

## **5. THE INDIAN OCEAN AND ADJACENT SEAS**

### **5.1 General environmental features.**

Exploitation of the marine resources depends on the knowledge of their distribution and abundance which vary with environmental characteristics of the ecosystem. The abundance and distribution of biotic community and their relationship to fisheries have been subjects of detailed investigation by several scientists over long periods of time. Any additional or new information emerging out of subsequent search are of crucial importance to formulate more viable economic policies for better management of the ecosystem. The development of multidisciplinary approach initiated in recent times linking physical, chemical, biological, geological and meteorological aspects has helped substantially to identify regions of economic importance and utilise the resources in the best way possible. The parameters which have direct relationship with growth, reproduction, abundance and distribution of organisms are mainly temperature, salinity, dissolved oxygen, nutrients, trace elements, water currents, transparency etc. All these parameters vary depending on the topography, latitude, seasons and prevailing atmospheric conditions.

The Indian Ocean is known to the maritime world for several centuries before Christ. But it is the least studied among the three great oceans. The nature of its potential resources is not fully known to countries bordering it. It is the smallest of the three oceans, having an area of 74, 917,000 km<sup>2</sup> which occupies about 20.7 per cent of the total ocean surface. It has a mean depth of 3897 m and a volume of 291,945,000 m<sup>3</sup> without the Arafura Sea according to the International Hydrographical Bureau. The maximum depth recorded is 7437 m (Fairbridge, 1966). The 200 m depth region occupies only five per cent of the total volume of the Ocean (Pollak, 1958).

### **5.2 Boundaries of the Indian Ocean:**

The northern boundary is landlocked and is formed by the marginal seas such as the Red Sea, and the Gulf of Aden. The Persian Gulf, the Gulf of Oman, the Arabian Sea including the Laccadive Sea, the Bay of Bengal including the Andaman Sea, the Malacca Strait and the Singapore Strait (the last one is sometimes included in the Pacific). At the north-eastern limit the boundary runs

from island to island through Singapore to Sumatra, Java and thence to the Lesser Sunda Islands.

On the east, the Indian Ocean is bordered by Australia. Controversy exists in regard to the eastern limits of northern Australia. Geologists prefer the narrowest sea crossing in Torres Strait, but the International Hydrographic Bureau gives the western limits of the strait from Cape York (11°05'S and 142°03'E) to Bonsback River, New Guinea (141°01') as the eastern limit of the Arafura Sea. However, the eastern limit south of Australia is fairly clear comprising the western boundary of the Bass Strait from Cape Otway to King Island, thence to Cape Grim (north-western Tasmania) and from south-east Cape of Tasmania along meridian 147°E to Antarctica near Fisher Bay, George V Coast. The southern boundary extends to 45°S latitude. The western boundary leads from the Antarctic to Cape Agulhas along 23° meridian.

### **5.3 Topography of the Indian Ocean:**

Unlike the Atlantic and the Pacific, the Indian Ocean has no temperate and polar regions in the northern hemisphere. The hydrobiology of the northern part is therefore, influenced by the great landmasses of Asia and Africa. The atmospheric circulation over the landmasses affect the ocean up to 10°S (Dietrich, 1973). The meridional circulation in the Indian Ocean is similar to that prevailing in an estuary, the heavy water on the bottom spreading towards the head of the bay and the lighter water in the upper layers towards the mouth. The southern part of the Indian Ocean is less affected by the land masses and the southern boundary is limited by Antarctica as in the Atlantic and Pacific Oceans. It is much broader than the narrow northern portion. The periodic reversal of the surface water circulation is very characteristic of the northern hemisphere and is related to the South West and North East monsoon.

The hydrography of the Indian Ocean is also influenced to some extent by the marginal seas and identifiable water bodies such as those in the Mozambique Channel, the Red Sea, the Gulf of Aden, the Persian Gulf, the Gulf of Oman, the Arabian Sea, the Laccadive Sea, the Bay of Bengal, the Andaman Sea, the Java Sea, the Davis Sea off Antarctica. The continental fragments like Madagascar, Socotra, Sri Lanka and other islands such as McDonald, Heard,

Prince Edward, Crozet, Kergulen, St. Paul, Amsterdam, Reunion, Mauritius, Cocos, Christmas, Comoro, Agalega, Chagos Archipelago, Amirantes, Seycheless, Laccadives, Minicoy, Maldives, Andaman Nicobar and rivers namely Limpopo, Zambezi, Shatel Arab, Indus, Ganges, Bhramputra and Irravaddy.

The Red Sea forms an extension of the Arabian Sea connected through the Gulf of Aden, a long, narrow but deep basin with a very shallow sill of 125 m at the narrow southernmost entrance the Strait of Bab-el-Mandeb. The Persian Gulf is a shallow basin having a maximum depth of 150 m and an average depth of 35 m. It is connected with the Arabian Sea through a 50 m sill at Hormuz Strait. The northern part of the Indian Ocean is formed by the Arabian Sea in the north-west, Laccadive Sea in the south-west and Bay of Bengal and Andaman Sea in the east.

It is reported that the Indian Ocean Basin was formed by the on-going processes of continental shift suggesting that the Indian Ocean is comparatively young with a complex basin. The basin is subdivided by four north-south running ridges. Of these the Carlesberg – Ridge of the Arabian Sea is an important one due to its role in upwelling which influences the hydrobiology.

