



Biodiversity of chaetognaths of the Andaman Sea, Indian Ocean

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ABSTRACT

Andaman Sea is a prominent biodiversity hotspot in the Indian Ocean. Stratified zooplankton collections were taken at 33 locations during 2003–2006. Average density of chaetognaths was 8.5/m³ in open ocean and 41.6/m³ in coastal waters. Twenty species of chaetognaths, including two recently described species occur in the area. In the oceanic sector *Sagitta enflata* dominated the layer above thermocline followed by *S. neglecta*, *S. bipunctata*, *S. pacifica*, *Pterosagitta draco*, and *S. regularis*. In the depths from thermocline to 500 m, *S. decipiens* dominated followed by *Eukrohnia fowleri*. Aggregations of *S. decipiens*, a mesopelagic species, were occasionally found in the mixed layer (up to 9.9/m³) during Northeast monsoon associated with the upward movement of species. In the coastal waters either *S. enflata* or *S. neglecta* dominated. Recently described *Krohmita balagopali* and *Sagitta meenakshiae* are endemic to the area. Maximum species diversity was observed at the thermocline. Invariably two clusters were found along each stratum at the 60 to 70% similarity level or higher. Latitudinally, species diversity increased towards south. Variability in the chaetognath community is influenced by unique physical features of the area.

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1. Introduction

The biogeography of chaetognaths on a global basis (Alvarino, 1965; Pierrot-Bults and Nair, 1991) reveals a biodiversity gradient of chaetognaths with greater diversity at the tropics than the poles due in part to larger habitable areas occupied by the species leading to higher chances of survival and propagation. Indian Ocean has rich biological diversity and is one of the 25 hot spots of the richest and highly endangered eco-regions of the world (NIO, 2008). Though many of the unique and protected areas are important biodiversity hot spots, studies of such ecosystems are limited. The Andaman Sea is one of the prominent biodiversity hot spots in the Indian Ocean. The Andaman Sea has a unique hydrography of the area as described below (Sewell, 1929; Ramaraju et al., 1981; Sen Gupta et al., 1981; Varkey et al., 1996; Madhu et al., 2003). During the International Indian Ocean Expedition (IIOE 1960–65), there was some biological sampling of the Andaman Sea (Nair, 1977). A later survey around the Andaman Sea in 1979 showed minor enhancement in species diversity of chaetognaths (Nair et al., 1981). More recently (2003–2006), extensive sampling was done in the oceanic and coastal waters of the Andaman. This sampling took place both before and after the great Tsunami of December 2004 that occurred in Sumatra and attracted global attention. While the pre and post Tsunami studies in the area did not show much variation in the hydrographic

or general biological properties (NIO, 2007), the resulting data are used herein to evaluate the biodiversity and variability of chaetognath community of the Andaman Sea in relation to the prevailing special physical features of the area.

2. Study area

The Andaman Sea is located along the eastern side of the Indian Ocean between the Malay Peninsula and the Andaman and Nicobar Islands (between approximately 6 – 14°N latitude and 93 – 99°E longitude; Fig. 1). The Andaman and Nicobar Islands on the western side of Andaman Sea are volcanic in origin. As a result, the water depth in the region changes rapidly from over 3000 m in the Indian Ocean to approximately 200 m in the areas around the islands. Average depths are between 800–1000 m with a maximum of 4267 m. All the islands of this archipelago have in general steep slopes on all sides and hence oceanic conditions prevail even in near shore regions.

The Andaman Sea is influenced by large quantities of fresh water run off from the perennial rivers of Myanmar, Thailand, and Malaysia. Intense evaporation of surface water occurs during winter. The southern parts of the sea are areas of intense air–sea interaction releasing enormous energy resulting in tropical cyclones (Varkey et al., 1996). During the south–west monsoon (SWM) period cyclonic circulation develops in the surface waters of Bay of Bengal and Andaman Sea and water movements are from west to east. The wind direction is reversed during north–east monsoon (NEM) period; the gyre becomes anticyclonic and circulation turns from east to west. The inter monsoon (IM) period is a transitional period.

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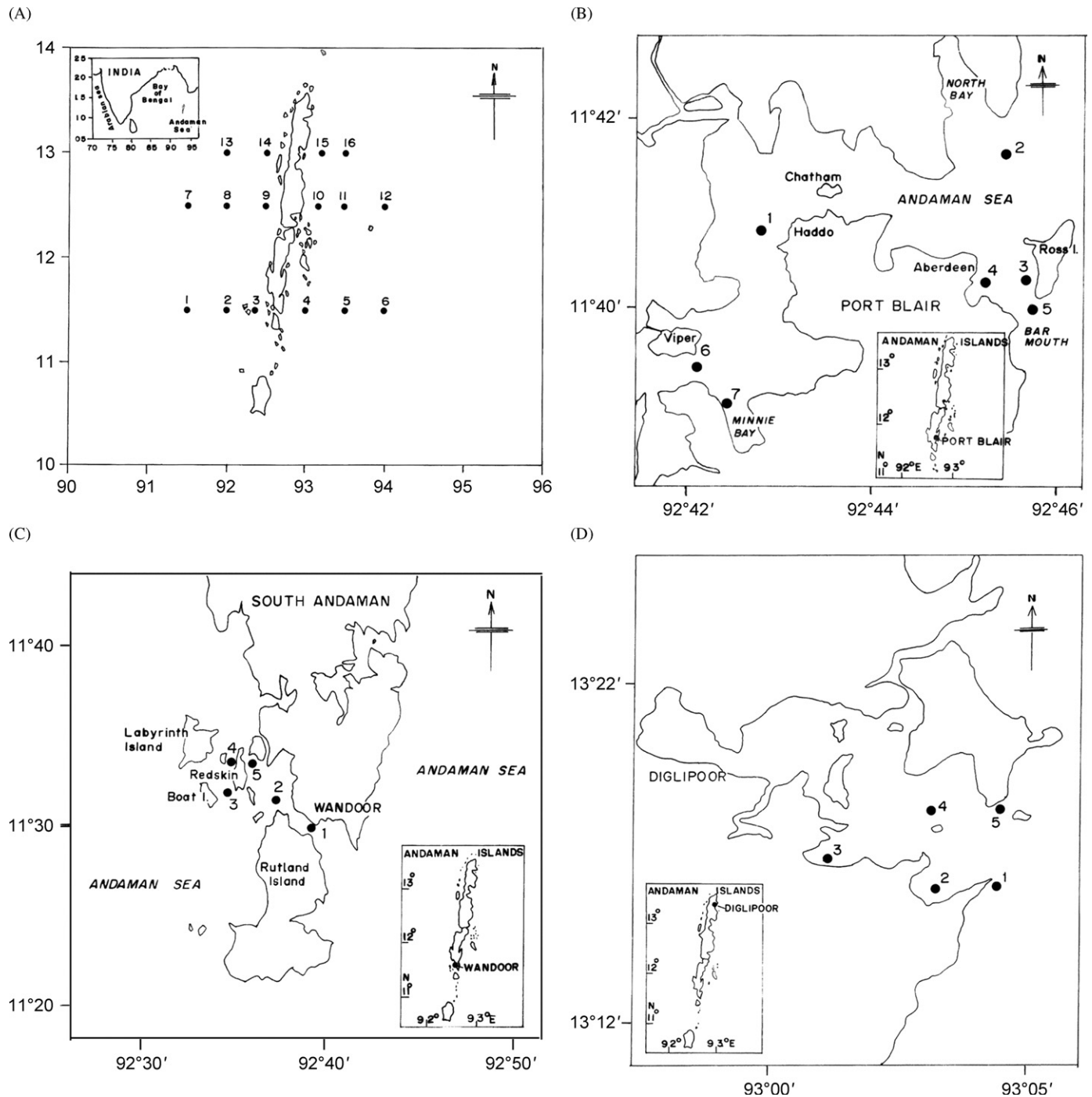


Fig. 1. Map of Andaman Sea showing location of stations (A) open ocean and coastal waters at Port Blair (B), Wandoor (C), & Diglipur (D).

