

## MONSOON REGIME IN THE INDIAN OCEAN AND ZOOPLANKTON VARIABILITY

VIJAYALAKSHMI R. NAIR

National Institute of Oceanography, Versova, Bombay, India

### INTRODUCTION

The effect of the monsoon in the Indian Ocean is limited to north of 10°S, the area being defined as the region of seasonally changing monsoon gyre (Wyrski, 1973). The southwest monsoon (SW) is prevalent from May to September when the cyclonic circulation in the surface waters of the Arabian Sea and Bay of Bengal results in water movement from west to east. The wind direction is reversed during the northeast monsoon (NE) period extending from November to March and the gyre becomes anticyclonic leading to a circulation from east to west. The monsoonal effects on zooplankton lead to characteristic zoogeographic patterns in the open ocean and coastal waters.

Studies of zooplankton variability were taken up since the International Indian Ocean Expedition (1960-65) and later surveys made by the National Institute of Oceanography (Rao, 1979; Rao et al., 1981). The various aspects presented here are based mainly on the author's investigations covering a period of about fifteen years. The evaluation is presented in three sections to show how the monsoon exerts its influence on zooplankton from different types of environment.

### OPEN OCEAN

The reversal of the monsoon circulation is one of the most important factors affecting the abundance and diversity of zooplankton in the open ocean and is reflected in the relative abundance of total zooplankton biomass (IOBC, 1968) and common groups like copepods (IOBC, 1970), chaetognaths (Nair, 1972), pelagic tunicates (Nair & Iyer, 1974), decapod larvae (IOBC, 1970), pelagic molluscs (IOBC, 1971) and others. This is true whether the entire group or a species belonging to

the group is concerned. Higher abundance of the group/species is observed along the north eastern part of the Indian Ocean (Bay of Bengal) during the SW monsoon, when the circulation is from west to east. During the NE monsoon period, the flow is reversed and the relatively higher population existing in the eastern side begins to spread along the west coast of the Indian peninsula. This is well marked in the zoogeography of *Sagitta bedoti*, *S. bipunctata*, *S. enflata*, *S. pacifica*, *S. regularis* and *S. robusta* (Nair, 1972; 1977) (Table I).

On the western side of the Arabian Sea, as a result of its reversal, the Somali current transports zooplankton meridionally across the equator both in southern and in northern directions according to the time of year. The samples collected during the Lusied Expedition in July/September 1962, along the equatorial region of the Indian Ocean with north-south transects covering the equatorial Current System show this (Nair, 1976). Common groups and different species of chaetognaths reach maximum population density west of 57°E, suggesting a meridional distribution on the western side and a zonal distribution along the remaining part of the equatorial zone (Fig. 1). Upwelling enriches the Somali waters during the SW monsoon period and the current carries part of the dense population seen off Somalia towards the eastern part.

### COASTAL WATERS

The coastal waters of the tropics are highly productive and sustain a rich and abundant plankton life. This area is also influenced by the seasonal variations in rainfall on account of the monsoon. Here the monsoonal effect is more during the SW monsoon (June to November) when freshwater influx from rivers and estuaries

Table 1 Average number of different species in the Arabian Sea with average numerical values of the selected 5° squares.

Species	AREA 1 (10-15°N & 50-55°E)			AREA 2 (20-25°N & 65-70°E)			AREA 3 (15-20°N & 70-75°E)			AREA 4 (5-10°N & 75-80°E)		
	NE	SW	TOTAL	NE	SW	TOTAL	NE	SW	TOTAL	NE	SW	TOTAL
<i>K.pacifica</i>	27.86	11.15	39.01	13.45	14.50	27.95	31.24	43.20	74.44	22.53	32.70	55.23
<i>K.subtilis</i>	2.61	21.99	24.60	1.62	---	1.62	1.00	---	1.00	12.53	5.28	17.81
<i>Pt.draco</i>	116.26	78.90	195.17	3.54	6.50	10.04	58.61	30.70	89.31	130.88	180.07	310.95
<i>S.bodoti</i>	381.90	215.94	597.84	116.51	31.30	147.81	75.06	21.05	96.11	232.78	505.37	738.15
<i>S.bipunctata</i>	76.09	84.28	160.37	75.71	9.80	85.51	168.23	22.70	190.93	80.90	19.85	100.75
<i>S.enflata</i>	1865.47	1423.34	3288.81	682.77	211.40	894.17	905.43	416.75	1322.18	1315.37	2520.28	3835.65
<i>S.ferox</i>	2.89	26.07	28.96	0.14	8.20	8.34	5.66	23.80	29.46	8.92	4.43	13.35
<i>S.hexaptera</i>	17.26	17.92	35.18	0.24	0.10	0.34	4.20	1.00	5.20	12.69	19.85	32.54
<i>S.minima</i>	4.44	12.92	17.36	0.10	---	0.10	---	---	---	1.08	---	1.08
<i>S.neglecta</i>	8.94	65.29	74.23	94.74	11.40	106.14	10.66	15.10	25.76	32.53	75.97	108.50
<i>S.pacifica</i>	164.78	274.23	439.01	62.50	19.10	81.90	190.00	18.95	208.95	184.41	425.54	609.95
<i>S.pulchra</i>	21.65	22.45	44.10	11.97	0.30	12.27	2.53	3.30	5.83	9.38	27.85	37.23
<i>S.regularis</i>	67.60	71.82	139.42	1.96	18.10	20.06	146.45	25.00	171.45	47.22	150.23	197.45
<i>S.robusta</i>	98.68	84.82	183.50	7.71	4.50	12.21	17.38	1.85	19.23	8.69	86.11	94.80
<b>TOTAL</b>	<b>2856.54</b>	<b>2411.12</b>	<b>5267.66</b>	<b>1072.96</b>	<b>343.70</b>	<b>1416.66</b>	<b>1617.91</b>	<b>623.40</b>	<b>2241.31</b>	<b>2108.11</b>	<b>4053.53</b>	<b>6161.64</b>