#### **5.4 Current systems and general pattern of circulation:**

The current systems in the southern Indian Ocean is similar to those prevailing in the Atlantic and the Pacific, namely, the Antarctic, Circumpolar and subtropical anticyclonic gyre. But the northern Indian Ocean is characterised by the seasonally changing monsoon gyre. This circulation is stronger and steadier during the South West Monsoon than during the North East. This has no parallel in other oceans. All the areas north of 10°S fall under this gyral system. The cyclonic and anticyclonic circulation of the Arabian Sea and Bay of Bengal, the North Equatorial Current, the Counter Current of the South Equatorial Current and the Somali Current are the major surface components of the surface gyre.

At the onset of the SW monsoon, a low pressure area is developed over central Asia causing persistent wind system from south-west. This generates

the Somali Current (Lighthill, 1969) which flows northwards along the east coast of Africa from south to north. This Somali Current results in a general clock-wise circulation in the Arabian Sea which develops into a relatively strong southerly current at the surface along the west coast of India. The southerly current which develops in May continues until November when the current system reverses. It attains greatest strength in July. At the height of its development, the Somali Current reaches as far north as 12°N latitude. However, most of the water leaves the coast and flows in an easterly direction as monsoon current south of latitude 12°N. In the Gulf of Aden, the flow of surface current is from Gulf to Arabian Sea during June to August. Along south Arabia the currents are weak and more in the east and northeasterly directions. It flows northerly along the Arabian coast and southerly along Indian coast. The southerly current brings comparatively high saline Arabian Sea water southwards and the northerly current transports the less saline equatorial water northwards.

In the Bay of Bengal the flow is generally northeast which turns southwards upon reaching the continental shelf region and flows along the shelf. South of Sumatra, the current flows south-easterly along the coast of Sumatra and merges with the South east Asian Water flowing into the Indian Ocean through the Timor Sea. This forms the basis of the South Equatorial Current in the Indian Ocean. During NE monsoon the Somali Current reverses the direction and flows southerly from December to February. The surface water from the Arabian Sea flows into the Gulf of Aden. A weak current flows northwards along the west coast of India for a brief period. In the Bay of Bengal, a cyclonic circulation exists in the entire Bay in February, However, this pattern does not prevail during the entire period of the NE monsoon.

The circulation pattern in the northern Indian Ocean for different months has been detailed by Varadachari and Sharma (1967) and Wyrтки (1973). Wyrтки (1973) has pointed out that in the northern portion of the South Equatorial current, a tongue of low salinity originating off Sumatra, stretches west near 10°S extending to Africa. This boundary is more marked by a sub-surface front which separates the low oxygen, high nutrient water in the northern Indian Ocean from the high oxygen, low nutrient water in the sub-tropical gyre.

The hydrographical properties of the shallow coastal waters are significantly more than those of the oceanic region. This mainly depends on the shallowness of the coastal zone. The continental shelves of the Indian Ocean are comparatively narrower than those of the Atlantic and Pacific. In the northern Indian Ocean, the continental shelf along the coasts of Malaysia, Thailand, Burma and north-west India are wide. The maximum width recorded off the coast of Bombay (200 km) is very productive. It is narrow along the east coast of India. Along the African coast the shelf again becomes narrow, the 200 m contour line lies within four km from the shore. In the Red Sea the shelf is wide at the central and southern parts.

A clear cut winter, spring, summer and autumn seasons are not pronounced in the northern Indian Ocean because of the land-masses in the northern latitudes. In this region the SW and NE monsoons play a dominant role in the hydrobiological and climatological properties of the northern section.

According to Wyrski the upwelling along the coast of Arabia is more in volume and enrichment of nutrients than that of Somalia. He states that "during the SW monsoon weak upwelling develops under favourable conditions along some parts of east coast of India but without noticeable effects". Along the west coast, subsurface water comes very close to the surface and the 20° isotherm rises to less than 50 m in July and August as a result of baroclinic adjustment of the water structure in the Arabian Sea to the anticyclonic monsoon circulation. When this circulation becomes very strong, cool water may locally appear at sea surface and be taken as upwelling. Although this water is rich in nutrients, it is also extremely depleted in oxygen and may cause adverse biological effects as discussed by Banse (1968).

In the Northern Indian Ocean two surface water masses are found a high salinity water of Arabian Sea and low salinity water of Bay of Bengal. The low salinity water from the Bay of Bengal flows during the NE monsoon, south of Sri Lanka to the west with one branch continuing westward along 5°N and the other along northwestward along the coast of India. During the SW monsoon it flows to the south-east along the coast of Sumatra where its salinity is further diluted by heavy rainfall in that region. This low salinity surface water forms portions of

the South Equatorial Current. The salinity of this water is kept low by the heavy north east rainfall in the Intertropical Convergence Zone.

The two ecological charts (Figs. 64, 65) show the comparative limits of the different water masses throughout the year (Krey, 1973).

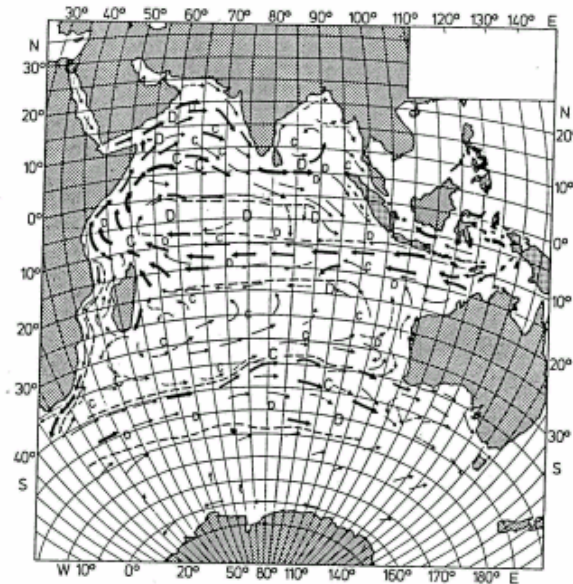


Fig. 64 - Ecological province of the Indian Ocean, as given by long-term hydrographical observations, for the main period of the SW monsoon (D; Divergence, C: convergence) (From Krey, 1973).

