

CHAETOGNATHS IN THE UPWELLING AREAS OF THE ARABIAN SEA

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ABSTRACT

An attempt is made to study how the ecological theory that in a marine environment individual groups are distributed according to their place in the trophic level, applies in the distribution of chaetognaths in two well known upwelling areas in the Arabian Sea - the Somalian and southwest Arabian coasts. Population maxima of chaetognaths were found not adjacent to the centre of upwelling, but shifted to the fringe of the enriched area. Chaetognaths which occupy the tertiary level in the food chain need more time for their development and so the places of their maximum abundance appear at a greater distance from the centre of upwelling. Highest densities of juvenile chaetognaths were also restricted to the stations located away from the coast. This apparent increase in the abundance of chaetognaths towards the margin of the upwelling area was statistically tested and their rate of production was calculated.

INTRODUCTION

The distribution of different groups of planktonic organisms varies greatly depending on their place in the food chain; the higher the trophic level they occupy, the farther they are removed in space and time from the areas of enrichment (Vinogradov and Voronina, 1962). Due to upwelling the surface waters get fertilized and spread under the influence of local currents and the development of the primary and secondary producers are displaced in space and time. By the time the predators attain their population maxima in the sequence of biological events in the sea, they may be located quite some distance away from the centre of upwelling.

Chaetognaths are exclusively carnivores and they occupy the tertiary level in the food chain. Naturally areas of maximum chaetognath population can be

expected to be located away from the upwelling areas. It is interesting to see how they are distributed in upwelling systems and how far this ecological theory holds true for these organisms. The previous studies on the chaetognaths of the Indian Ocean (Vijayalakshmi, 1969) indicate that population maxima during the southwest monsoon period are not adjacent to the upwelling region but shifted towards the fringe of the enriched area.

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MATERIAL AND METHODS

Four series of samples taken from the Somalia and Arabian coasts during July-August, the peak period of upwelling (Currie *et al.*, 1971), were selected

