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## SHORT COMMUNICATION

# Chaetognath community and their responses to varying environmental factors in the northern Indian Ocean

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The ecology of the chaetognath community and its relation to varying environmental factors were studied in the eastern half of the northern Indian Ocean. Analysis of data from two major oceanographic programmes performed over four decades apart suggests a pronounced shift in the community composition and a poleward migration of chaetognaths. This migration has led to an aggregation in the north, as the Eurasian land mass prevents further movement beyond 30°N.

**KEYWORDS:** chaetognath ecology; distribution; physico-chemical variables; northern Indian Ocean

In the marine ecosystem, environmental variables have significant influence on the relative abundance and species diversity of plankton communities (Barton *et al.*, 2013). As zooplankton plays a pivotal role in structuring and regulating the food web and in the functioning of the

biological pump, long-term monitoring of their interactions with physico-chemical variables is crucial in understanding responses to changes in the environment. Though there have been a number of studies on this topic in the Pacific and Atlantic Oceans (Beaugrand and

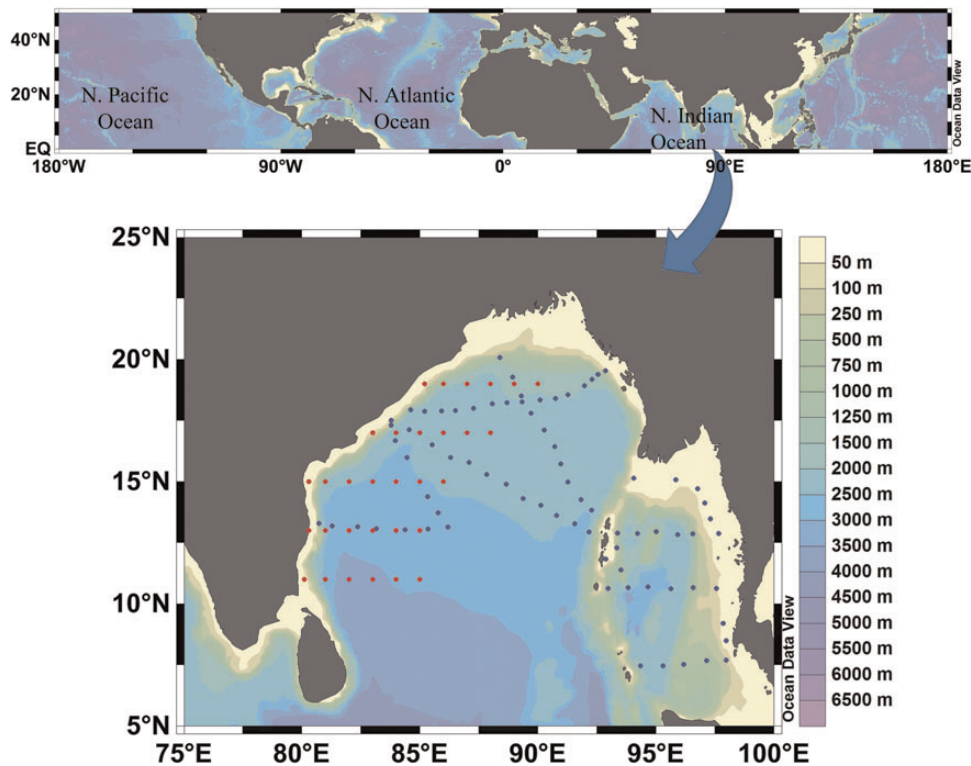
Ibanez, 2004; Chiba *et al.*, 2006), such studies are relatively few in the Indian Ocean (IO). The IO, which is distinguished from other world oceans by its northern landlocked boundary, forms a unique natural laboratory for the analysis of the responses of the plankton community to changes in the physico-chemical variables and for understanding the influence of the Eurasian land mass on their distribution. Though systematic studies on the plankton community of the IO gained momentum during the International IO Expedition (IIOE; 1960–1965), successive oceanographic research programmes dealt mainly with the biogeochemistry and carbon dynamics of this region. Later, the Marine Research on Living Resources Programme (MRLR) made significant contributions to the understanding of plankton ecology by providing considerable data on the hydrography and plankton distribution of the IO.