The temperature of the surface waters fluctuates mildly from a monthly average of about 30 °C in the summer months to about 27.5 °C in the winter months. In general, the mixed layer and the lower reaches of thermocline, halocline, and pycnocline are distinctly deeper on the Bay of Bengal side of Andaman island compared to eastern Andaman Sea water and surface temperature are higher in the latter than the former. Thus, the upper water column on the south western side of Andaman Island as a whole is different from the Andaman Sea water on the eastern side.

The surface salinity exhibits strong seasonal variations due to heavy fresh water influx from rivers during monsoon seasons. The surface water is estuarine-like while the subsurface water shows typical marine conditions. Below the surface the salinity increases

rapidly resulting in the development of a strong halocline in the top layer. Below the halocline, there is a gradual increase in salinity with maximum value in the region of 75–1000 m in the eastern sections (NIO, 2008). Thus, strong vertical and horizontal gradients of salinity occur particularly in the upper layer of the Andaman Sea.

3. Methods

Hydrographic and biological observations from the Andaman Sea were carried out on board FORV Sagar Sampada between 11° and 13°N latitude and 91° and 93°E longitude. Sixteen stations

were fixed in three transects along three latitudes 11°30'N (southern transect), 12°30'N (middle transect) and 13°N (northern transect) (Fig. 1A). Along the coast at Port Blair Bay, seven stations were distributed throughout the bay (Fig. 1B); at Wandoor and at Diglipur there were 5 stations in each area (Fig. 1C, D). In this study, seasons are divided into the summer or south-west monsoon (SWM, June – September), the winter or north-east monsoon (NEM, October – February), and the inter monsoon (IM, March – May).

Physical parameters (temperature and salinity) were collected using a SBE 911 plus CTD. These data were quality controlled using the seabird data processing software. Water samples for chemical parameters were collected from 0, 50, 100, 150, and 200 m depths. Sampling was done using a CTD rosette sampler equipped with 1.8 litre Niskin bottles. Dissolved Oxygen (DO) was estimated by the Winkler's titration method. Nutrients (nitrite, nitrate, phosphate and silicate) were determined by using an on board segmented Flow Auto Analyser (SKALAR).

Mesozooplankton were collected around Andaman waters covering all the 16 oceanic and 17 coastal locations (Fig. 1) during 2003–2006. The sampling period covered Dec.–Jan. 2003–04 (NEM), Jun.–Jul. 2004 (SWM), Jan.–Feb 2005 (Post Tsunami), Oct.–Nov. 2005 (NEM), April–May 2006 (IM) and Aug.–Sept. 2006 (SWM).

From the oceanic sector, stratified samples were obtained using Multiple Plankton Net (MPN – Hydro Bios; Weikert and John, 1981; mouth area 0.25 m², mesh size 200 µm). Sampling was stratified according to the temperature profiles obtained with the CTD cast prior to collection. The net was hauled vertically from four different depth strata: 500–300, 300 to the base of thermocline (BT), BT to the top of thermocline (TT), and TT to Surface (mixed layer) wherever the depth permitted. The net was retrieved at a speed of 1 m/s and the volume filtered was calculated from each depth based on the distance towed and the hauling speed. Surface samples were made using a 60 cm diameter Bongo net (0.33 mm mesh) for 10 minutes at 2 knots. In coastal waters, samples were collected by 10-minute oblique hauls using a WP net (mesh size 0.2 mm, mouth area 0.25 m²) with an attached general oceanic flow meter.

After collection, samples were filtered, drained of excess water on absorbent paper and added to a known volume of water to estimate biomass as a displacement volume. Samples were preserved in 4% formaldehyde for later enumeration and identification, which was done from 25–75% aliquots for upper layers and entire samples for deeper layers. Chaetognaths were identified to species level following Alvarino (1965) and Nair (2003). Species diversity indices for species of chaetognaths were calculated to obtain richness, dominance, diversity, and concentration (Heip, 1974; Margalef, 1968; Shannon and Weiner, 1963). Abundance of species at each depth was accounted for by group-average sorting with a Bray-Curtis analysis after normalizing the data using a root-root method (Field et al., 1982). Species grouping were made based on identifying clusters with at least 60 to 70% similarity in the hierarchical cluster analysis.

4. Results

4.1. Environmental characteristics

Depth variation in the mixed and the thermocline layers for the three seasons showed that the depth of the mixed layer is more for SWM. Variation in thermocline layer was comparable for NEM and SWM periods (Table 1).

Among the physical-chemical variables measured, emphasis is given to temperature, salinity, and dissolved oxygen as they are related to the diversity patterns of chaetognaths more than the

Table 1

Depth variation in the mixed layer and the thermocline layer in the Andaman Sea during the three seasons.

Depth	NEM	IM	SWM
0-TT	0–46	0–37	0–77
TT-BT	11–185	11–160	14–182

other parameters (Nair and Srinivasa Kumar, 2006). Temperature gradually declined from upper 50 m to 500 m, with a maximum gradient observed during SWM period (Fig. 2). During NEM, a strong thermal inversion of about 3 °C at 25–50 m was observed in the northern latitude with decreasing intensity up to 10 °C (NIO, 2008). North-south variation in temperature did not indicate a consistent pattern. During the NEM and the SWM, an enhancement in salinity from north to south in the 100–200 m water column was observed. In general, relatively higher temperature was observed on the western than the eastern side of Andaman Sea. Seasonal variation in salinity was not observed. Salinity was relatively low in the upper 50m and gradually increased to 500 m. The surface waters were well oxygenated during the three seasons. DO level drastically decreased from 0 to 100 m and was more evident during SWM. The Oxygen Minimum Zone (OMZ) increased in thickness towards the north in depths between 200–700 m. The thermal inversion and associated stratification are the reasons for the formation of the oxygen depleted layer. The lowest value was recorded at 200 m during the SWM.

The water column remained slightly alkaline during all the three seasons. pH was higher above 50 m. The nitrite concentration was relatively high during the NEM compared to the IM and SWM periods. The maximum concentration encountered was 0.5 µM at 50 m while the minimum concentration (0.2 µM) was observed at the surface layer. Very low levels of nitrite were encountered during the SWM.

Maximum concentrations of nitrate were recorded during the IM, which ranged from not detectable (ND) to 29.0 µM at 200 m depth. As in the case of nitrite, low levels of nitrate were recorded during the SWM. There were moderate amounts of nitrate during the NEM; the values ranged between ND and 27.0 µM.

Moderate to high concentrations of phosphate were observed during all the seasons of the year with the maximum value (2.8 µM) during the IM at 200 m depth. The surface layers as expected, recorded low concentrations (0.5 µM). During IM season, the highest concentration was observed at 200 m depth and the lowest in the surface layers.

In general, nutrients showed enhanced values from 100 to 200 m during the SWM. Values were highest in the southern latitude (11.5°N) with relatively low values at 12.5°N and 13.0°N.

In the coastal waters, temperature varied from 27.45 to 30.06 °C with maximum value during the IM period. Salinity at surface and subsurface fluctuated from 32.43 to 33.38. DO in the area was fairly high showing a variation of 4.32 to 4.98 ml/l. The area is rich in nutrients.

4.2. Chaetognath population

4.2.1. Oceanic zone

In the Andaman waters, chaetognaths rank second in abundance after copepods contributing 0.10 to 40.71% (av. 6.6%) in the oceanic realm. In the open ocean, the population density for the 0 to 500 m water column varied from 20–168533/1000 m³; av. 9123/1000 m³ and was higher than that right at the surface, which varied from 63 to 29,228/1000 m³; av. 7866/1000 m³.

