3}) (Fig. 4d). Maximum biomass and abundance average (0.38 ml m^{-3}; 20,869 no 10 m^{-3}) was observed along 8° 28′ N, 9° 56′ N and 11° 21′ N (upwelled waters) and minimum (0.1 ml m^{-3}; 2557 no 10 m^{-3}) along 15° 30′ N (non-upwelled waters). Zooplankton diversity was observed to be high in the coastal waters (H′ = 1.54) from 8° 28′ N to 11° 21′ N; however, further north (15° 30′ N) diversity was maximum in the offshore waters (H′ = 1.14).

Community structure of mesozooplankton along the South Eastern Arabian Sea was dominated by copepods (80%). Cladocerans (10%) ranked second in abundance, followed by chaetognaths (9.1%). Other important mesozooplankton groups included tunicates, jellyfish, fish egg, decapod larvae and ostracods. The mesozooplankton groups like amphipods, polychaete larvae, doliolum, echinoderm larvae, pteropod and lucifer were observed in the least abundance. The coastal water off Kochi was dominated by cladocerans (85%) and the coastal and shelf water off Calicut was dominated by fish eggs (34% and 45% respectively). Zooplankton community structure in upwelled waters was dominated by copepod (> 60%), although along some regions cladocerans (coastal waters of 9° 56′ N) and fish eggs (coastal waters of 11° 21′ N) peaked. Other zooplankton groups included chaetognath, tunicates, cladocerans, amphipods, pteropods, siphonophores, decapod larvae, lucifer, echinoderm larvae, and doliolum. However, non-upwelled waters was dominated by copepods (> 80%) with other groups, chaetognath, fish egg, decapod larvae, tunicate, pteropod, only forming a minority of the population.