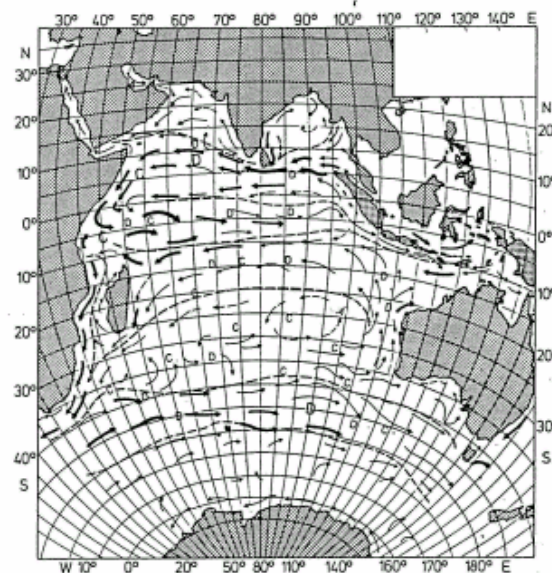


Fig. 65 - Ecological province of the Indian Ocean, as given by long-term hydrographical observations, for the main period of the NE monsoon (D; Divergence, C: Convergence) (From Krey, 1973).

The high salinity water in the central and northern Arabian Sea spreads southwest into the area of Somalia and from there into the Equatorial Counter Current and can be followed up to 90°E as a tongue of high salinity water. During SW monsoon, it first spreads south and then turns east and penetrates with monsoon current into the region south of Sri Lanka. Some portions of this high salinity water occurs in the Arabian Sea above the thermocline north of 10°S but does not penetrate into the Bay of Bengal. The high salinity outflow from the Persian Gulf and Red Sea affect the intermediate layers of the Arabian Sea. In the Central Arabian Sea, Subsurface High Salinity water masses, the Arabian Sea water, the Persian Gulf Water and the Red Sea Water form a thick layer known as North Indian High Salinity Intermediate Water occupying 150 to 900 m in the Arabian Sea. Near 300 m depth the High salinity water spreads east with SW monsoon current and fills the region west of Sumatra and the entire Bay of Bengal.

The monsoon gyre consisting of high nutrient, low oxygen water is separated from the low nutrient, high oxygen subtropical gyre. The subtropical gyre consists of the South Equatorial Current, the Agulhas Current system and those portions of the West Wind Drift, which is found north of Subtropical Convergence near 40°S. The warm water in the gyre i.e. 12° isotherm is extended to 600 m deep in the South Western Indian Ocean but only up to 300 m along the northern boundary of the gyre. This gyre is developed differently from those of the Atlantic and Pacific because of the peculiar topography of the Indian Ocean. A long ridge extends from Agulhas Current system to Timor Sea dividing the westward flow to the north of the ridge from the eastward flow south of the ridge. The equator-ward turn of the isobars is lacking in mid-latitude. The absence of north-south running coast line and restricted connection with the Pacific Ocean in midlatitude seems to be the reason for this. The South Equatorial Current situated north of the ridge is formed to the south of Java. It draws water from the Timor Sea and south-west Sunda Strait and strengthened by the Counter current turning south and west.

An upwelling area south of Java occurs during SW monsoon period, where the surface temperature is low and the nutrient concentration is increased in layers above 100 m. Even though this increase is not up to the same degree as in the region of Arabia, the area covered is more.

The Agulhas Current in the Western Boundary Current of the Indian Ocean is different from other Western Boundary Currents. It draws water from the South Equatorial Current through Madagascar Channel. It is the strongest Western Boundary Current in the southern hemisphere. The current reaches depths more than 2000 m. On reaching the Agulhas Bank, it turns south and east in a sharp anticyclonic eddy and forms the Agulhas Return Current, both the currents forming an elongated Agulhas eddy the centre of which is filled up with warm, high salinity subtropical water extending down to 500 m. The eddies drift into the Atlantic. There is no direct and continuous flow of subtropical water from the Indian Ocean to the Atlantic.

The deep sea basins of the Indian Ocean are filled with water having 1.2°C in Arabian Sea, 1.0°C in the Central Indian Ocean and 0.7°C in the NW Australian basins. The deep water circulation in the Indian Ocean is weaker than in the Atlantic. Deep water enters the Indian Ocean from the North Atlantic at depths of 2500 and 3200 m having salinities about 34.84 PSU, temperature 2.2°C and high oxygen content 5ml/l. It spreads east into the Pacific.

The Arabian Sea is filled with high salinity water formed at the sea surface and outflow from the Persian Gulf and the Red Sea. at 300 and 800 m respectively which is isolated but vertically mixed high salinity water called North Indian Intermediate Water. At 2000 m the salinity is as high as 34.8 PSU. The salinity at 1500 m exceeds 34 PSU north of 5°S (Arabian Sea and Bay of Bengal). This isolated and stagnant North Indian Intermediate Water has horizontal advection and High productivity which cause development of a layer of extremely low oxygen concentration less than 1.0 ml/l. everywhere to the north of 3°N and extending from 200 to 1200 m in the Arabian Sea. This huge layer of oxygen deficient water mass is the deep oxygen minimum layer which covers the entire Indian Ocean. Near the equator it lies at about 800 m which deepens to more than 1700 m at 40°S. The lowest oxygen concentration of the oxygen



minimum layer is different from the other two oceans and occurs along the eastern side on either side of the equator (in the Arabian Sea and Bay of Bengal). This is not only due to the land locking in the northern hemisphere but more so to the advection of water of moderate oxygen concentration from the Pacific through Indonesian waters.