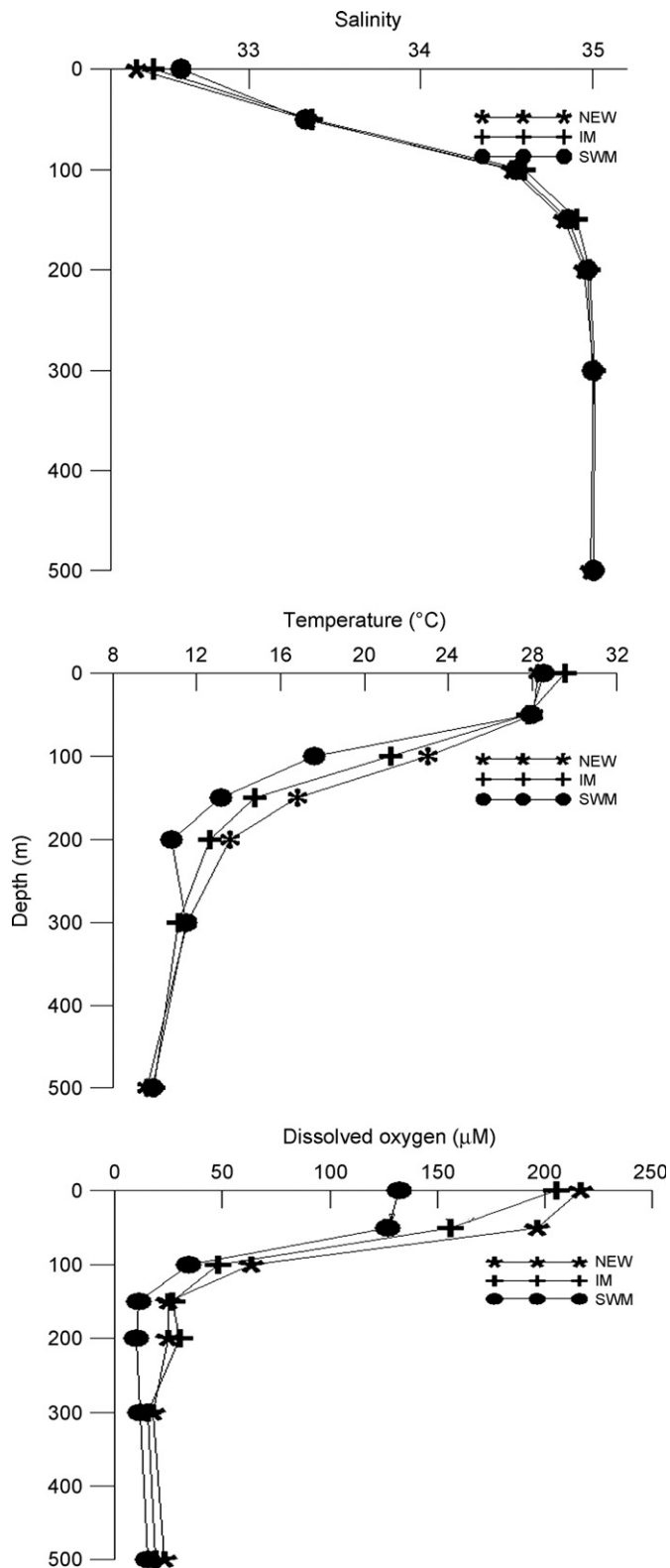


Fig. 2. Seasonal distribution of salinity, temperature, and dissolved oxygen during NEM (north-east monsoon), IM (inter monsoon), and SWM (south-west Monsoon) periods.

A maximum density of the chaetognaths was in the mixed layer (Table 2).

There was steep decrease in the chaetognath population from 0-TT to the 300-500 m stratum (Table 2). On average, the

population densities of chaetognaths at 0-TT, TT-BT, BT-300 m, and 300 - 500 m were respectively 275, 290, 7,387, 1,513, and 222/1000 m³. This indicates a decrease in population size of 3.7: 4.9: 6.8 respectively relative to the zone above. The percentage contribution of the chaetognaths to the total zooplankton abundance also showed reduction of 6.9, 6.6, 4.1, and 2.7 for the four strata in the respective order.

Seasonally, the maximum population abundance occurred during IM (10380/1000 m³) followed by SWM (av. 9281/1000 m³) and NEM (av. 8599/1000 m³). In general, higher population numbers of chaetognaths were found on the middle 12.5°N and southern (11.15°N) transects. In the surface (Bongo collections), average densities for SWM, NEM, and IM were respectively 8536, 7894, and 6441/1000 m³. There were higher densities along the eastern Andaman during the SWM, while higher densities occurred in the other two seasons on the western side of the Andaman Sea.

4.2.2. Coastal zone

Populations of chaetognaths were much higher in coastal waters as compared to the oceanic zone. Densities ranged from 119 to 308197/1000 m³ (av. 41613)/1000 m³ and the percentage contributions to zooplankton community were (0.10 to 34.62% (av. 5.33%) and were comparable to the oceanic sector. The IM period supported a maximum population of chaetognaths (56638/1000 m³) as compared to the SWM (42748/1000 m³) and the NEM (av. 25454/1000 m³). The average percentage contributions of chaetognaths to total population in the respective order were 6.07, 4.33 and 5.59%.

The abundance of chaetognaths had the highest average density at Port Blair during IM followed by NEM (Table 3). Population maximums occurred during the SWM period at Wandoor and Diglipur.

Irrespective of the seasons, the average density of chaetognaths at Port Blair, Wandoor, and Diglipur were respectively 58,242, 30,788, and 17,840/1000 m³.

4.3. Species diversity

Twenty species belonging to four genera namely *Eukrohnia*, *Krohniitta*, *Pterosagitta*, and *Sagitta* are found in the area and the names are listed in Table 4.

In the oceanic waters, the recently described species, *S. meenakshiae* (Nair et al., 2008), was the only one absent. In the 500 m water column, between seasons there were minor differences in the number of species present with a maximum during NEM (16), followed by SWM (15), and IM (14) periods. At the surface, number of species found at different seasons in the respective order was 15, 13, and 12. In general, the southern transect showed the maximum number of species. Though there is decline in species representation below thermocline (Fig. 3) north-south variation in number of species did not show a regular pattern and the differences, if any, are minor. Invariably, the highest number of species was found along the eastern side of Andaman Sea.

At the surface, *S. enflata* dominated and the other most common species were *S. neglecta*, *S. pacifica*, *K. pacifica*, *S. bedoti*, *P. draco*, and *S. robusta*. Vertical profiles indicated maximum representation of species as well as their population density down to the TT- BT layer. *S. enflata* was the dominant species followed in abundance by *S. neglecta*, *S. bipunctata*, *S. pacifica*, *P. draco*, and *S. regularis*. In the BT-300 stratum, *S. decipiens* dominated. Other species common in this stratum were *S. enflata*, *S. pacifica*, and *S. bipunctata*. *S. decipiens* was also the most abundant species in the 300-500 m stratum and *E. fowleri* became more common in

Table 2Average population (no/1000 m³), contribution (% in parenthesis), and reduction ratio of chaetognaths under 0–500 m water column.

Season	0-TT	TT-BT	0-TT:TT-BT (Ratio)	BT-300	TT-BT:BT-300 (Ratio)	300-500	BT-300:300-500 (Ratio)
NE	26528 (5.47)	6587 (4.78)	4.02	2804 (3.61)	2.35	245 (1.55)	11.44
SW	26699 (6.85)	3538 (5.92)	7.55	1140 (5.07)	3.10	178 (3.77)	6.40
IM	28644 (8.28)	12035 (9.10)	2.38	595 (3.64)	20.23	244 (2.92)	2.44

Table 3Average values of chaetognaths (no/1000 m³) and percentage contribution (in parenthesis) at different areas along the coastal sector.

Season	Port Blair	Wandoor	Diglipur
NE	47474 (9.20)	5033 (2.28)	13437 (5.89)
SW	21551 (3.95)	82926 (3.26)	33812 (5.50)
IM	105702 (7.35)	4405 (4.59)	6272 (1.10)

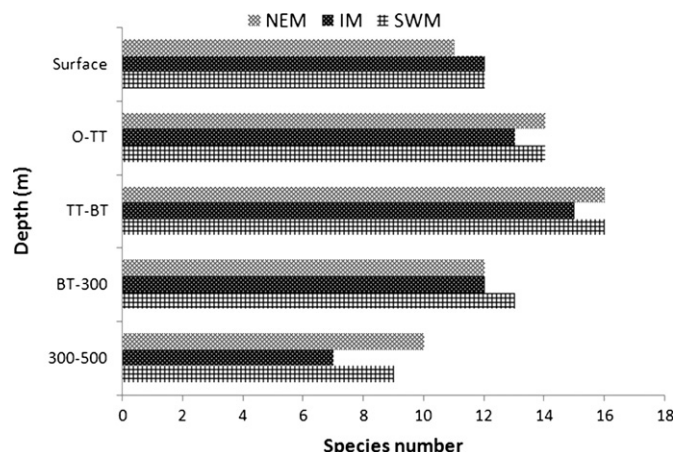
Table 4

List of chaetognath species recorded from the Andaman Sea.