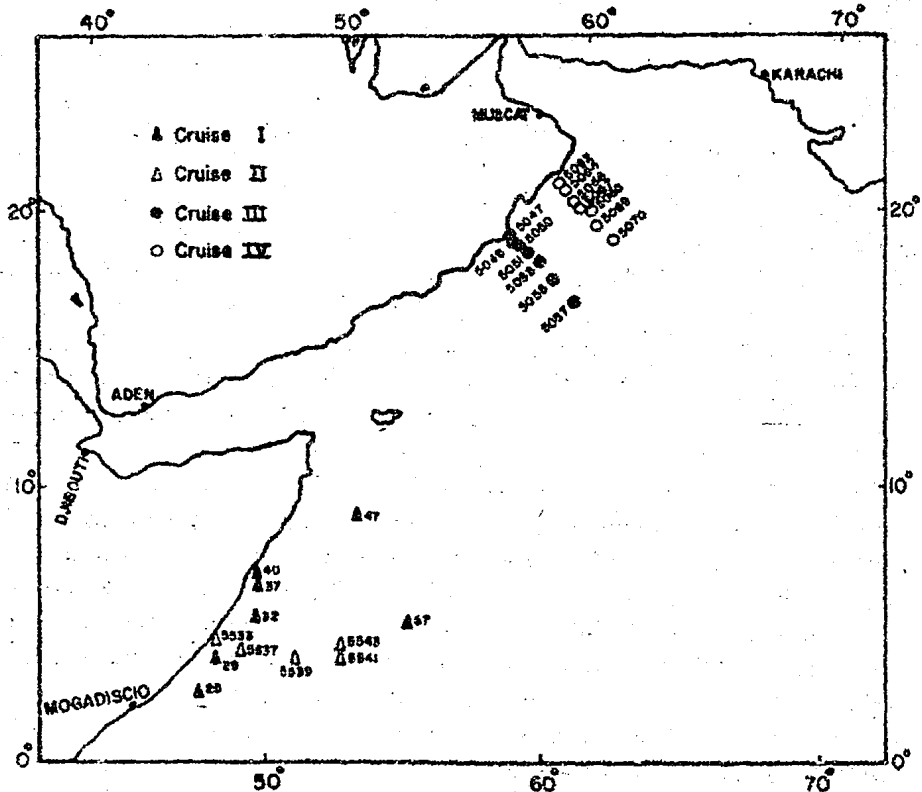


Fig. 1. Map showing the location of stations off Somalia and Southwest Arabia.
 Cruise I — "Argo" collections during 12th - 29th August, 1964;
 Cruise II — "Discovery" collections during 8th - 13th August, 1964;
 Cruise III — "Discovery" collections during 10th - 13th July, 1963 and
 Cruise IV — "Discovery" collections during 15th - 18th July, 1963.

from the International Indian Ocean Expedition (IIOE) collections for the present study. In all the four series the stations were worked from the coastal areas towards the sea, following the direction of the prevailing surface currents. The location of stations is indicated in Fig. 1. The details of the collections are given in the Handbook (IOBC, 1969). Chaetognaths from these stations were examined for species composition and stages of maturity. Based on the condition of the gonad the stages were isolated, those in which gonads are absent designated as juveniles, those with developing gonads as immature and those with fully developed gonads as mature individuals. The number of animals given always refers to number per standard haul (IOBC, 1969).

RESULTS

Fourteen species of chaetognaths—*Krohnitta pacifica*, *K. subtilis*, *Pterosagitta draco*, *Sagitta bedoti*, *S. bipunctata*, *S. enflata*, *S. ferox*, *S. hexaptera*, *S. minima*, *S. neglecta*, *S. pacifica*, *S. regularis*, *S. robusta*, and *S. pulchra*—were found in these collections. For the distribution curves only the common species were considered as the other species present constitute only an insignificant part of the total chaetognaths in these samples.

The abundance of the total chaetognaths and the common chaetognath species is represented in Fig. 2. In Fig. 2a the maximum density of chaetognaths (14288/std. haul) is seen at St. 47, located away from the Somali coast. Compared to the values at station 25, 29, 32, 37 and 40, the majority of the common species maintain high density at St. 47. The surface temperature in all these stations were low (22.44-24.22°C) indicating upwelling. However, at station 67 there is a sudden lowering of the chaetognath population. The hydrographical data for this station do not show any upwelling and the surface temperature was 27.20°C. Fig. 2b represents another section near Somalia and the results are almost identical with that in Fig. 2a. These stations also indicate upwelling. There is no station beyond 5543 in Cruise II to compare chaetognath abundance with a non-upwelling station. Fig. 2c shows steady increase in the abundance of chaetognaths towards the open ocean and the maximum value was found at station 5051. The density of chaetognaths was minimum at stations 5055 and 5057 and the hydrographical data for these two stations do not indicate upwelling. An almost similar pattern of distribution is observed in Fig. 2d, another series of stations near south-west Arabian coast.

S. enflata was the dominant species and the proportion of the maturity stages of this species for the four cruises (Fig. 1) is shown in Fig. 3 a-3 d. The distribution curves show an increase in the population of different stages to-

wards the outer margin of the upwelling area. If juveniles are considered as an index to breeding the maximum population observed at stations 47 (Fig. 3 a), 5543 (Fig. 3 b), 5053 (Fig. 3 c) and 5070 (Fig. 3 d) would indicate these to be areas of intense breeding.