To improve knowledge on the responses of the zooplankton community to varying physico-chemical variables in the IO, we studied chaetognaths, a major carnivorous taxon. The prime objectives were to investigate: (i) the ecology of the chaetognath community and its relation to varying environmental variables and (ii) the

potential influence of the northern landlocked boundary on chaetognath distribution.

For a detailed evaluation of chaetognath ecology in response to variability in the physico-chemical environment, zooplankton data from two different sampling expeditions in the eastern half of the northern IO, separated by more than 40 years, were analysed (Fig. 1). Data collected onboard FORV Sagar Sampada as part of the MRLR during two periods (November 2005–January 2006 and September–October 2006) were compared with data sets from the Anton Bruun Cruise of the IIOE (March–May 1963) ([www.cmarz.org](http://www.cmarz.org)).

During the MRLR, mesozooplankton samples were collected from five discrete depth zones up to 1000 m, including the mixed layer depth (MLD), the thermocline (TC), the bottom of the thermocline (BT) to 300, 300–500 and 500–1000 m, using a multiple plankton sampling net (Hydro-Bios, Germany), whereas during the IIOE, samples were collected by vertically towing an IO Standard net from a depth of 200 m to the surface. During MRLR, a total of 124 samples (62 each from MLD and TC) and during IIOE 76 samples were analysed. The chaetognath abundance in both studies was



**Fig. 1.** Sampling locations. The blue/dark colour indicates the sampling locations during IIOE period and the red/light colour indicates the locations during MR-LR period. For the MR-LR study, stations were distributed along four zonal transects from 11°N to 21°N and the transects were fixed at a 2° latitude interval, and in each transect, stations were sampled at an interval of 1° longitude, extending from the coast to offshore. For the IIOE, the samples collected from locations distributed in the region of 7–20°N and 80–97°E were used for the study.

expressed as ind/1000 m<sup>3</sup>. As the variation in mesh size mostly affects the sampling of smaller sized zooplankton, the different net mesh sizes used during the IIOE (330 µm) and the MRLR (200 µm) should not affect the assessment of temporal variation in chaetognath abundance, as all chaetognath specimens collected using both nets were >330 µm. For a better evaluation of the spatial variation in chaetognath abundance, the sampling area was divided into two regions, i.e. “north”, for locations from the northernmost boundary to 15°N, and “south”, for locations south of 15°N to 7°N. For the MRLR chaetognath samples, maturity stages (McLaren, 1969) were analysed to understand their growth stage responses to the physico-chemical variables.

Long-term variation in physico-chemical variables was assessed using the published data and records. During the MRLR, a SBE Seabird 911 plus CTD was used at all stations to obtain temperature and salinity profiles of the water column. Water samples for dissolved oxygen (DO) were collected in Niskin bottles (5 L) using a Rosette sampler and were estimated using Winkler’s method (Grasshoff, 1983).

The IIOE zooplankton samples were collected from the upper 200 m of the water column; therefore, to allow comparison of the respective data sets, the total chaetognath abundance of only the upper two layers of the MRLR (MLD and TC) was used. As the average depth of the upper two layers was 168 m, the small difference in sampling depths between the two programmes was considered unlikely to affect the data comparison. The chaetognath abundance of the upper two layers of the MRLR was consolidated accordingly:

$$A_{\text{consolidated}} = \sum_{i=1}^n \frac{z_i A_i}{z_j}$$

where  $A_i$  is the abundance at a particular stratum and  $z_i$  the depth of the particular stratum.