Genus	Species
<i>Eukrohnia</i>	<i>Eukrohnia fowleri</i> Ritter-Zahony, 1909
<i>Krohnittia</i>	<i>Krohnittia balagopal</i> ^a (Nair et al., 2008)
	<i>Krohnittia pacifica</i> (Aida, 1897)
	<i>Krohnittia subtilis</i> ((Grassi, 1881)
<i>Pterosagittia</i>	<i>Pterosagittia draco</i> (Krohn, 1853)
<i>Sagittia</i>	<i>Sagittia bedoti</i> (Beraneck, 1895)
	<i>Sagittia bipunctata</i> (Quoy and Gaimond, 1827)
	<i>Sagittia decipiens</i> (Fowler, 1905)
	<i>Sagittia enflata</i> (Grassi, 1881)
	<i>Sagittia ferox</i> (Doncaster, 1903)
	<i>Sagittia hexaptera</i> (d'Orbigny, 1843)
	<i>Sagittia lyra</i> (Krohn, 1853)
	<i>Sagittia maxima</i> (Conant, 1896)
	<i>Sagittia meenakshiae</i> ^a (Nair et al., 2008)
	<i>Sagittia minima</i> (Grassi, 1881)
	<i>Sagittia neglecta</i> (Aida, 1897)
	<i>Sagittia pacifica</i> (Tokioka, 1940)
	<i>Sagittia pulchra</i> (Doncaster, 1903)
	<i>Sagittia regularis</i> (Aida, 1897)
	<i>Sagittia robusta</i> (Doncaster, 1903)

^a Recently recorded species Nair et al. (2008).

this zone, often ranking second in abundance. Seasonally during the IM period, population densities of species were low compared to the SWM and NEM periods. During SWM and NEM periods, *S. decipiens* was found even in the mixed layer along the middle and southern transects. In the NEM, unusual aggregations of *S. decipiens* (9909/1000 m³) were observed. The maximum population of *E. fowleri* (50/1000 m³) was recorded at 11.5°N latitude during SWM period. There was a latitudinal increase in the population density of individual species from the northern to southern transects. Though *S. enflata* dominated the eastern and western sides of Andaman Sea above the BT and *S. decipiens* below the BT, the distribution of most common species showed variation during different seasons (Fig. 4). Along eastern side *S. bipunctata* and *K. pacifica* were very common in the NEM, *S. pacifica* and *P. draco* were common during the SWM and *S. neglecta* and *S. regularis* were common during the IM period. On the western side *S. neglecta* was second in abundance during all seasons along with the high abundance of *P. draco*, *S. regularis*, and *K. pacifica*. Unlike on the western side, on the eastern side between 300 and 500 m, *S. enflata*, *S. bipunctata*, *S. pacifica*, and *S. regularis* were common.

**Fig. 3.** Vertical disposition of species along different strata during NEM (north-east monsoon), IM (inter monsoon), and SWM (south-west monsoon) periods. TT: Top of thermocline, BT: Base of thermocline.

In the coastal waters, thirteen species namely *K. balagopal*, *K. pacifica*, *P. draco*, *S. bedoti*, *S. bipunctata*, *S. enflata*, *S. ferox*, *S. meenakshiae*, *S. neglecta*, *S. pacifica*, *S. pulchra*, *S. regularis* and *S. robusta* were found. The maximum number of species was recorded during the NEM (12) followed by the SWM (10) and the IM (8) period (Fig. 5). In general, *S. enflata* and *S. neglecta* were the dominant species and the latter often outnumbered the *S. enflata* population. The chaetognaths species composition at the different locations in the coastal waters is shown in the Fig. 6. During the NEM, *S. enflata* dominated at Wandoor, while at Port Blair and Diglipur, *S. neglecta* dominated. At station 6 in Port Blair, *S. meenakshiae* contributed 91% to the total chaetognath community. Invariably, *S. enflata* dominated the entire coastal waters during the SWM and *K. pacifica* and *P. draco* were common during this period. The seasonal pattern changed during the IM period with the dominance of *S. neglecta* at Wandoor and Port Blair, while aggregations of *S. meenakshiae* contributed 53.6 to 88.5% to chaetognath community at Diglipur. At Wandoor and Port Blair, *S. meenakshiae* also contributed substantially to the total population.

4.4. Species diversity and community structure

4.4.1. NEM period

At the surface, spatial variation was very low with respect to all community structure indices (Fig. 7). The cluster analyses of the surface community revealed with 70% similarity a major community group of the nine most abundant species and a second one that consisted of two species of *Krohnittia* (Fig. 8A). In the mixed layer, species diversity, richness and dominance were relatively high along the eastern Andaman as compared to western sector. Two major clusters were formed containing eight species in a large cluster and three species in a second cluster. Maximum diversity in the TT-BT stratum was observed along the western Andaman as compared to eastern sector. In this stratum, three major clusters

were observed with two species in cluster one, seven in cluster two, and two in cluster three. The maximum diversity in the BT-300 m stratum was at station 6 (2.05). The clusters were formed at 60% similarity, with the two species in the first one, six species in the second, and two species in the third. In 300-500 m stratum, higher diversity occurred in the eastern Andaman. In this stratum, two species were found in each of the two clusters (Fig. 8B1).

4.4.2. IM period

All the diversity indices for chaetognaths in the surface and mixed layer are higher for the western Andaman than the eastern side (Fig. 7). The six most abundant species accounted for similarity in one group and two species found in second group have been identified. Species dominance and concentration in the mixed layer was high on the the eastern side. Two major clusters were formed containing 5 species in cluster one and two species