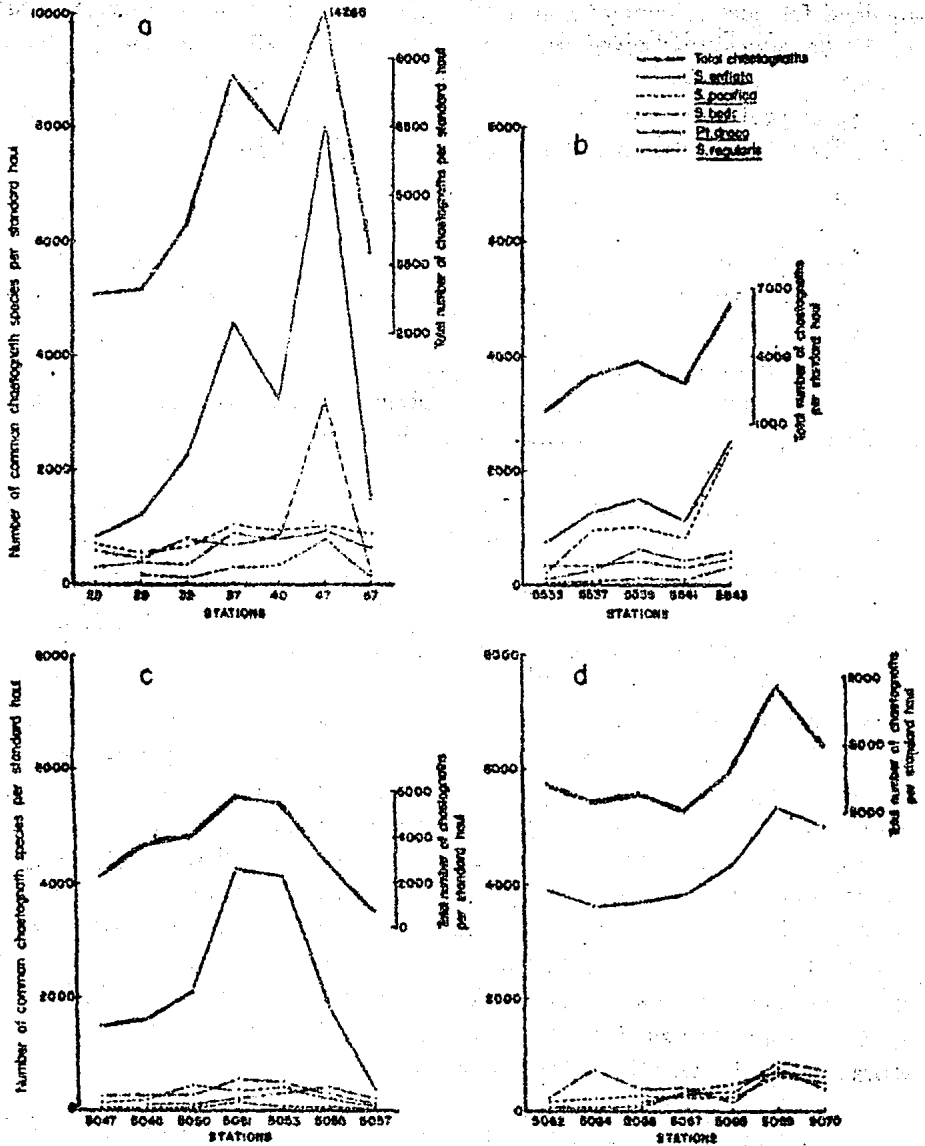


Fig. 2. Quantitative distribution of chaetognaths in the four cruises. a-Cruise I; b-Cruise II; c-Cruise III and d-Cruise IV.

All the stations having the maximum density of chaetognaths are on the outer limits of the upwelling areas. The upwelling area as indicated by the temperature distribution (25°C isotherm in July—Wyrki, 1971) extends off the African coast to a distance of nearly 400 km and off the Arabian coast to nearly 100 km. The stations mentioned above are located farther out in the sea; St. 47 approximately at 268 km., 5543 at 447 km., 5053 at 121 km and 5070 at 363 km from the coast.