To check the similarity in the distribution of chaetognath species, agglomerative hierarchical cluster analysis was performed based on the Bray-Curtis similarity during both periods and a similarity profile test (SIMPROF) was further done to identify the significantly correlated species. A permutation-based hypothesis testing (ANOSIM) was carried out to recognize the variation between the chaetognath assemblages of the two periods. The individual species contributing to the dissimilarity in assemblages between the two time periods were further identified through the similarity percentages routine (SIMPER) implemented in PRIMER 6 (Clarke and Gorley, 2006). The Shannon diversity index ( $H'$ ) was also carried out to assess the variability in the species

diversity. The unpaired  $t$ -test was performed to verify whether stage-wise chaetognath abundance exhibits any significant variation between the northern and southern part during the MRLR period. In the northern IO, physico-chemical variables change markedly over a few metres in the vertical (Kumar *et al.*, 2010). Hence, to delineate the interrelationship between physico-chemical variables and the chaetognath community, Pearson’s correlation analysis was carried out separately for the upper two layers using the MRLR data set. Later, multi-variate principal components analysis (PCA) was performed between the abiotic variables and the abundant chaetognath species for detail understanding of their relationship.

The decadal mean value of the sea surface temperature (SST) in this region indicated a gradual increase with time, particularly after 1960s (Supplementary data, Fig. S1). The observed temperature increase during a 100-year period was ~0.7°C, consistent with ocean warming in response to climatic change (Levitus *et al.*, 2000). Published reports on the other two major abiotic variables, salinity (Boyer *et al.*, 2005) and DO (Stramma *et al.*, 2008), provide further evidence for the variability in the physico-chemical environment in this tropical ocean.

The SST distribution pattern in the MRLR study agrees with the general trend of decreasing temperature from the equator towards the poles (Nair and Thampy, 1980) (Supplementary data, Fig. S2). The relatively lower surface salinity observed in the north during both seasons might be due to the high riverine influx (Subramanian, 1996). In the DO profile, the thickness of the oxygen minimum zone (OMZ < 0.5 mL L<sup>-1</sup>) exhibited a gradual increasing trend towards the north (Supplementary data, Fig. S2) and is similar to that observed in the Arabian Sea (Kusum *et al.*, 2011).

Little variation was evident in overall chaetognath abundance between the two studies (9748 and 9627 ind/1000 m<sup>3</sup> for IIOE and MRLR, respectively). However, detailed analysis of the spatial variation along a temporal scale indicated a change in both community structure and distribution of the chaetognath population corresponding to the changes in physico-chemical variables (Fig. 2a). In the south, chaetognath abundance for the MRLR was less than that for the IIOE, but the opposite was observed in the north (Fig. 2a). This result is particularly robust when species composition and distribution is considered. That more species were observed during the MRLR (24) than during the IIOE (14) clearly validates the change in community composition (Fig. 2b and Supplementary data, Fig. S3). The significant differences observed in the one-way ANOSIM test (Global R: 0.926; p: 0.1%) between the chaetognath species assemblages further support the variation in the community