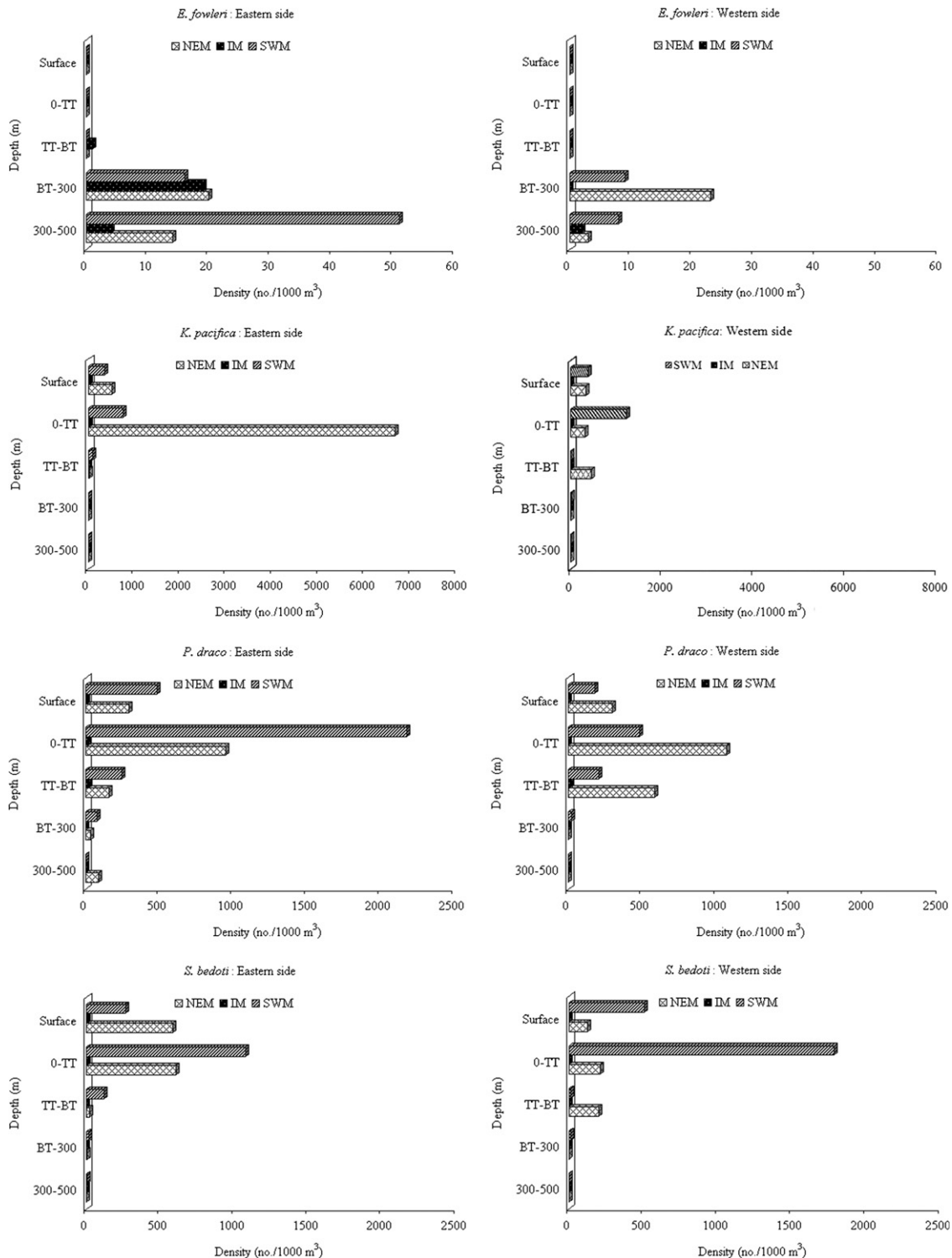


Fig. 4. Vertical distribution of common species of chaetognaths along the eastern and western side of Andaman Sea during NEM (north-east monsoon), IM (inter monsoon), and SWM (south-west monsoon) periods. TT: Top of thermocline, BT: Base of thermocline.

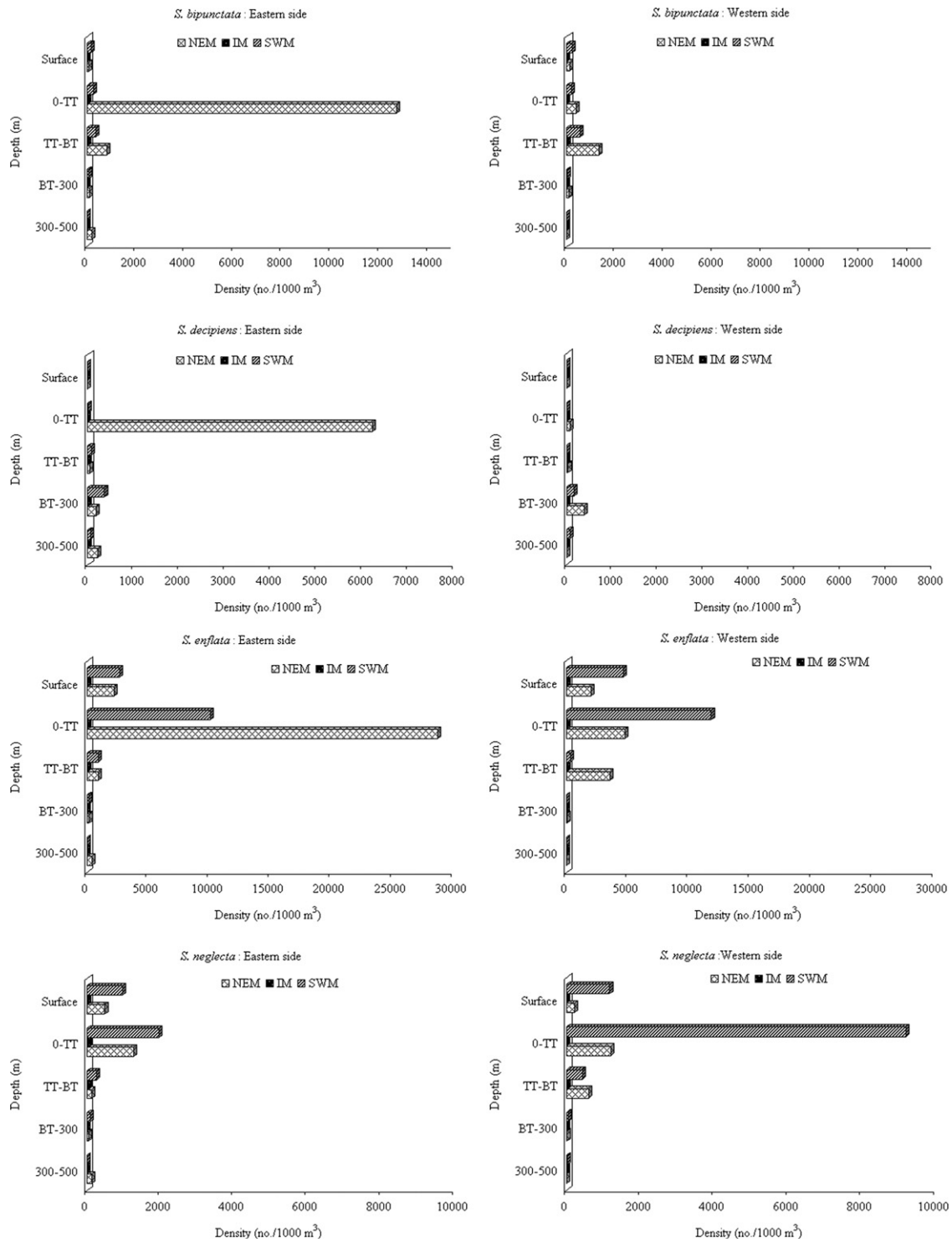


Fig. 4. (Continued)

under cluster two. At TT-BT layer, maximum diversity was observed with a CV% of 70 along western side (Fig. 8B2). Two major clusters were identified with 2 species in one cluster and 7 species in a second cluster. BT-300 m stratum showed the highest diversity along eastern Andaman with three major clusters consisting of three, two, and two species in each one. All diversity indices were high at 300-500 m with CV% of 75 along the east. Here only one cluster was formed at 60% level of similarity with three species.

4.4.3. SWM period

At the surface, maximum chaetognath species diversity was found on western side. Two clusters were identified, one up to 60% of similarity with the six most abundant species and the other with four species. The mixed layer had higher species dominance and concentration on the eastern Andaman whereas species diversity was similar on both sides. Two major clusters with 60% level of similarity were observed with 8 species in cluster one and two species in cluster two. Maximum diversity