Extensive areas of upwelling occurs on the western margin of the Arabian Sea (Currie *et al.*, 1973) and also on the eastern margin of the Indian Ocean (Banse, 1968) during the SW monsoon period making the Arabian Sea a potentiality fertile area.

Nutrient concentration in the Arabian Sea is about twice that of North Atlantic (Ryther and Menzel, 1965). The nutrient properties of different water masses in the Indian Ocean are affected by the circulation in the northern Indian Ocean by the monsoon wind (McGill, 1973). Vertically the maximum phosphate zone begins at a depth of 600 m down, which is beneath the oxygen minimum layer. Values in the Arabian Sea are as high as 2.70  $\mu\text{g at/l}$ . Maximum  $\text{PO}_4\text{-P}$  of 3.00  $\mu\text{g at/l}$  is found at 1200 m. Concentration remains high in the northern areas at 2000 m. At deeper levels 2000 to 3000 m the oxygen values increase.

## **5.5 Temperature :**

The most significant phenomenon of the thermal structure prevailing in the Indian Ocean is that there is a seasonally varying upper thermocline, a mixed layer above, a lower oceanic thermocline and a deep layer of very little change of temperature with depth. The mixed layer occurs almost throughout the tropical and subtropical regions between 40 and 100 m depth except in some localities and seasons when it may extend to several hundred metres deep. During upwelling season, along the coast of Arabia the mixed layer is less than 20 m. But mixed layer of more than 100 m occurs frequently in the Arabian Sea during SW monsoon period. In the southern subtropical gyre and off Sumatra it occurs in winter. The mixed layer is several 100 metres deep in regions between 40 and 50°S. The upper thermocline strongly developed in the tropical region is found between 70 and 300 m. The temperature gradient is maximum in this region. In late winter, the upper thermocline vanishes in many regions of the temperate and subpolar waters. Along the south west coast of India the

thermocline usually occurs at depths of 100 to 125 m except during summer monsoon period. As the summer monsoon advances the thermocline travels upwards to 20 to 30 m and sometimes reach the surface, in the Arabian Sea. Because of the monsoon effect the thermocline depth fluctuates widely in coastal areas of the Arabian Sea which is subjected to upwelling. In the Bay of Bengal, the thermocline is usually below 50 to 55 m but occasionally it goes down to 100 m. When the thermal structure shows considerable amount of fluctuation in the coastal waters of the west coast indicating seasonal trends, that of the east coast is almost isothermal or near isothermal except in a small area of the central region. The permanent thermocline occurring at depths ranging from 300 to 1,200 m is found everywhere in tropical, subtropical, temperate and subpolar regions. The 20°C isotherm in the middle of the upper thermocline in tropical and subtropical region reaches the surface in the southern parts and separates the warm surface water from the cooler waters of the oceanic thermocline. A temperature of 1°C per 10 m is seen just below the mixed layer in tropical region where strong summer thermocline is formed. A strong 3°C gradient per 10 m is common in equatorial region. The salient features of the temperature density structure in the upper layer of the equatorial region are the strong, shallow upper thermocline in the tropics, the forming of isotherms between the equator and 10°S, the almost horizontal isopycnal surfaces in the northern Indian Ocean and the spreading of the isotherms and isopycnals south of 15°S. The surface density varies with temperature except in upwelling areas where variations are related to upwelling. Meridional shift of surface density is strongest in the eastern part of the Indian Ocean between 30° and 50°S. In the main thermocline, the temperature gradually decreases to about 5°C. Below this main thermocline is the deep water layer of 2-4°C at about 1000 m in mid-latitudes. The thermocline is deepest at mid-latitudes but shallower at the equator. The surface temperature varies seasonally, the wind keeps them well mixed. The tropical waters are the warmest averaging above 20°C and cools to less than 0°C in the vicinity of ice fronts. A uniform zonal distribution of surface temperature is not found. The global pattern of the currents and counter currents modify the temperature considerably. The warm water from the equatorial region is carried away in the well known western boundary currents and cool water return to the lower latitudes in the often less well defined eastern boundary currents along the western shores. This results in the fact that north-

south distance between the same isotherm tend to be greater in the west of the Ocean than in the east.

The fluctuations in the average surface temperature are conspicuously different in the Arabian Sea from the Bay of Bengal. Those of the Arabian Sea vary between 23° and 30°C (Gallagher, 1966) where those of the Bay of Bengal between 27° and 29°C. The usual range along the Indian coast is 23° to 29°C. Cool surface water prevails in regions south of 15°N and the coast of Somalia and Arabia as a result of upwelling during June-September (summer or SW monsoon). A bimodal surface temperature was observed in the Arabian Sea and Bay of Bengal (Robinson, 1966).