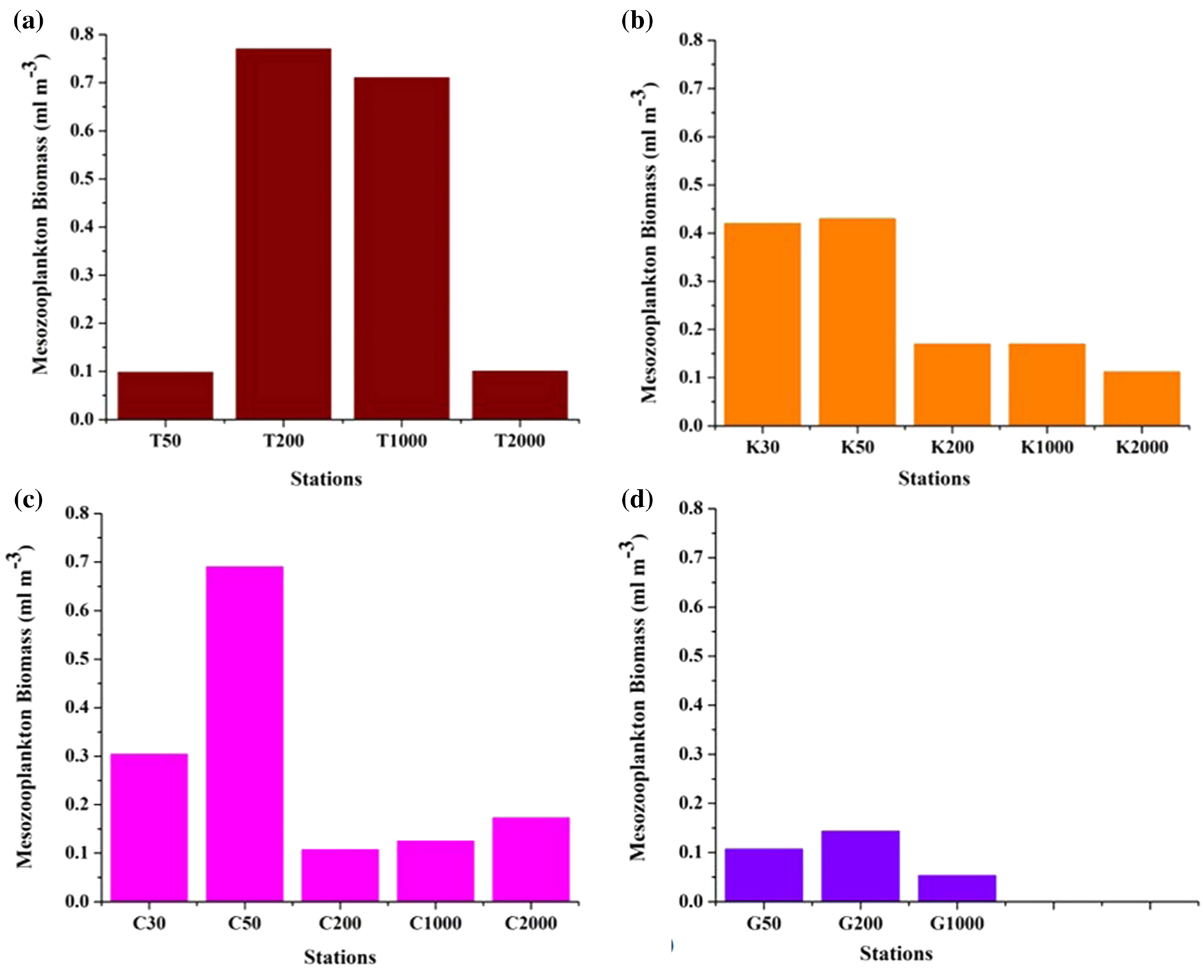

Fig. 4 Variations in mesozooplankton biomass along **a** off Thiruvananthapuram (8°28′N) **b** off Kochi (9°56′N) **c** off Calicut (11°21′N) and **d** off Goa (15°30′N)

Chaetognath community structure

The abundance and diversity of chaetognaths varied along the study area with high numerical abundance in the southern upwelled transects (106 no 10 m^{-3}) which decreased towards northern region with non-upwelled conditions (49 no 10 m^{-3}). Within transects, the abundance of chaetognaths decreased from the coast to offshore except for the region off Thiruvananthapuram where the numerical abundance increased towards the offshore region (Fig. 5). Diversity was observed to be highest ($H' = 2.13$) in the offshore waters along all transects and lowest ($H' = 0.8$) in coastal waters. Species richness of chaetognath was maximum in the offshore waters (d = 1.51) along all transects and minimum (d = 0.71) in the coastal waters. Chaetognath evenness was observed to be maximum ($J' = 0.65$) in the coastal waters of all transect except along 9°56′N where it was maximum ($J' = 0.86$) along offshore. Considering upwelled and non-upwelled waters, diversity was high in the non-upwelled waters ($H' = 2.76$) than the upwelled waters ($H' = 2.41$). Cumulative dominance analysis and the resultant *k*-dominance plot clearly depicted the higher dominance in the upwelled waters than the non-upwelled waters (Fig. 6).

About 10 genera were identified during the study. Genus *Flaccisagitta* was dominant (54%) followed by *Serratosagitta* (20%), *Mesosagitta* (18.2%), *Sagitta* (12.3%), *Ferosagitta* (11%) and *Krohnitta* (6.4%). Common chaetognath species included, *Flaccisagitta enflata, Pterosagitta draco, Sagitta bipunctata,*