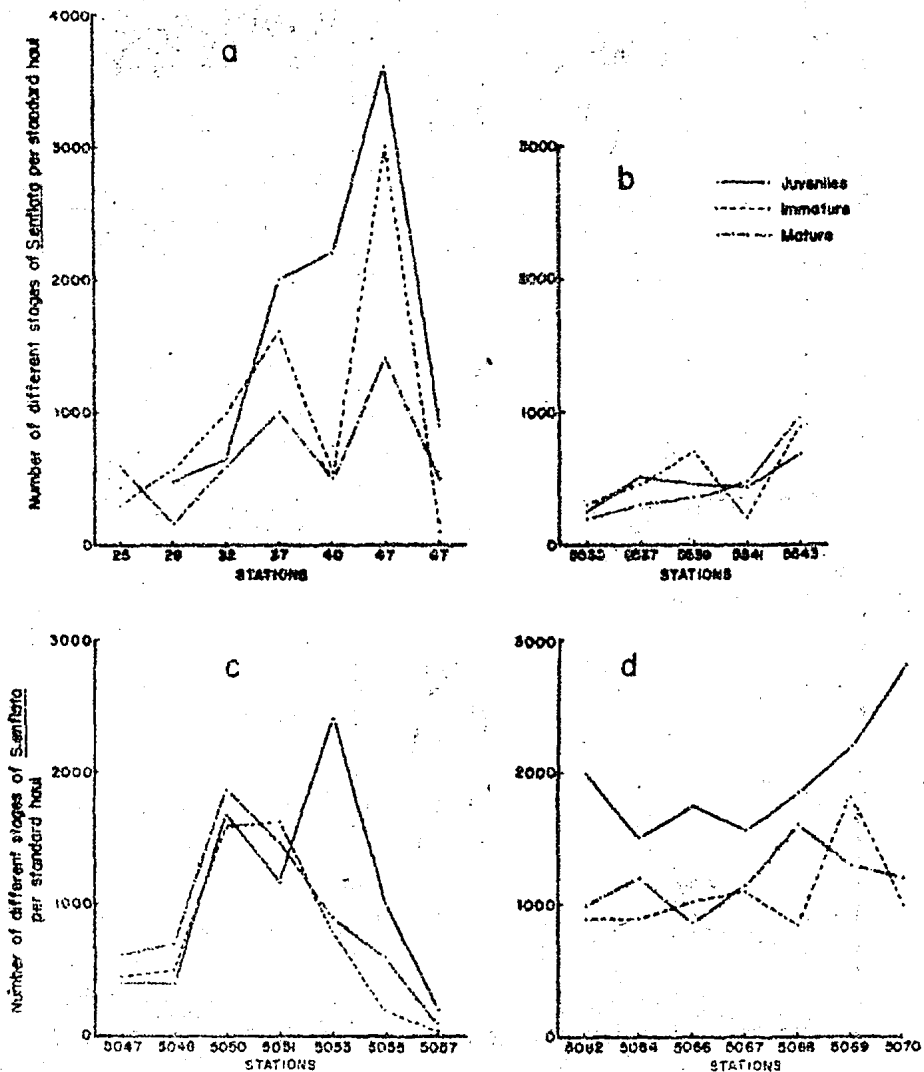


Fig. 3. Distribution of different maturity stages of *S. enflata* in the four cruises. a—Cruise I; b—Cruise II; c—Cruise III and d—Cruise IV.