## **5.6 Salinity :**

The salinity of the Indian Ocean varies from 30 to 37 PSU. In the northern and Central Arabian Sea, the prevalence of high rate of evaporation and less precipitation (Venketaswaran, 1956 ; Muromtsev, 1959) as well as influx of high saline water (37 to 41 PSU) from the Red Sea and Persian Gulf cause high salinity in the Arabian Sea. The high rate of precipitation and substantial amount of fresh water discharged from the rivers lead to low salinity values in the Bay of Bengal. The salinity in the Bay of Bengal and in regions between Sumatra and Australia always remains less than that of the Indian Ocean in general, because of the low saline water flowing from the Pacific and higher rate of precipitation in the intertropical convergence zone during the NE monsoon period. Wyrki (1971 b) has stated that high salinity waters occur in the northern part of the Arabian Sea and low salinity in the west coast of India as well as in the Bay of Bengal ; low salinity water from the Bay of Bengal is advected to the south of Sri Lanka during the NE monsoon ; extension of a tongue of high salinity water to the east during SW monsoon ; spread of low salinity water from the eastern Indian Ocean around 10°S, the presence of a subtropical cell of high salinity being confined to eastern part of the cell ; existence of high salinity water from November to May (34.1 PSU in March and April) near the Anatarctic Divergence.

The average salinity values of the Arabian Sea ranges from 34 to 37 PSU and that of the Bay of Bengal from 30 to 33 PSU. The salinity of the Arabian

Sea decreases from north to south while in the Bay of Bengal it increases from north to south (Gallagher, 1966).

According to Wyrcki (1971 b) the high salinity water of the Arabian Sea extends southwest into the area off Somalia during NE monsoon period. It is further drawn into the Equatorial Current as a distinct tongue of high salinity water up to 90°E and this high salinity water spreads southwards during SW monsoon period. It flows along with the monsoon current and is traceable up to south of Sri Lanka. A portion of this high salinity water sinks and forms a subsurface salinity maximum water which spreads throughout the entire monsoon gyre of 10°S. However, this water does not penetrate into the Bay of Bengal. This water along with the high saline water from the Red Sea and Persian Gulf form the North Indian High Salinity Intermediate Water of almost uniform salinity. It occupies from about 150 to 900 m depth in the Arabian Sea, spreading in different directions in the Monsoon Gyre at a depth of 300 m and filling an area west of Sumatra and the entire Bay of Bengal (Rochford, 1964 ; Wyrcki, 1971 a, b). The warm, low salinity surface water of the tropical Bay of Bengal has its maximum coverage in Bay of Bengal and to the south-west of Sumatra from where it extends west to Africa near 10°S. The tongue of low salinity water may be found anywhere between 4° and 15°S. Below this low salinity Tropical Water of Indian Ocean, a water front is situated extending several hundred metres down. Within the upper thermocline this front is marked by a horizontal salinity minimum separating the salinity maximum of the subtropical waters of northern and southern hemisphere. This front of salinity maximum extends from Timor to north of Madagascar. It is stationary at 10°S and fluctuate between 7° and 12°S depending on the variable penetration of the two salinity maxima to the north and south. Deeper down in layers between 300 and 1000 m depth the front separates the high salinity water of the northern Indian Ocean, mainly of Red Sea origin from the low salinity waters of the Southern Indian Ocean of Antarctic origin. The upper branch of the Antarctic Intermediate water occurring at 1000 m depth at 25°S with a salinity of 34.5 PSU rises to 700 m at 10°S with a salinity of 34.7 PSU. Subtropical surface water of high salinity forms, in the subtropical anticyclonic gyre under the influence of an excess of evaporation over precipitation. The highest salinities occur in the area between 25° and 35°S with maximum near to Australia. The salinity above 35

PSU extend to more than 500 m depth. From this high salinity core a subsurface salinity maximum extends throughout the subtropical anticyclonic gyre spreading mainly equatorwards.

The low salinity (below 34 PSU) of the Antarctic surface water caused by excessive precipitation and melting of ice meets the high salinity Antarctic Polar front lying between 48° and 53°S. The Indian Ocean Deep Water originates from the Deep Atlantic Water. In general, north of 5°S at 1500 m depth the salinity exceeds 34.8 PSU. In the Arabian Sea at depths of 200 m, the salinity is as high as 34.8 PSU.

Different water masses can be recognised in the Indian Ocean. They are (1) the shallow salinity maximum water containing the Arabian Sea water in the northern Indian Ocean and the subtropical water in the southern Indian Ocean. (2) The water of high salinity originating from the Red Sea and Persian Gulf outflow. (3) The maximum salinity of the Antarctic Intermediate Water originating at the Antarctic Polar front. (4) The High Salinity Antarctic Deep Water ending in the Indian Ocean. (5) The shallow oxygen minimum layers usually found in the thermocline region. (6) The intermediate oxygen maximum layer originating north of the Polar front and spreading above the Antarctic Intermediate water, and (7) The deep oxygen minimum layer.

Characteristic water masses are formed primarily at the sea surface by the influence of climatological factors, temperature, salinity, dissolved oxygen and phosphate. Of these temperature and salinity can be changed only at the surface by the climate.

High rate of evaporation causes the formation of high salinity areas in the Arabian Sea and in the northern subtropical region from where it spreads. Salinity maximum also results from the outflow of water from the Red Sea and the Persian Gulf as well as from the North Atlantic Deep Water. The subtropical surface water of the southern subtropical Anticyclonic Gyre and the Arabian Sea shallow (maximum salinity) water mass (salinity maximum exceeding 36.5 PSU) occurring in the northern part of the Arabian Sea spreads south up to 10°S and then east. It does not enter the Bay of Bengal. On its southward spread, the