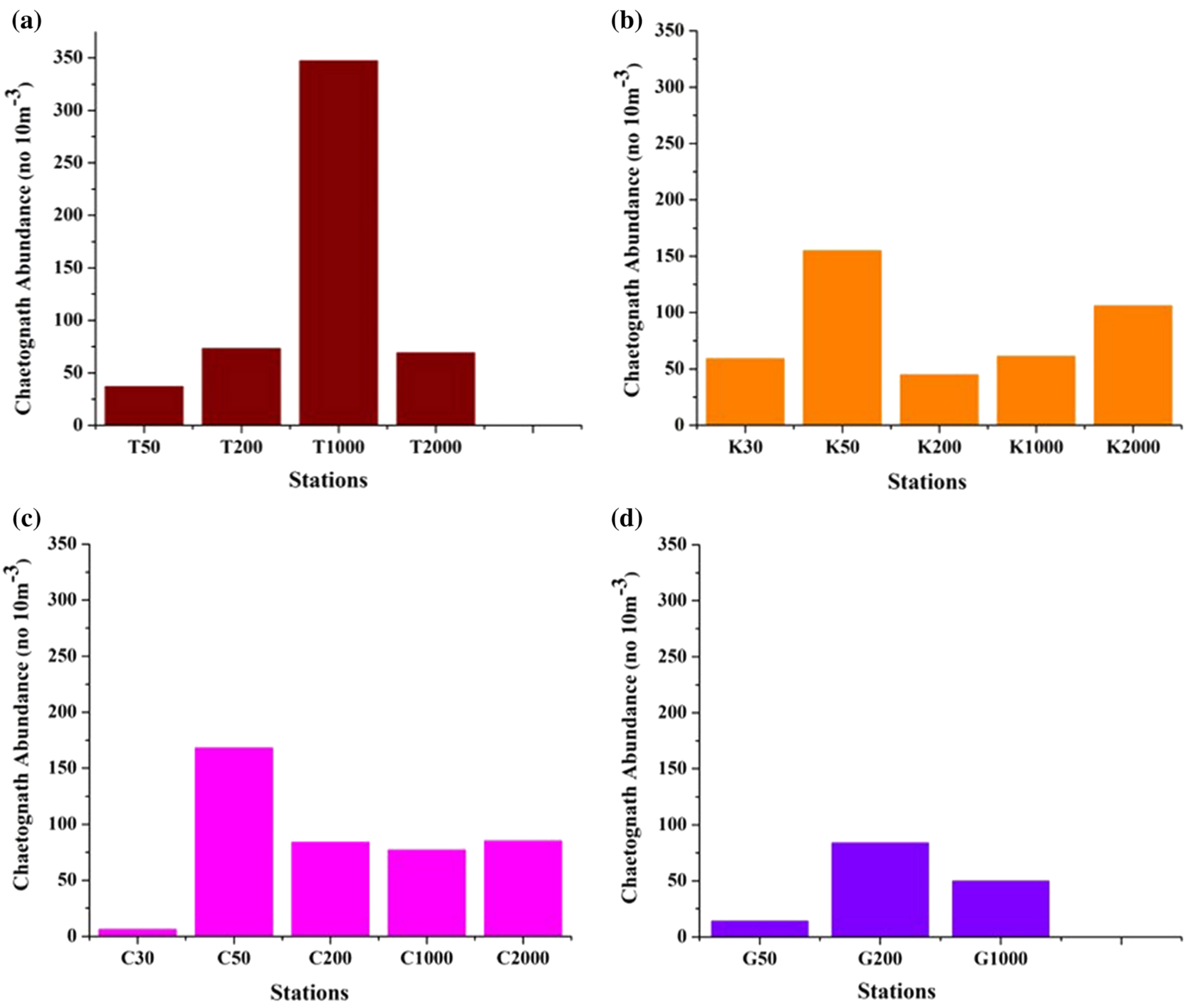

Fig. 5 Variations in the numerical abundance of chaetognath along **a** off Thiruvananthapuram (8°28′N) **b** off Kochi (9°56′N) **c** off Calicut (11°21′N) and **d** off Goa (15°30′N)