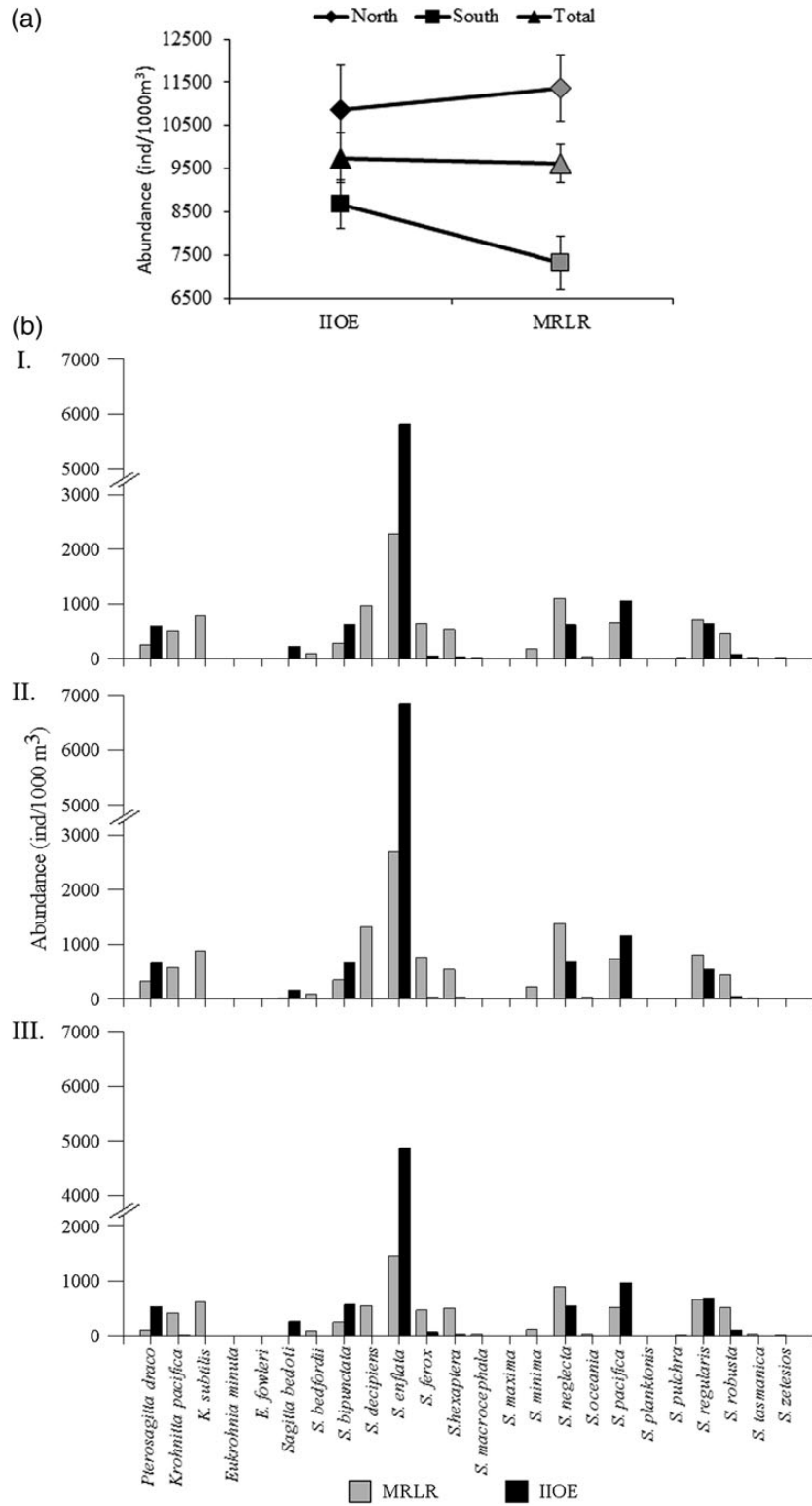


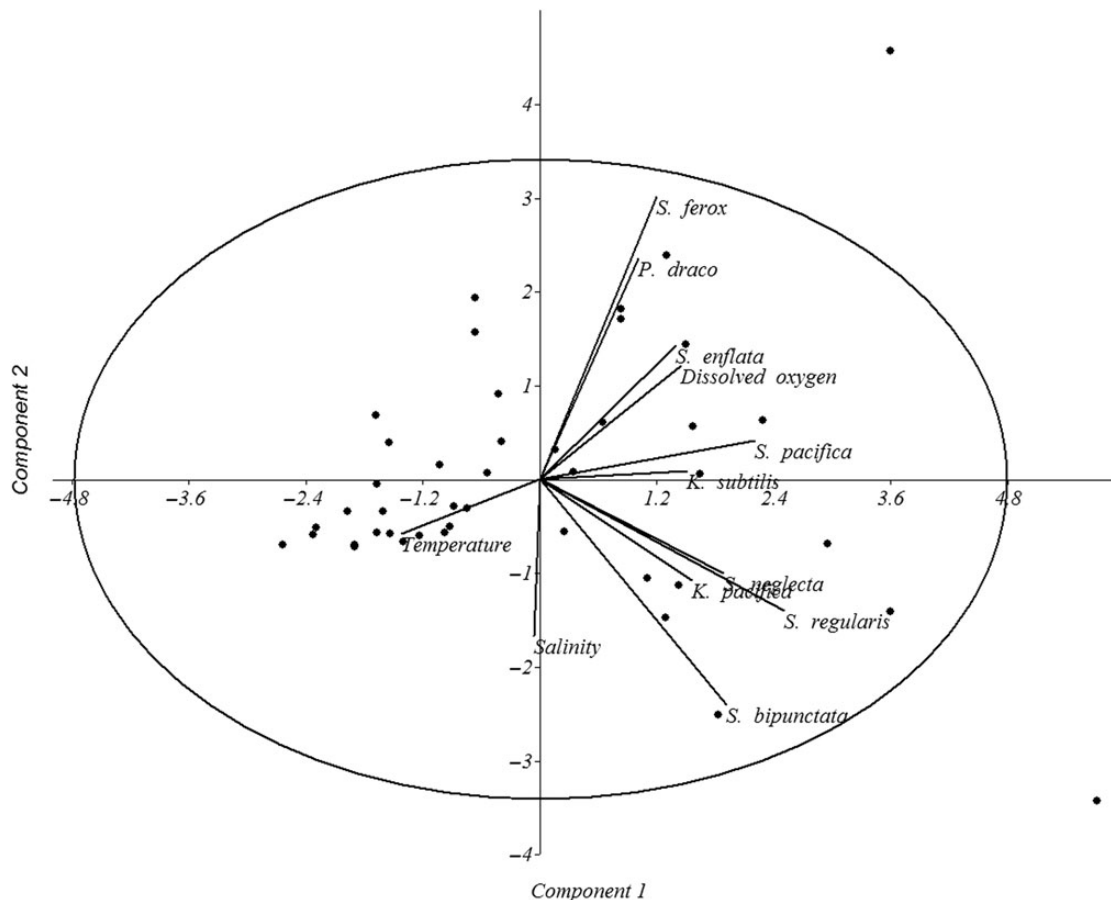
Fig. 2. (a) Spatial variation in chaetognath abundance along the temporal scale; (b) temporal variation in the chaetognath community composition (I) total, (II) northern region and (III) southern region.

composition between the two periods. Chaetognath abundance in the upper 200 m during the IIOE was composed of epipelagic species, while during the MRLR a conspicuous change in the community structure was observed, with several mesopelagic species also contributing to the total population. The disparity in species number between the north and south might be due to the thicker OMZ in subsurface water of the northern region (Supplementary data, Fig. S3).

A more detailed study of the variation in species contribution provided further insight into the change in chaetognath community structure for this region. Thus, during both study periods, *Sagitta neglecta*, *Sagitta pacifica* and *Sagitta regularis* were abundant, but *Pterosagitta draco* and *Sagitta bipunctata*, which comprised a substantial proportion of the total population during the IIOE, were less prevalent during the MRLR (Fig. 2). In contrast, *Krohnitta pacifica*, *Krohnitta subtilis*, *Sagitta decipiens*, *Sagitta ferox* and *Sagitta hexaptera*, although not prominent during the IIOE, contributed greatly during the MRLR, indicating a major change in community structure. A marked decline in the abundance of the dominant species, *S. enflata*, between the two time periods suggests the changing nature of its distribution. Among