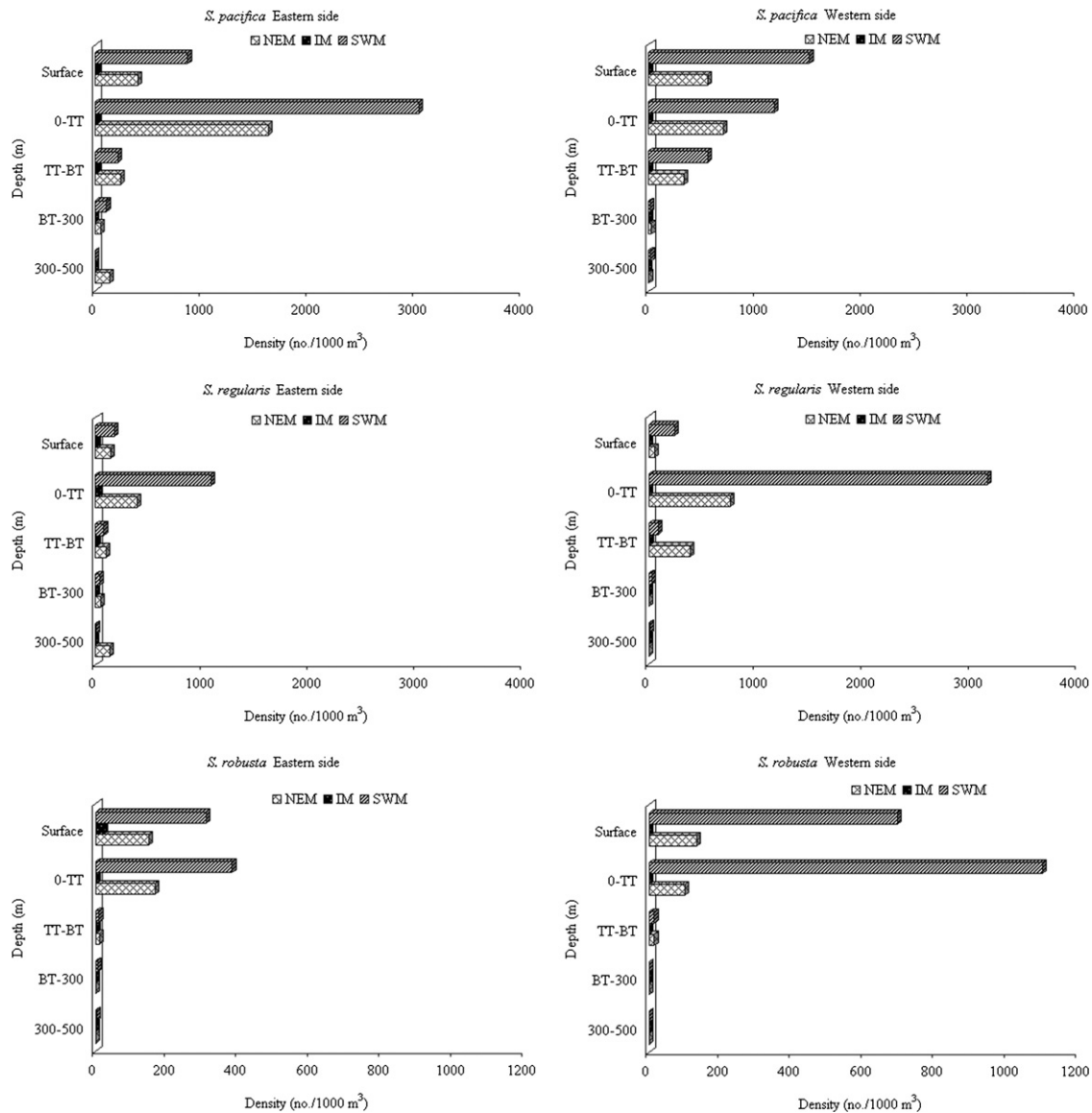


Fig. 4. (Continued)

was observed at TT-BT layer along western side. Three clusters were found, the first one with two species and the second and third ones with four species in each (Fig. 8B3). In the BT-300 m layer, higher diversity was found at station 6 (2.04) with maximum richness (1.52). The first cluster consisted of two species, the second with three species and the third with two species. In the 300-500 m layer, species diversity was comparatively high on eastern side. Three clusters were formed at 40% level of similarity with three species in cluster one, four in cluster two, and three in cluster three.

5. Discussion

In the samples collected during the International Indian Ocean Expedition (IIOE, 1960-65), the average population of chaetognaths was reported by Nair (1969) as 20,000/1000 m³ and later observations done exclusively around Andaman (Nair et al., 1981) population was reduced to 7000/1000 m³. The present observation, after about 25 years, showed the population density remained at a comparable level (av. 8500/1000 m³) to that of 1981 report. The

marginal enhancement in population could be due to the type of sampling and stratum sampled. In the IIOE collections, 10 epipelagic species were found while in 1981, 13 species were observed with *S. enflata* being the dominant. The number of species present in this study (20) indicated a much higher diversity. However, sampling in the earlier studies never extended below 200 m and the sampling down to 500 m could explain the higher diversity in this study. The present investigation in the Andaman Sea covers the period before and after the Tsunami of December 2004 around Sumatra and a comparative evaluation indicated no change in the population density or community structure of chaetognaths.

The mixed layer was shallow (0-46 m - Table 1) during NEM and IM and it deepened (0-77 m) during SWM. The maximum density of chaetognaths observed in the mixed layer was synchronized with the highest standing stock of zooplankton (NIO Report, 2008). In the vertical realm temperature, DO and pH were high in the mixed layer and these parameters showed rapid decrease below 100 m. Salinity, however, showed an opposite trend. The large quantity of fresh water run-off together with warmer SST (~30 °C) resulted in a strongly stratified surface layer. Maximum species diversity was observed in the thermocline layer for all three seasons (Fig. 3).

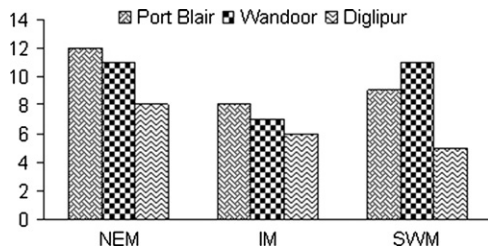


Fig. 5. Total number of species recorded at different areas in coastal waters of Andaman Islands.

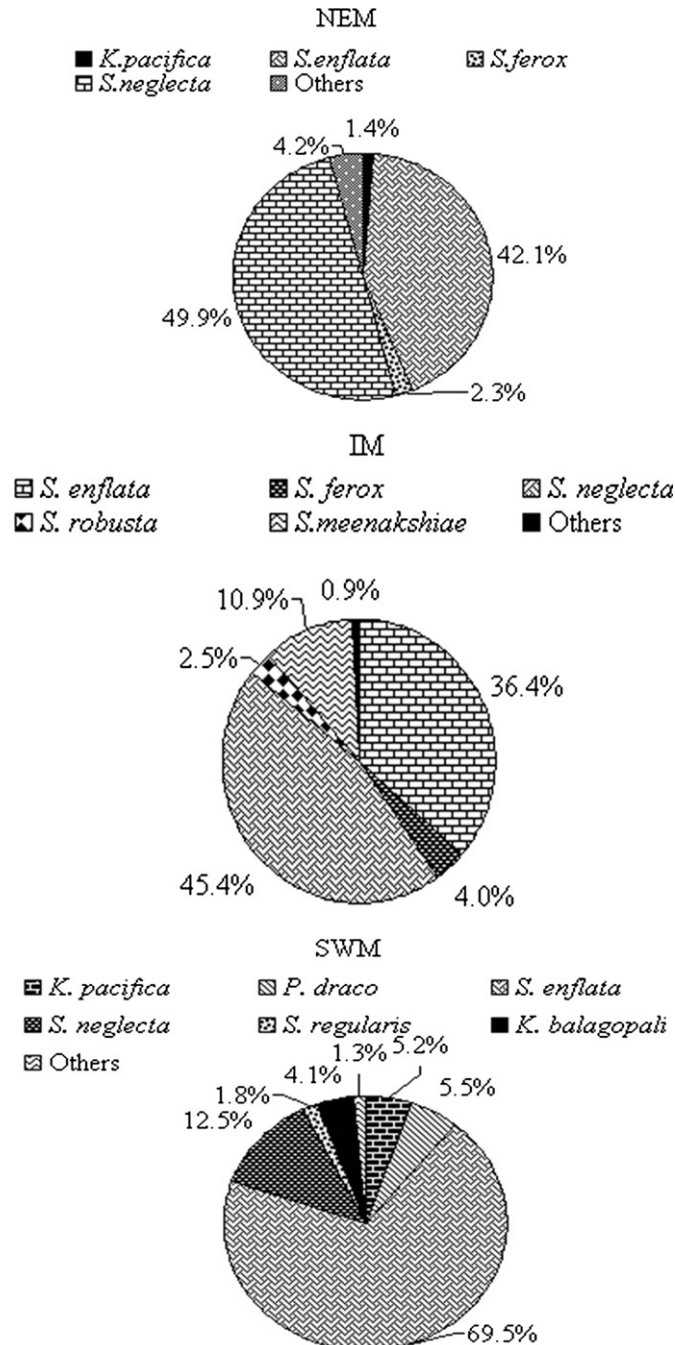


Fig. 6. Species composition of chaetognaths in the coastal waters during the NEM (north-east monsoon), IM (inter monsoon), and SWM (south-west monsoon) periods. TT: Top of thermocline, BT: Base of thermocline.