Serratosagitta pacifica. Flaccisagitta dominated all transects of the South Eastern Arabian Sea with maximum abundance along coastal waters and a gradual decrease towards offshore waters. Along the coastal waters, the abundance was maximum along 9° 56′ N (97%) and minimum along 15° 30′ N (31%) showing a decreasing trend from south to north. *Flaccisagitta enflata* formed the most dominant chaetognath species along all transects with high abundance in the southern upwelling regions. Another species *Pterosagitta draco* (only species under genera *Pterosagitta)* was observed only in offshore waters of southern transects (8° 28′ N and 9° 56′ N). However, other chaetognath genera, *Serratosagitta* were present only in shelf and offshore waters of Kochi, Calicut and Goa with maximum along 9° 56′ N and 15° 30′ N (39%; 41%). Similarly, genus *Ferosagitta* dominated the offshore waters. Genus *Mesosagitta* dominated the shelf (81%) and open waters (73%) along 11° 21′ N and coastal waters (33%) of 15° 30′ N. Genus *Sagitta* was present along the entire study area with a higher dominance in southern transect than the north transect. The genus dominated the open water of 9° 56′ N (29%). *Sagitta bipunctata* dominated the upwelling regions of southern transects. The genus *Krohnitta* were identified mainly along the offshore waters of southern transects and was absent towards north. Other minor genera recorded during the study period include *Aidanosagitta* sp, *Solidosagitta* sp and *Decipisagitta* sp.

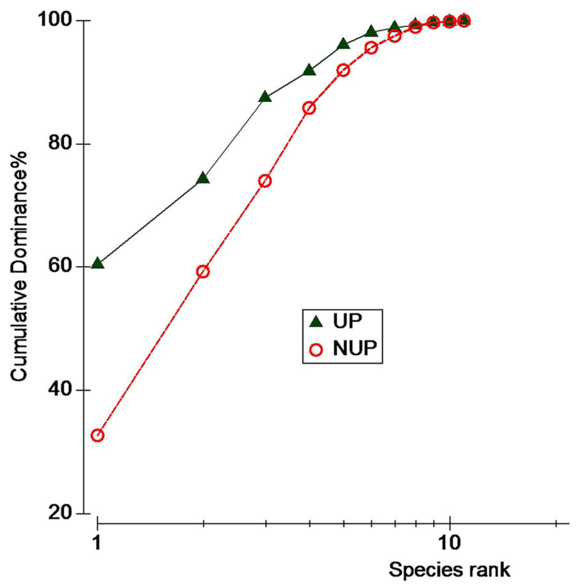

Fig. 6 k-Dominance plot showing the cumulative dominance of chaetognaths along the upwelled (UP) and non-upwelled (NUP) waters of SEAS

Within the upwelled waters, highest average abundance of chaetognaths were observed along 8° 28′ N (153 no 10 m^{-3}), with highest abundance in offshore waters (347 no 10 m^{-3}) and lowest along the coast (37 no 10 m^{-3}) (Fig. 5a). The chaetognath community was dominated by *Flaccisagitta* sp. followed by genus *Serratosagitta, Sagitta, Ferosagitta, Krohnitta, Pterosagitta* and *Solidosagitta*. Along 9°56′N, maximum chaetognath abundance was in the coastal waters (155 no 10 m^{-3}) and minimum along the shelf waters (45 no 10 m^{-3}) (Fig. 5b), with an average abundance of 82 no 10 m^{-3}. Genus *Flaccisagitta, Serratosagitta, Sagitta, Ferosagitta, Krohnitta, Mesosagitta, Pterosagitta, Solidosagitta* and *Aidanosagitta* consisted the chaetognath community along transect. The chaetognath abundance along 11°21′N varied between 6 no 10 m^{-3} to 168 no 10 m^{-3} (Fig. 5c), with an average of 83 no 10 m^{-3}. *Flaccisagitta* sp. dominated the chaetognath community along the region. Other genus included, *Mesosagitta, Sagitta, Serratosagitta, Krohnitta, Solidosagitta* and *Ferosagitta.* The northern non-upwelling transect (15° 30′ N), observed a low average chaetognath abundance (49 no 10 m^{-3}) when compared to southern transects. The highest abundance was reported in the shelf waters (84 no 10 m^{-3}) and lowest in coastal waters (14 no 10 m^{-3}) (Fig. 5d). *Mesosagitta* sp. followed by *Flaccisagitta* and *Serratosagitta* dominated the chaetognath community. Other chaetognath genus included, *Ferosagitta, Sagitta, Decipisagitta* and *Aidanosagitta.* Genus *Krohnitta* and *Pterosagitta* were entirely absent from these region. Thus, it can be observed that the major chaetognath genus dominating the upwelled waters included, *Flaccisagitta, Pterosagitta, Serratosagitta, Sagitta, Krohnitta* and *Ferosagitta* with *Flaccisagitta enflata* and *Sagitta bipunctata* forming the major species in upwelled waters. The genus *Mesosagitta* dominated the non-upwelled waters of northern transects. Other chaetognath genus apart from *Mesosagitta,* were also present in the northern transects but in lower abundance indicating their higher affinity towards upwelled waters.