the 24 species, 14 species (identified through SIMPER) contributed mostly for discriminating the community structure between the two periods (Supplementary data, Table S1). The dendrogram of chaetognath species exhibited the similarity in distribution during both IIOE and MRLR periods (Supplementary data, Fig. S4). During the MRLR, though several mesopelagic species were present along with the epi-pelagic species, they were always found in different clusters indicating a variation in their distribution. Though  $H'$  values did not show much variation between northern (0.843–1.597, ave.  $1.32 \pm 0.17$ ) and southern parts (1.016–1.742, ave.  $1.44 \pm 0.2$ ) during the IIOE, the values were relatively less than that observed during the MRLR (north: 1.73–2.543, ave.  $2.3 \pm 0.23$ ; south: 1.7–2.36, ave.  $2.1 \pm 0.18$ ). The occurrence of the mesopelagic species along with the epipelagic species might have contributed to the increase of  $H'$  value during MRLR. The elucidation of the variation in the abundance and community structure remains ambiguous without considering the geographical setting of this region. A notable decrease in chaetognath abundance in the southern region and an increase in the north might have resulted in the poleward migration of the chaetognaths, as observed for copepods in the Atlantic and Pacific Oceans (Beaugrand *et al.*, 2002; Batten and Walne, 2011). The Eurasian landmass bordering the northern IO is expected to hinder northward migration of the chaetognath population beyond 30°N, thus resulting in an aggregation in the north.