temperature and dissolved oxygen values decrease, while the nutrients increase. Thus off Arabia, phosphate and nitrate values are very high, suggesting areas of upwelling. Subsurface salinity maximum of the subtropical gyre is rather shallow in the area of formation where winter temperature is lower and the density higher. A branch of this salinity maximum water mass extends to south, where its depth and density increases. The north branch becomes as deep as 250 m under South Equatorial Current. Near 10°S it meets with the water core layer originating in the Arabian Sea. Nutrients which are very low in the subtropical region increases both south and north wards. Throughout the salinity maximum layer there is strong linear relation between dissolved oxygen, phosphate and nitrate. Along 10°S salinity is lowest due to mixing of core layer by the overlying water of low salinity. Dissolved oxygen is low and the nutrient is high. The Intermediate salinity maximum is found in the Indian Ocean at depths between 150 and 900 m associated with outflow from Gulf of Oman and Persian Gulf. This water seems to spread into the oxygen minimum layer in the northern Arabian Sea and then along the west coast of India to south. Salinity maximum in the Gulf of Aden is due to outflow from the Red Sea and spreads to the Arabian Sea at depths between 500 and 800 and is identifiable far east to Sumatra and to the south into the Madagascar Channel up to 1100 m depth at 25°S. The Arabian Sea consists of three upper salinity maxima – shallow maxima, intermediate maxima and Red Sea maxima. The deep salinity maximum of the Indian Ocean originates from the North Atlantic Deep Water at 2000 m with a salinity of 34.84 PSU, temperature of 2.2°C and dissolved oxygen 5 ml/l.

The Antarctic intermediate water of low minimum salinity is the result of high rate of precipitation and melting of ice while the low salinity in the Bay of Bengal and Indonesian waters does not form subsurface salinity minima because of the low density of these waters.

### **5.7 Dissolved oxygen :**

The dissolved oxygen values of the surface waters largely depend on the surface temperature. In almost all cases it is close to saturation. In some areas, the values are slightly over saturation. In the well mixed surface layers of the Arabian Sea up to 100 m depth, values vary between 4.5 ml and 5.0 ml/l. In the

lower layers the oxygen values decrease sharply and the subsurface oxygen minimum layer is formed. The values are less than 0.5 ml/l, below a depth of 150 m and the low values persist up to 1500 m (Sankaranarayanan, 1978). At 2000 m depth the variation in dissolved oxygen value is below 1.25 ml/l and 2.5 ml/l. The upwelled waters have very little oxygen.

The oxygen minimum values of the subsurface water in the northern monsoon gyre have been reported by several authors. According to Wyrski (1973) the North Indian Intermediate Water layer extending from above 200 m to more than 1,200 m depth in the Arabian Sea has an oxygen content of less than 1.0 ml/l, everywhere to the north of 3°N. The deep oxygen minimum layer prevailing in the entire Indian Ocean is directly connected with this. It lies at about 800 m near the equator but extends to deeper than 1,700 m near 40°S. But it rises to 400 m depth below the Antarctic Divergence. In the Southern Indian Ocean it lies above the deep water and below the Antarctic Intermediate Water. The values in the oxygen minimum layer increases gradually southwards and reaches 4 ml/l at 40°S. The oxygen maximum layer is found in the entire Subtropical Gyre at depths between 400 and 500 m. The oxygen values decrease only very slightly to the north. Between the low oxygen content of the monsoon gyre and high values of subtropical gyre a very sharp horizontal gradient is developed which is most pronounced at 15°S. Wyrski (1971 b) has summarised that oxygen values decrease suddenly from 5 ml/l to less than 3 ml/l between 15°S and 10°S. This oxygen maximum extending to 8°N is situated between the shallow oxygen minimum near 200 m depth (developed in the thermocline) and the deep oxygen minimum between 400 and 1,700 m. North of 8°N these two layers unite into one huge layer extremely of low oxygen content (0.5 ml/l) where an oxygen maximum layer is absent. A weak oxygen minimum layer is found near a depth of 180 m in the central and northern parts of the subtropical gyre. Below the subtropical gyre, water of high oxygen content is found at depths of 400 to 500 m. The deep water of the Indian Ocean has a rather high oxygen content of 5 ml/l decreasing in the direction of spreading.

In the Indian Ocean two oxygen minima are observed. The consumption of oxygen for oxidising the organic detritus sinking down from the productive upper layers appears to be responsible for the oxygen minima layers. The

distribution of these is determined by the pattern of circulation (Wyrski, 1962). In the northern Indian Ocean the deep oxygen minimum layers varying widely in oxygen values is found at depths less than 600 m which goes on extending to 1800 m near 40°S from where it rises to 400 m below the Antarctic convergence. The extremely low oxygen concentration prevailing in the north increases towards south and the concentration reaches as high as 5ml/l, the oxygen minimum near Antarctica. As stated elsewhere linear relation exists between oxygen values and the temperature. To the north of 20°S the minimum is situated between 12°C and 5°C. Between 30°S and 50°S and near the Antarctica this is at 1°C only. Phosphates and nitrates are high throughout the oxygen minimum layer, northern water having slightly higher values than Antarctica.

The shallow oxygen minimum layer usually found within the thermocline at depths of about 200 m and at temperatures between 12° and 20°C is present in all tropical and subtropical regions. Lowest values of oxygen content are found in the northern Arabian Sea and in Bay of Bengal. In these areas shallow and deep oxygen minimum layers often form a continuous stretch of extremely low oxygen which probably changes a little with the seasons. In the northern and equatorial Indian Ocean the oxygen minimum layer is situated below the shallow salinity maximum. It is above the salinity maximum between 10°S and 20°S. In the area of the subtropical anticyclonic gyre, the shallow oxygen minimum is only weakly developed and fades away gradually between 35°S and 40°S. A layer of higher oxygen content, the intermediate oxygen maximum, originating in the temperate region north of the Polar Front near 42°S (where oxygen content is more than 5.5 ml/l) which is the transition zone between subtropical and subpolar water and spreading above the Antarctic Intermediate Water to the north, separates the two minima. The oxygen maximum is found in the main oceanic thermocline at temperature between 10 and 12° near the boundary between the warm water and cold water (Wyrski, 1973). This maximum sinks to the depths of more than 500 m below the subtropical Gyre and then rises to 300 m near the equator where it is often missing as the oxygen content is reduced to 1 ml/l. This line of 1 ml/l has been used as its northern boundary. The nutrient content in this layer is lowest between 30° and 35° S and increases to rather high values as oxygen decreases northward.