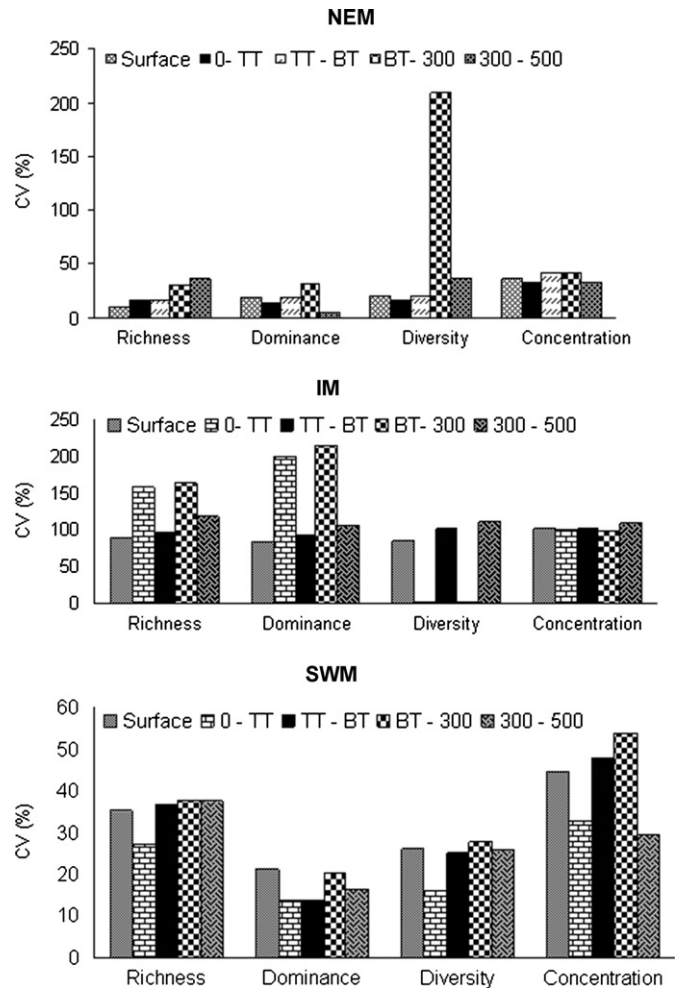


Fig. 7. Variations in diversity indices for chaetognaths during NEM (north-east monsoon), IM (inter monsoon), and SWM (south-west monsoon) periods. TT: Top of thermocline, BT: Base of thermocline.

The presence of an oxygen depleted layer occurs in all seasons in the Andaman Sea. Stratification due to fresh water influx is one of the reasons for the development of oxygen-depleted layer. Less dense surface water resides above the saltier, cooler, and denser subsurface water masses. The thermal inversion associated stratification is high in winter and at a minimum in summer. Zooplankton standing stock was high in the surface layers and markedly reduced in the oxygen depleted layer (NIO Report, 2008). Various taxa showed different distributional responses to the oxygen gradients depending on their physiological ability to cope with low oxygen. Probably, simpler groups like chaetognaths lack obvious physiological system that could be adapted to low oxygen concentrations and may rely primarily on anaerobic metabolism in the oxygen minimum zone (Childress and Thuesen, 1992).

Most of the chaetognaths species are more abundant in the eastern than the western side of the Andaman Sea. This east-west difference in the species abundance could be explained on the basis of the difference in physical features between eastern and western Andaman Sea waters as explained in the study area and environmental characteristics section above. The surface water column is warmer on the eastern side as compared to the western side (Murty et al., 1981). Also the mixed layer depth is deeper in the west than in the eastern side. On the eastern side there are marked temperature inversions of low magnitude at 20 and 30 m with the depths of inversion extending further down towards south (NIO, 2008).

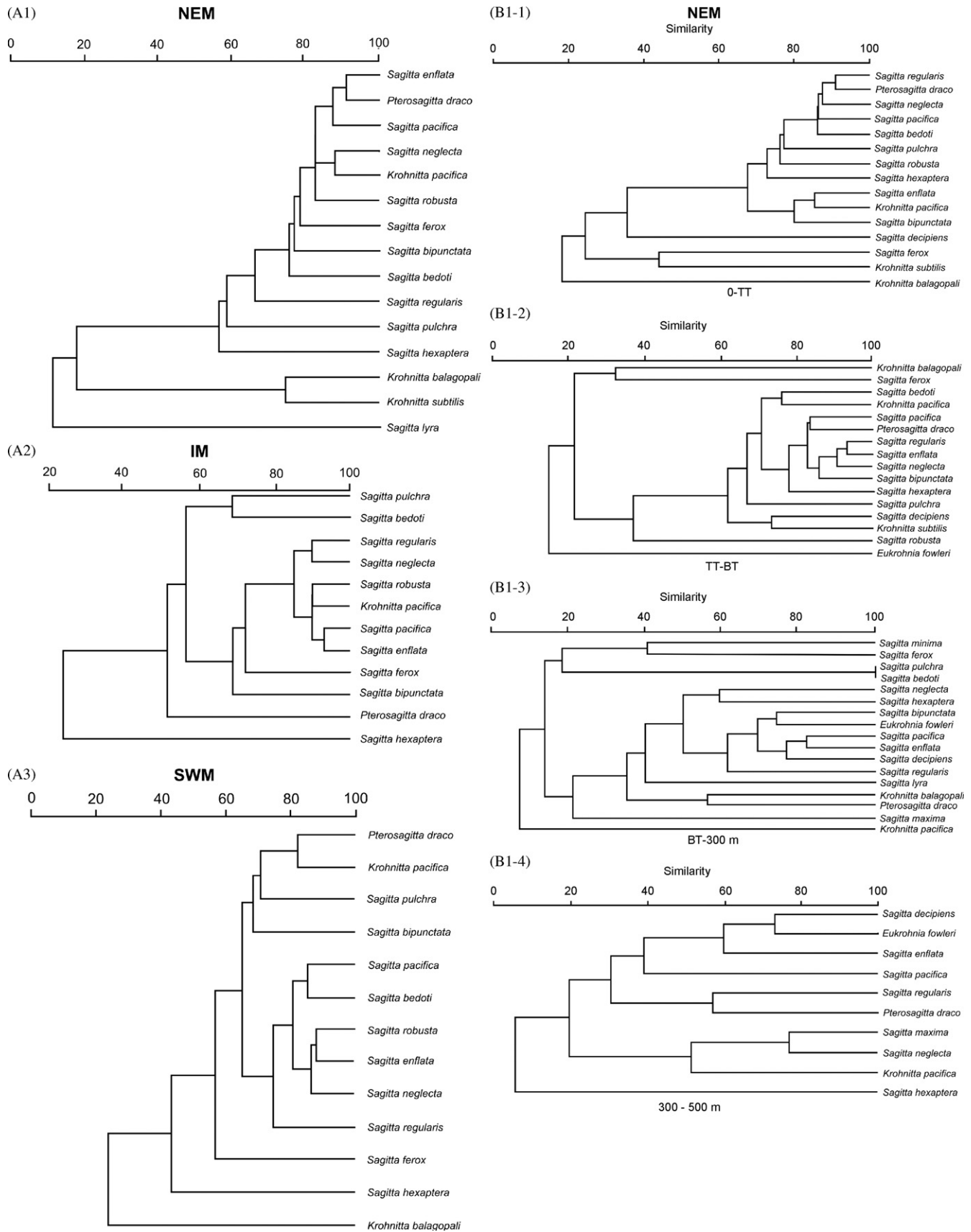


Fig. 8. Species cluster formation based on Bray-Curtis analysis showing affinities among 20 species of chaetognaths at the (A) surface and (B) along different strata during NEM (north-east monsoon), IM (inter monsoon), and SWM (south-west monsoon) periods. TT: Top of thermocline, BT: Base of thermocline.