In the upper layer (MLD), chaetognath abundance exhibited a negative relation with temperature, whereas in the layer below TC no particular trend was noticed (Supplementary Data, Table S2). This is relevant when we consider that the warming resulting from climatic variation is faster in the surface water than in deeper layers due to air–sea interactions (Shenoi *et al.*, 2005). Of the other two abiotic variables, no clear trend in abundance was observed with salinity, while DO showed a positive influence on the abundance in the upper layer, further validating the crucial role of DO in the sustenance of this planktonic group. Since significant influence (either positive or negative) of the abiotic variables on abundance was seen only in the upper layer (MLD) (Supplementary data, Table S2), further statistical analysis (PCA) was restricted to the MLD data. This analysis provided clues for the preferred abiotic environment of the nine abundant species. Though all species exhibited a negative relation with temperature and a positive association with DO, the intensity of the association varied among different species (Fig. 3). The preference for an oxygenated and relatively less warm environment was most pronounced in *S. enflata* and *S. pacifica*, which validates the long-term decrease in their abundance due to ocean warming and spreading of the OMZ.

Examination of the distribution of growth stages of different species highlighted their varied responses to changes in abiotic parameters. The northern IO is one of the major oxygen deficient zones in the global ocean (Levin, 2002) and, in this environment; immature individuals were reported to be more active than maturing and adult chaetognaths (Kusum *et al.*, 2011). The higher percentage contribution of the immature individuals in the upper layer of the northern region (Supplementary data, Fig. S5) might have resulted from their greater tendency to migrate towards a preferable environment. As most chaetognath species responded negatively to increased temperature, the relatively low SST in the north might represent a more suitable habitat. The greater abundance of the immature population of the epipelagic species *S. enflata* and *S. pacifica* in the north further corroborates this view (Supplementary data, Fig. S5). In the case of mesopelagic *S. macrocephala*, *S. planktonis* and *S. zetesios*, which were mostly reported from depths <200 m (Nair, 1978), mature organisms dominated in the northern region. As the oxygen demands of mature organisms are greater than those of immature individuals due to egg and sperm production (Wishner *et al.*, 2000), a smaller fraction of their mature population might have migrated to the relatively oxygenated upper layer from the oxygen-deficient subsurface layers. The significant variation in the immature and mature population of chaetognath species between northern and



**Fig. 3.** The principal component analysis biplot displaying the ecological relationship between physico-chemical variables and abundant chaetognath species. The analysis was done based on the correlation matrix and in the biplot the relative direction of the straight line of different variables indicates the correlation among them.

southern parts (*t*-test, Supplementary data, Fig. S5) further corroborates this view.

Levitus *et al.* (Levitus *et al.*, 2000), based on SST distribution, indicated that climatic variation in the IO became more pronounced after 1960s, and this was also apparent from our observations. Hence, of the two time frames selected for our study, the IIOE might represent the ecological state before this shift, whereas the MRLR might represent the ongoing effects of climatic variation. The change in chaetognath abundance and community structure was conspicuous, and might be due to varied species-specific sensitivity to alterations in the abiotic variables analysed. As a dominant species, which shows negative responses to variation in physico-chemical parameters indicative of climatic variation, *S. enflata* can be considered a suitable indicator of climate change in this region. The present study will provide baseline information on chaetognath ecology and population dynamics in a future warmer world.

## SUPPLEMENTARY DATA

Supplementary data can be found online at <http://plankt.oxfordjournals.org>.

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