## 5.8 Transparency:

Measurement of light intensity in the marine environment often presents several difficulties. The use of simple instruments like the Secchi Disc employed by several workers does not give all aspects of spectral distribution. The secchi disc measures the depth of visibility. The values are subject to the state of the sea, diameter of the disc, colour as well as the limitations of the eye sight of the observer. Tyler (1968) has stated that although individual observations of depth of visibility with secchi disc have only limited values, the average of a series of measurements has been accepted as valid.

During the International Indian Ocean Expedition, 738 observations on transparency have been made from September 1959 to December 1965 (U.S. National Oceanographic Data Centre). These observations were mostly from the eastern Indian Ocean and that too from inshore locations. Voytov and Dementjeva (1970) have compiled a chart of relative transparency of the Indian Ocean and related sector of Antarctica based on 824 observations with secchi disc mainly during November to March. A relatively uniform transparency of 30 to 35 m is found over the entire open part of the Ocean, which is in agreement with the observations made by Yerlov in 1964. Voytov and Dementjeva have shown that the extensive region in which relative transparencies above 35 m and even 40 m predominate corresponds to the Central Anticyclonic Gyre that occupies almost the entire latitude belt south of 20°S. This region is also poor in plankton. The boundary between equatorial current and equatorial counter current appears as areas of low (less than 30 m) relative transparency, running from SW to NE in the equatorial region of the Central Indian Ocean.

Prasad (1952) has reported a depth range of 10 to 24 m for transparency off the east coast of India. He has observed the silt laden water from the river Ganges has reduced the transparency to about 4 m in areas near the mouth of Ganges. According to Rao (1957) the west drift of the NE monsoon picks up turbid water from the river discharges and transports it all along the east coast. When the current is reversed in February-April, the water becomes clear due to incursions of oceanic water. Rao has correlated changes in the transparencies with variations in copepod and chaetognath populations. The inshore data from

Kakinada Bay by Sarma and Ganapati (1968) confirm the observations of Rao. Qasim, Bhattathiri and Abidi (1969) have shown that light penetration in Cochin backwater is at a low level throughout the year but at a minimum during the SW monsoon. Wickstead (1962) has shown that the plankton biomass (dry weight) per m<sup>3</sup> in the upper 200 m declined with increasing transparency. The vertical migration of the planktonic population is affected by transparency of the water column. According to Wickstead variation in plankton biomass need not be indicative of rich or poor areas, but of transparency at the time of sampling. The blue colour of the open ocean is due to selective absorption by water itself and due to multiple scattering by the water molecules which also favours short wave length. In turbid waters, selective absorption by particles and yellow substances leads to shift of colour towards longer wave lengths (Jerlov, 1965). Wickstead (1961 b) has noted the bottle green colour of the sea over north Kenya Banks and compared with that of the temperate waters of the North Sea. Such an area is markedly different from the usual clear blue of the offshore waters of East Africa and also the dirtier blue or pale green of inshore waters. Increasing organic production is commonly associated with a change towards longer wave lengths. Raman and Murthy (1968) have reported that waters off Madras (Coromandel coast – Bay of Bengal) were more transparent than near those Cochin (Malabar coast – Laccadive Sea). Clarks and Kelly (1964) have observed the variations in attenuation are related to complexity of water movements in the equatorial region. Thus, extremely optically clean water corresponded roughly with the tongue of Indian Ocean Central Water at 60°E longitude. A tendency for attenuation of visible light to become less is reported with increasing depths. They have found that no further change in the transparency below 800 m occurs. It is estimated that a deep sea fish could perhaps detect day light at 1300 m at noon in Indian Ocean at 22°58'S and 59°45'E. The least transparent water at 1-°39'N and 60°07'E was estimated to allow light perception to about 700 m in deep sea fish. These values indicate the range of depth down to which light would be sufficient for vision and for control of vertical diurnal migration (Clarks & Kelley, 1964).

## 5.9 The nutrient profile and oxygen concentration :

### Western Indian Ocean and Arabian Sea :

**Oxygen and inorganic phosphate** : The survey made by Atlantis II revealed that during the SW monsoon period, the strong and persistent winds blowing offshore from Africa, displaces transparent surface water away from the shore, and the nutrient rich deep water reach the surface (McGill, 1966) along the Arabian coast. During peak upwelling time, the surface temperature was less than 18°C near Cape Guardafui and Socotra. Phosphate phosphorus in the upwelling area of Socotra was greater 1 µg at/l. Oren (1963) has reported values of 0.25 to 5.4 µg at/l in the SW Indian Ocean, the values still increasing southward. Highest oxygen concentration is found in Gulf of Aden and values in excess of 5 ml/l are seen in the western equatorial region and south of Madagascar. As excessive oxygen depletion of 0.05 ml/l is seen the Arabian Sea (Mc Gill, 1973) but no hydrogen sulphide was noticed, contrary to the observations of Ivanenkov and Rozanov (1961). Reddy and Sankaranarayanan (1968) have observed variations in the concentration and thickness of phosphate and silicate in the upper 200 m of the Central Western North Indian Ocean. Ryther and Menzel (1965) report that general level of nutrients in the western Arabian Sea are higher than those of North Atlantic by about two times. Nitrates and silicates as well as other non-conservative nutrient elements are distributed much the same as inorganic phosphate.