The BEST analysis (statistical analysis linking biotic patterns to environmental variables), of various environmental and biological parameters influencing the distribution of chaetognaths revealed that temperature, dissolved oxygen and abundance of copepods as a source of food are the major factors that determine their distribution pattern. Temperature showed a negative correlation whereas dissolved oxygen and copepod abundance showed a positive correlation towards the numerical abundance of chaetognaths. The abundance of chaetognaths was positively correlated with copepod abundance (at a significant level of 0.05). The high abundance of chaetognath in offshore waters of 8° 28′ N can be related to the subsurface cold waters and also high abundance of copepod (16,327 no 10 m^{-3}). Among the chaetognaths, genus *Flaccisagitta* observed a strong positive correlation with copepod abundance (significant at 0.01 level). Principal component analysis (PCA) of various physicochemical parameters in different stations of the study area showed that PC1 and PC2 clearly defined the cumulative variations between the study areas by 69.1% and an addition of PC3 contributed a cumulative variation of 83% (Table 1). The analysis indicated

Table 1 Eigen values and cumulative variations of principal component analysis (PCA)

PC	Eigen values	% Variation	Cum.% variation
1	3.6	45.0	45.0
2	1.92	24.0	69.0
3	1.12	14.0	83.0

the relationship between numerical abundance of chaetognaths with copepod abundance, preference to low SST and high dissolved oxygen (Fig. 7).

Discussion

Eastern Arabian Sea ecosystem bordering the west coast of India is environmentally unique owing to the reversing monsoon patterns and accordingly driven biophysical responses. Intense biological production occurs in South Eastern Arabian Sea (SEAS) along the southwest coast of India in response to summer monsoon upwelling extending from May–June to September (Banse and English 2000). The vertical flux of inorganic nutrients results in high biological productivity in the region (Bhattathiri et al. 1996; Ryther et al. 1966; Qasim 1982).

Winds during summer monsoon are generally south west over most of the Arabian Sea and become northerly along the west coast of India. With the onset of the summer monsoon, weak to moderate upwelling occurs off the Kanyakumari coast (8° N) that spreads northwards along the west coast as monsoon advances and reaches up to Goa coast during peak monsoon (Smitha et al. 2008). During the present study, upwelling signatures are evident along the South

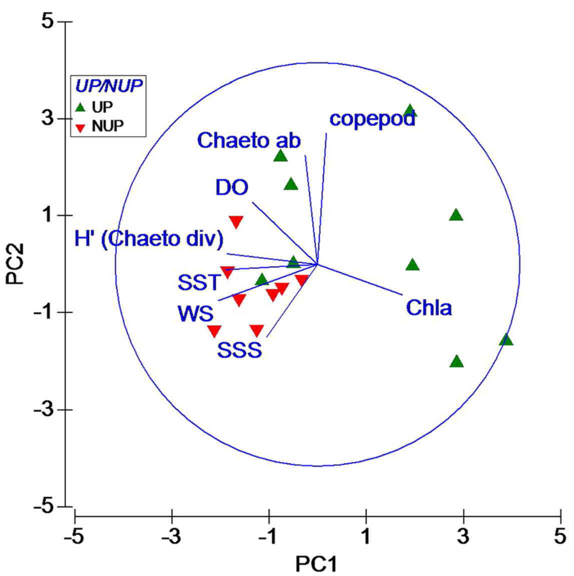

Fig. 7 PCA showing the relationship between various environmental variables and chaetognaths along the upwelled and non-upwelled waters of SEAS