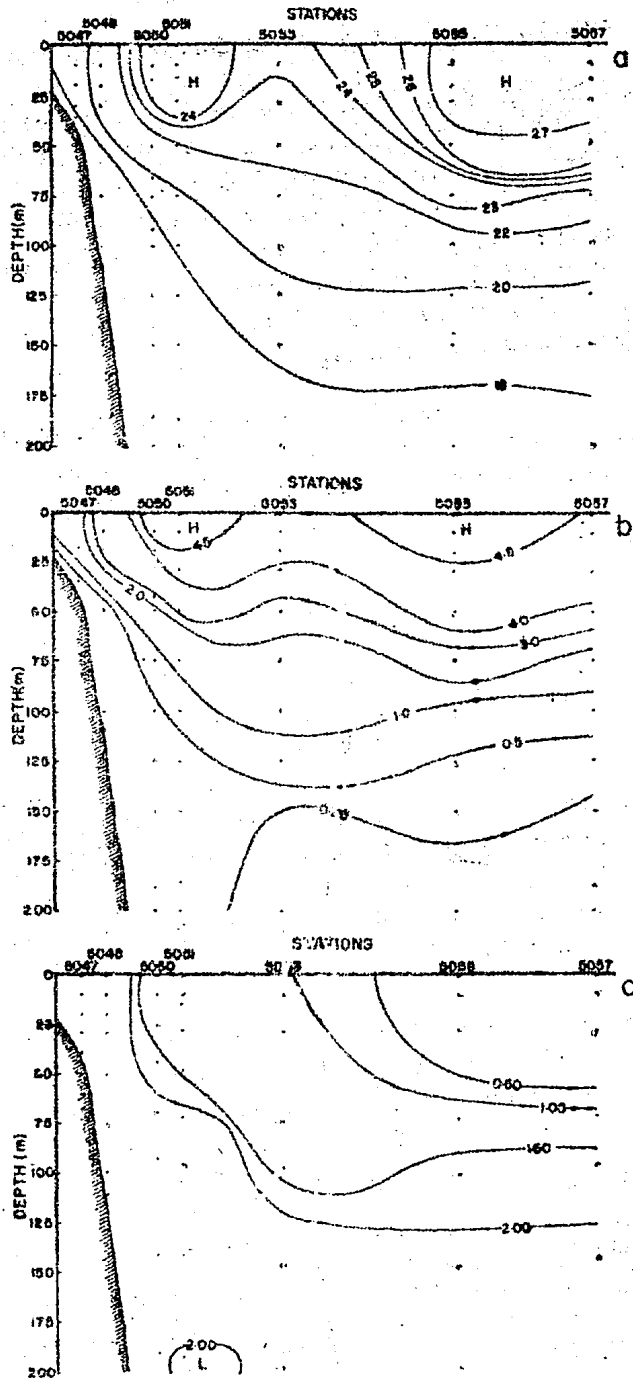


Fig. 4. Vertical distribution of temperature, oxygen and phosphate phosphorus in Cruise III. a-temperature °C; b-oxygen m³/l and c-phosphate phosphorus µg-at/l.

The hydrographical data for all the selected stations except station 67, 5055 and 5057 indicate upwelling. The vertical profiles of temperature, oxygen and phosphate values for the upper 200 m water column for Cruise III are depicted in Fig. 4 a-4 c. The first five stations indicate zones of upwelling as seen by the deepening of the thermocline, low temperature at the surface, low oxygen values and the high concentration of phosphate at the surface. Station 5055 and 5057 show the abrupt change in the hydrographical condition where there is no indication of upwelling.

This apparent increase in the population density of chaetognaths towards the periphery of the enriched area was analysed using the Chi-square test to infer whether the total chaetognaths were uniformly distributed over the different regions under study. The formula used for calculation of Chi-square is

$$\chi^2 = \sum \left[\frac{(fo - fe)^2}{fe} \right]$$

where

fo—observed number of individuals

fe—expected number of individuals

The significant difference in the relative abundance of *S. enflata* in the different regions was also tested by the same method. The calculated values of the Chi-square in both the cases are given in Table 1. From the Table 1 it could be seen that all the calculated values of Chi-square are highly significant ($p < .001$) indicating that different regions mentioned were having different rates of population density.

In order to examine which are the more productive regions under study, the data under different cruises were further analysed. The results are given in Table 2. It could be inferred that as far as total chaetognaths are concerned

TABLE 1. Calculated values of χ^2 under different regions

Cruise	χ^2 value for total Chaetognaths	Degrees of Freedom	Remarks	χ^2 value for juveniles of <i>S. enflata</i>	Degrees of Freedom	Remarks
I	40071.54	5	P < .001	3640.5	4	P < .001
II	3485.21	4	P < .001	206.9	4	P < .001
III	1540.34	4	P < .001	1294.9	4	P < .001
IV	2929.14	6	P < .001	194.5	6	P < .001

the station 47 in Cruise No. I is 5 times more productive than station 25. In Cruise II the station 5543 is 4 times more productive than station 5533, in Cruise III, the station 5051 is 2.5 times more productive than station 5047 and in Cruise IV station 5069 is 1.68 times more productive than station 5062.