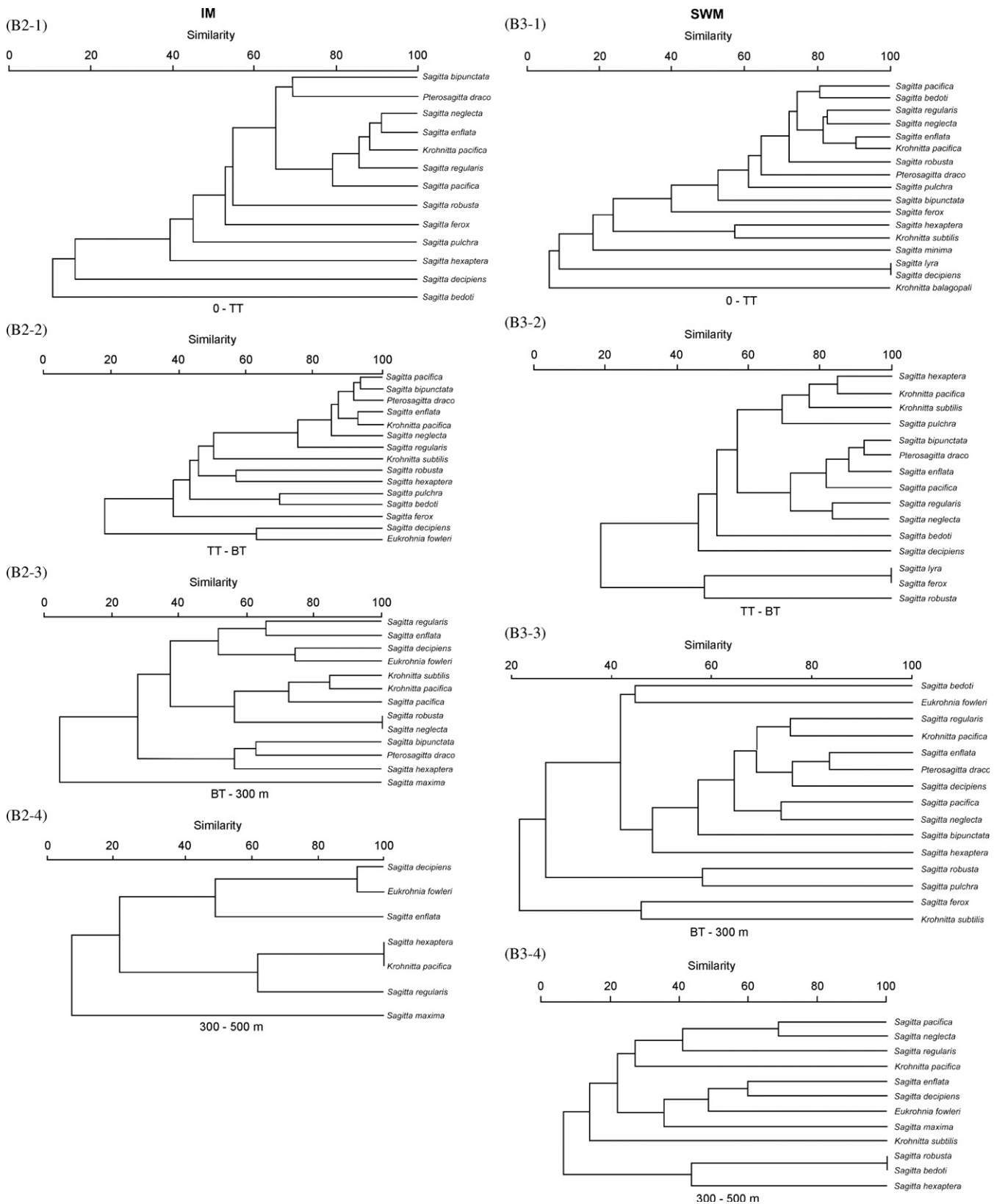


Fig. 8. (Continued)

The contrast in the abundance and diversity of chaetognaths between coastal and open ocean was well defined. The population density of chaetognaths in the coastal waters was about 5 times higher than that of open ocean. However species diversity was

reduced to 13 as compared to 19 in the open ocean. High population numbers with lower diversity of chaetognaths in the coastal waters had already been reported (Nair, 1977, 2001). Being shallower, mesopelagic species are absent in coastal waters.

Species dominance also showed variation. *S. enflata* and *S. neglecta* were dominant in coastal waters, but with some seasonal variation. In the NEM both the species were abundant, while in the SWM *S. neglecta* dominated, and in the IM *S. neglecta* became dominant with aggregations of the recently described species, *S. meenakshiae*.

In the open ocean at the surface, invariably *S. enflata* dominated and abundance of Indo-Pacific species was characteristic of this layer. Vertical diversity and population density of species were high in TT-BT layer. Here again, *S. enflata* was dominant and common species were cosmopolitan and Indo-Pacific. In the BT-300 m stratum, *S. decipiens* dominated and a few cosmopolitan species were common. In 300–500 m, *S. decipiens* dominated and the next most abundant species was *E. fowleri*. *E. fowleri* was considered to be bathypelagic in northern Indian Ocean (Nair, 1978; Pierrot-Bults and Nair, 1991). Seasonally, the SWM and the NEM periods maintained a rich chaetognath community. Aggregations of *S. decipiens* were observed in the mixed layer during the NEM when the layer had temperatures of 28–28.3 °C, salinities of 32.3–33.3, and DO's of 196.6–217.1 µM. The population of *E. fowleri* also showed much higher density in the BT-300 m than the 300–500 m stratum during the NEM. This zone had relatively low temperature (9.6–16.8 °C), high salinity (34.8–35.0), and relatively low DO (22.7–24.9 µM).

Invariably two species clusters were found in each stratum accounting 60–70% similarity. Though there is overlapping in the co-existence of species, the following groupings were evident in the different strata.

1. Surface: A major cluster was formed by seven species *S. enflata*, *S. robusta*, *S. neglecta*, *S. pacifica*, *K. pacifica*, *S. regularis*, and *S. bedoti* and a minor one with three species of the genus *Krohnitta* and *S. pulchra*.
2. Mixed layer: Eight species namely *S. pacifica*, *S. neglecta*, *S. regularis*, *S. robusta*, *S. bedoti*, *P. draco*, *K. pacifica*, and *S. enflata* formed a cluster.
3. TT-BT: *S. bipunctata*, *S. enflata*, *P. draco*, *S. pacifica*, *S. neglecta* and *S. regularis* formed a cluster.
4. BT-300 m: *S. pacifica*, *S. enflata*, *E. fowleri*, and *S. decipiens* formed a cluster.
5. 300–500 m: *E. fowleri* and *S. decipiens* formed a cluster.

On the basis of spatial and vertical profile of the 20 species of chaetognaths recorded from the Andaman waters, they can be categorized into (i) epipelagic and cosmopolitan species (*K. subtilis*, *P. draco*, *S. bipunctata*, *S. enflata*, *S. hexaptera*, and *S. minima*), (ii) epipelagic and Indo-Pacific (*K. pacifica*, *S. bedoti*, *S. ferox*, *S. neglecta*, *S. pacifica*, *S. pulchra*, *S. regularis*, and *S. robusta*) (iii) deep water species (*S. decipiens*, *S. lyra*, *S. maxima*, and *E. fowleri*), and (iv) endemic species (*K. balagopali* and *S. meenakshiae*).

6. Conclusion

This study demonstrated that there is fairly high biodiversity of chaetognaths in the Andaman Sea. Among the 20 species in the area, there are seven epipelagic cosmopolitan species, eight epipelagic Indo – Pacific Species, four deep-water species, and two new endemic species. In the epipelagic zone down to the thermocline, *S. enflata* dominated and below this stratum, *S. decipiens* became dominant. The vertical profiles indicated higher population density and species diversity down to the bottom of the thermocline. The population density of chaetognaths in the coastal waters was five times higher than in the open ocean, but the species diversity was reduced. Surfacing of deep water species,

S. decipiens and *E. fowleri*, was a characteristic feature of the NEM period associated with physical environmental features. Co-existing species as evidenced by the cluster analyses were distinct for each stratum with some amount of overlap between strata in the species in a cluster. A comparison of present data with those collected four decades back indicates decrease in total chaetognath abundance with subtle changes in the community structure.

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