Eastern Arabian Sea. The low surface water temperature (24.5 °C) prevalent along the region and an upsloping of 24 °C isotherm from 75 m to surface waters, evident along 8° 28′ N (off Thiruvananthapuram) indicates intense upwelling along the region (Fig. 2a). Upwelling signatures were prevalent along 9° 56′ N (off Kochi) (Fig. 2b) with an upsloping of 24 °C isotherm to the subsurface waters (20 m). Along 11° 21′ N upwelling signatures (Fig. 2c) were confined to coastal waters. In the region offshore and further north towards 15° 30′ N spring inter-monsoon condition with high SST and highly stratified waters prevailed indicating the absence of upwelling (Fig. 2d).

The Sea Surface Salinity (SSS) in the study area shows a decreasing trend from the south (off Thiruvananthapuram) to the north (off Goa) along the coastal waters (34.73 to 32.43 psu). Dissolved oxygen decreased from 8° 28′ N to 15° 30′ N (4.85 ml L^{-1}–5.17 ml L^{-1}) along the coastal waters. However, there was a considerable decrease in the dissolved oxygen concentrations along the coastal waters off Kochi. Nitrate concentration in surface waters of Arabian Sea is considerably higher during the summer monsoon upwelling and winter monsoon convective mixing (Prasannakumar and Prasad 1996). During the present study the surface concentrations of nitrate along the upwelled waters reached a maximum of 3.25 µmol L^{-1} along the coastal waters of 8° 28′ N and ~ 2.88 µmol L^{-1} along coastal waters of 9° 56′ N with a decreased concentration (2.36 µmol L^{-1}) in the non-upwelled waters (15° 30′ N). Maximum chlorophyll *a* concentration was observed along the coastal waters of southern transects (regions of upwelling). Chlorophyll *a* concentration peaked along the coastal waters of 8° 28′ N (~ 10.84 mg m^{-3}) followed by 9° 56′ N (6.02 mg m^{-3}). Although, highly stratified waters (non-upwelled waters) were observed along 15°30′N, chlorophyll *a* concentration (6.31 mg m^{-3}) was comparatively high along the region. Previously high primary production with chlorophyll *a* observed in the region was attributed towards the riverine influx through Zuari-Mandovi estuary adjoining the coast of Goa (Gurumurthy et al. 2017).

Zooplankton plays a pivotal role in the shaping of the marine ecosystem. The region south of 20°N in the eastern Arabian sea was reported to have high zooplankton biomass (Nair et al.1998) and it is more within the area of upwelling (Smith et al. 1998b) during the southwest monsoon season (Ashjian et al. 2002; Smith et al. 1998; Wishner et al. 1998). In the present survey, high average zooplankton biomass (0.41 ± 0.4 ml m^{-3}) was observed along 8° 28′ N (off Thiruvananthapuram) with high values towards the shelf and offshore waters (Fig. 4a). This can be attributed to the coastal upwelling with offshore extension and high phytoplankton production. Zooplankton biomass was also recorded to be high along the coastal upwelling region 9° 56′ N (Fig. 4b) and 11° 21′ N (Fig. 4c). However, further north (15° 30′ N) biomass was considerably low along the coastal as well as the offshore region (Fig. 4d).

The biomass of zooplankton varied significantly between upwelled and non-upwelled waters with comparatively high values along the upwelled areas. Zooplankton taxa studied during IIOE showed a pattern of increased abundance during the southwest monsoon season characterized by coastal upwelling (Panikkar 1969; Panikkar and Rao 1973). Copepods are numerically dominant in the mesozooplanktonic community (50–88% of total), both along the coastal and oceanic waters of Eastern Arabian Sea (Kasturirangan et al. 1973; Nair et al. 1978; Kumari and Achuthanktty 1989). Other mesozooplankton groups include tunicates, ostracods and chaetognaths. During the present study, also copepods (80%) dominated the mesozooplankton community. However, there was an abundance of cladocerans (85%) along coastal waters off Kochi and fish eggs along the shelf waters off Calicut (40%). In general, copepods were followed by cladocerans and chaetognaths in abundance. Other mesozooplankton groups included tunicates, fish larvae, amphipods, polychaete larvae, doliolum, echinoderm larvae, pteropod and lucifer. Although numerical abundance was greater along the upwelling regions, average mesozooplankton diversity was observed to be more along the offshore waters.