Regarding the juveniles of *S. enflata* station 25 in Cruise I is not at all productive and station 47 is 7.5 times more productive than station 29. In Cruise II the station 5543 is 2.7 times more productive than station 5533 and station 5053 is 6 times more productive than station 5047 in Cruise III. The station 5070 is more productive compared to all other stations in Cruise IV.

TABLE 2. Production ratio under different regions

Cruise	Stations	Production ratio of total Chaetognaths	Production ratio of juveniles of <i>S. enflata</i>
I	25:29:32:37:40:47	10:10:15:27:22:50 (Calculated $\chi^2 = 8.38$, not significant at 5% level)	0:10:14:42:46:75 (Calculated $\chi^2 = 1.58$, not significant at 5% level)
II	5533:5537:5539:5541:5543	10:20:24:18:40 (Calculated $\chi^2 = 0.12$, not significant at 5% level)	10:20:18:17:27 (Calculated $\chi^2 = 0.02$, not significant at 5% level)
III	5047:5048:5050:5051:5053	10:16:18:25:19 (Calculated $\chi^2 = 0.01$, not significant at 5% level)	10:10:42:29:60 (Calculated $\chi^2 = 0.87$, not significant at 5% level)
IV	5062:5064:5066:5067:5068: 5069:5070	100:88:93:82:108:168:127 (Calculated $\chi^2 = 0.18$, not significant at 5% level)	10:8:9:8:9:11:14 (Calculated $\chi^2 = 8.41$, not significant at 5% level)

DISCUSSION

Cushing (1971) in his comprehensive review on the upwelling areas in the world oceans has discussed at length the production cycle in upwelling systems. According to him the peak production reaches the surface not far from

the centre of upwelling and the plant and animal populations move away from the centre of upwelling. The dynamic boundary of the coastal upwelling is at about 100 km from shore. However, the effect of upwelling continues towards the open ocean and "the biological boundary must be at the imprecise edge of the wind system" (Cushing, 1971).

In a marine community—which may be defined as an aggregation of mixed taxa—the individuals in the unit are distributed according to the position they occupy in the trophic level. Animals like chaetognaths which feed on smaller zooplankton and whose position is higher than the herbivores, need more time for their development (Vinogradov and Voronina, 1962). Fig. 3 shows that the three maturity stages of *S. enflata* are represented in all the collections. However, maximum numbers of different stages are restricted to stations located away from the coast. Breeding of chaetognaths is continuous in tropical waters and periods of heavy spawning are superimposed on continual spawning (Owre, 1960; Vijayalakshmi, under publication). By the time the individuals reach maturity, currents might carry them away from the region of upwelling and the places of their population maxima appear at a greater distance from the area of divergence. As a result the zones of upwelling and the bulk of chaetognath population are divided in space and shifted to the margin of the enriched areas.

The surface current during July-August, the period under discussion, consists of a strong northerly Somali Current flowing nearer the coast off Somalia upto 8–10° North latitude. Around these latitudes the current turns eastwards. Similarly off the Arabian coast a coastal current flows in the northeast direction and offshore the general drift is eastwards. In both these areas the enriched waters reaching the surface as a result of upwelling are taken away towards the open sea in an easterly direction and this is reflected in the distribution of the plankton populations of different trophic levels. The tertiary population like that of the chaetognaths is removed farthest from the upwelling region.

The foregoing account on the chaetognaths in upwelling areas supports this ecological theory that in a marine environment individuals are distributed according to their place in the trophic level. Fig. 2 a and 2 c give a clear picture of this phenomenon where the lowering of the population density of chaetognaths beyond the high density observed in the zone of upwelling, and coincident absence of any hydrographical evidence of upwelling.

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