\* Maximum observed value during the SW monsoon period

\*\* Maximum observed value during the NE monsoon period

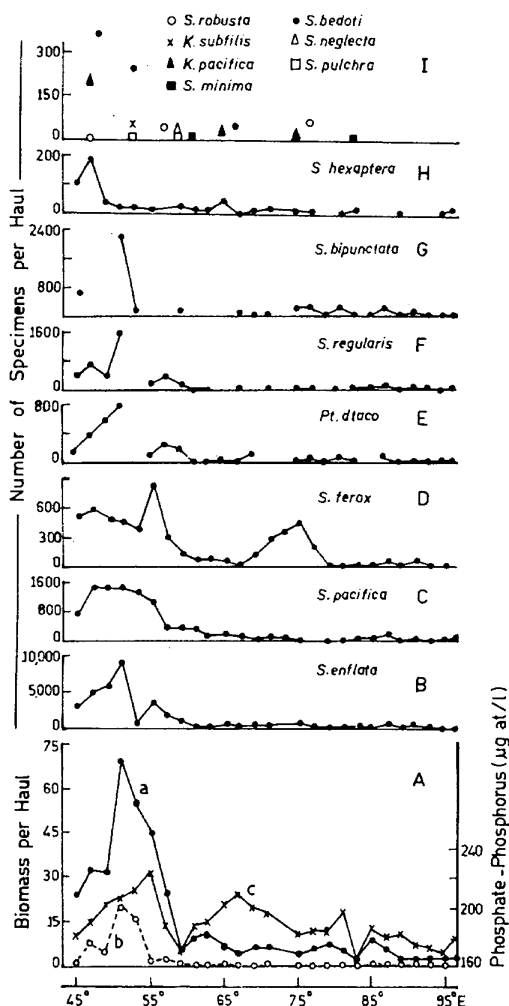


Fig.1 Distribution of (A) total zooplankton, chaetognath volume, phosphate phosphorus and (B to I) different species of Chaetognaths along the equatorial east-west transect of the Lusied Expedition in the Indian Ocean (a, total zooplankton; b, chaetognath volume and c, phosphate phosphorus).

lower the salinity along the coast to 30-34.5‰.

In general, throughout the Indian coastal waters the annual zooplankton distribution is bimodal with two peaks - one just before the monsoon and the other just after the rain. (Rao, 1979, Rao et al., 1983). The plankton production triggered

during the SW monsoon period (June - September) makes the region an excellent pasturage for the plankton feeders and in general, the peak fishing season along the coastal waters coincides with this period (Nair, 1982).

Along the east coast there is an increase in the biomass of zooplankton from north to south whereas a reverse pattern has been observed during October to November along the west coast (Nair, 1977). The incidence of high densities of chaetognaths along the two coasts also follows a similar pattern. Along the west coast, off Bombay the population maximum of chaetognaths was seen in November-December (Nair et al., 1981), south of Bombay, off Calicut in October - November and further south at Trivandrum the peak observed was much earlier (July - September). On the east coast, the peak periods for the chaetognath species were found off Madras during May - August, and towards the South in the Gulf of Manner it was in November and December (Rao et al., 1981). The prevailing difference in salinity, periods of upwelling and surface currents may contribute to this pattern of abundance. Upwelling along the west coast starts in March and continues during the SW monsoon with its maximum effect in August - September. It sets in earlier in the south and gradually extends to the north (Rao, 1979) and concomitant with this, the movement of peak zooplankton abundance is also from south to north.

## ESTUARIES

The monsoon exerts stress on estuarine fauna by bringing about a drastic change in salinity, which was more marked towards the upper reaches. During the high salinity period zooplankton maintained a high level of production of about 3 to 7.5 times that of the relatively low standing stock of zooplankton observed during the low salinity period (Nair, 1982).

The low saline fauna replacing the high saline species are not at all diverse or rich in comparison (Rao et al., 1981). Neritic species like *Sagitta bedoti* penetrate to the upper reaches of the estuarine system during the premonsoon period when a uniform salinity (25.3

- 33.5<sup>0</sup>/oo) prevailed throughout the system (Nair, 1974). In the postmonsoon period the chaetognath population synchronically followed the steep gradient in salinity (0.2 to 28.6<sup>0</sup>/oo) along the estuary and became restricted to its seaward end.

#### CONCLUDING REMARKS

In the open ocean the semi annually reversing system of currents exert profound influence on the shifting of zooplankton populations. The assumption is based on samples mostly collected from the upper 200m of the Indian Ocean and the limit of such influence is yet to be ascertained. In the coastal waters the time lag involved in the north to south or reverse pattern of movement of species along with associated factors responsible for such variability calls for detailed investigation. Estuaries with the characteristic fluctuations in salinity on account of monsoon and the theory of repopulation are aspects to be studied in detail.

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