Chaetognath occupies a prominent position in zooplankton community structure (Reeve 1971) and is included in the top five most abundant zooplankton groups in the ocean (Alvarino 1964). Their close relationship with certain environmental variables and their species-specific horizontal and vertical distribution make them excellent indicators of water masses (Bieri 1959) and distribution pattern of some species is associated with certain hydrographic event like upwelling. The present study during the early phase of summer monsoon upwelling, observed differences in chaetognath community along the upwelled and non-upwelled waters of South Eastern Arabian Sea. The abundance of chaetognaths was comparatively high along the upwelled waters whereas diversity was more in the non-upwelled waters. Hence according the propagation of upwelling northward, high abundance and low diversity was observed in the southern upwelled transects and vice versa in the northern non upwelled region (Fig. 6). Nearly, ten genera of chaetognaths were identified, mainly, *Flaccisagitta, Serratosagitta, Mesosagitta, Pterosagitta, Ferosagitta* etc. The genus *Flaccisagitta* was observed to be the dominant one present along the SEAS during the study period.

The major environmental and biological factors that determine the chaetognath distribution pattern according to BEST analysis included temperature, dissolved oxygen and abundance of copepods. According to Kusum et al. (2014), most chaetognath species shows a negative correlation towards temperature and positive correlation towards dissolved oxygen. The high abundance of copepods resulting from the upwelling induced primary production in the Indian Ocean was observed to positively influence the abundance of chaetognaths that prey upon the copepods (Madhupratap et al. 1990). The present study also corroborates with these observations. Principal component analysis (PCA) of the relationship between various hydrographical parameters of the study area (Fig. 7) observed lower SST, higher copepod abundance and high dissolved oxygen in upwelled waters showing high chaetognath abundance.

Along the southern transects (off Thiruvananthapuram, off Kochi and off Calicut) the prevalent low temperature and abundance of copepod support the high abundance of chaetognaths. *Flaccisagitta,* being the most dominant chaetognaths genus, was present mainly in the upwelled coastal waters of SEAS, and their abundance decreased towards the north as well as open ocean waters where indications of upwelling were less. *Pterosagitta, Serratosagitta, Sagitta, Krohnitta* and *Ferosagitta* were the other major genera observed in the upwelled waters. *Flaccisagitta enflata* and *Sagitta bipunctata* were significantly high in upwelling waters. However, *Mesosagitta* sp. was mainly observed towards the non-upwelled waters of SEAS.

The present study unveils the community structure of zooplankton with emphasis to chaetognaths along the SEAS during the southwest monsoon. Upwelling signatures were evident mainly towards the southern part of SEAS and were characterized by high mesozooplankton biomass and chaetognaths abundance. Major zooplankton groups identified were copepods, ostracods, fish eggs, chaetognaths, amphipods, etc. Chaetognath observed high abundance in the upwelled waters; however, diversity was comparatively high in the non-upwelled waters. Nearly, ten genera of chaetognaths were identified, mainly, *Flaccisagitta, Serratosagitta, Mesosagitta, Pterosagitta, Ferosagitta* etc. The genus *Flaccisagitta* dominated the upwelled waters of south and genus *Mesosagitta* dominated the non-upwelled waters of the north. Also, the distribution pattern of chaetognaths along the SEAS was influenced by various environmental and biological factors such as temperature, dissolved oxygen and copepod abundance. Chaetognaths share a major part of zooplankton composition of the productive waters, and the community structure of chaetognaths is important to understand the food web dynamics of upwelled waters along the Southeastern Arabian Sea.

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Author contributions AP wrote the manuscript with input from LCT. AP conducted the field study. AP and LCT contributed to the taxonomic identifications. SBN and KBP supervised this study and provided research materials. All authors read and approved the manuscript.

Data availability The manuscript has no associated data.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest.

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