At 600 m depth the phosphate maximum is observed. Values as high as 2.70 µg at/l are found in the Arabian Sea. This lies below the oxygen minimum layer recognised by Mokievskya (1961). The phosphate value increases to 3.00 µg at/l at about 1200 m in the Arabian Sea. The values from the central and equatorial regions vary from 2.50 to about 2.80 µg at/l. In the Antarctic Intermediate Water, south of the equator, the concentration is similar to the levels found in the Atlantic (2.50 to 2.70 µg at/l). The oxygen values in the North Indian Ocean range from 0.3 to 1.25 ml/l. The concentration decreases towards north in the Antarctic Intermediate Water to about 1.5 ml/l in the area east of Mascarene Ridge between Seychelles and Mauritius. The phosphate concentration is high in the northern area (more than 2.6 µg at/l) at depths 2000 m. Towards south it is slightly lower. Near South Africa a maximum concentration was reported by Mostert (1966). He reports that pockets of high

phosphate concentration up to 2.6  $\mu\text{g at/l}$  occur throughout the area and attributed the same as due to decay of sinking organic matter. Orren (1963) found a region of maximum phosphate concentration at about 2000 m in South West Indian Ocean. Oxygen concentration in deep waters increase but a north-south gradient 2.00 to 4.00 ml/l is seen near Madagascar.

The top of mid-ocean ridge, including Mascarene Ridge appears at 3000 m. At this depth, the phosphate phosphorus values are found to be greater than 2.5  $\mu\text{g at/l}$  in the Arabian Sea basin and the oxygen increases to 5.0 ml/l.

According to Ivanenkov and Gubin (1960) in the West Indian Ocean the top of the distinct bottom water lies at 4000 m. At this depth the oxygen concentration varies from 3.75 to 3.80 ml/l in the Arabian Sea, more than 4.00 ml/l in the South Indian Ocean Bottom Water (temperature 1.1 to 1.5°C, salinity 34.72 to 34.73 PSU) increasing southwards and more than 5.00 ml/l (temperature 1.0°C and salinity 34.73 PSU) in water south of the Mozambique Channel which closely corresponds to the Antarctic Bottom Water. The phosphate concentration varies from 2.4 to 2.5  $\mu\text{g at/l}$  in the Arabian Sea, close to 4.0  $\mu\text{g at/l}$  in the South Indian Ocean Bottom Water and 2.10  $\mu\text{g at/l}$  in waters south of Mozambique Channel which is lower than in other regions of this depth.

#### **Eastern Indian Ocean, the Bay of Bengal:**

Rozanov (1964) reported low surface phosphate values 0.1  $\mu\text{g at/l}$  in the Bay of Bengal and the Andaman Sea increasing to a maximum of 2.90  $\mu\text{g at/l}$  at depth. Kabanova (1964) reports very low surface phosphates in the Bay of Bengal while the phosphate is almost absent in the Andaman Sea because of high production. Rochford (1962) reports high surface phosphate levels of 0.2 to 0.3  $\mu\text{g at/l}$  along shelf and slope of north-west Australia, south of Timor during upwelling in September. Wyrski (1962) reports high concentrations of phosphates (0.7  $\mu\text{g at/l}$ ) along Java and Sumatra coasts at the bottom of the euphotic zone during the main upwelling of the South East monsoon. Brujewicz *et al.* (1966) have reported seasonal changes in nutrient concentration in low latitudes especially in the eastern part of the southern tropical zone of the Indian Ocean. A marked change of dynamic condition due to monsoon changes affect the layers from surface to 1500 m in this region.

Along the south west coast of India, upwelling is prevalent between 7° and 18°N latitudes from August to early October (Panikkar and Jayaraman, 1966). Sharma (1968) has reported northward progression from February to July-August. Rao (1957) reported high values for total phosphorus in the inshore waters off Calicut from January to March and July to October. These high values coincide with high inorganic phosphate in the SW monsoon period as against the inverse relation along the east coast. Jayaraman and Seshappa (1957) also reported high values of total phosphorus on the west coast when compared with the east coast during SW and NE monsoons. Panikkar and Jayaraman (1966) correlate rich sardine – mackerel fisheries along the south west coast and upwelling. Similarly Rao and Jayaraman (1966) correlate tuna fishery and upwelling in the Minicoy area.

Concentration of nitrate nitrogen varies from 5 to more than 15 µg at/l in the surface waters near Socotra during upwelling of the SW monsoon period (Mc Gill, 1973) while at other regions it was negligible. Kabanova (1964) found still enriched condition in the surface waters of the Gulf of Aden and the Somalia current during October-April period. Highest nitrate values more than 25 µg at/l was found in the western Arabian Sea at 200 m. A maximum of 80 µg at/l near South India and Sri Lanka. The equatorial region showed values less than 20 µg at/l. On either side of Madagascar, it reduced to less than 5 µg at/l. At 600 m, high concentrations were found near the South Indian coast. At 1200 m, values around 35 µg at/l were found in the entire of Arabian Sea. Lower concentrations in the intrusive Antarctic Intermediate water east of the Mascarine Ridge. At deeper levels, the values, were 30-35 µg at/l at 2000 m and about 30 µg/l at 3000 m and 4000 m in the western Indian Ocean basin.

The nitrate and nitrite values were also low in the surface waters of the Bay of Bengal and increases sharply to 15 to 20 µg at/l at thermocline depths and 22 to 26 µg at/l, in deeper parts. Concentrations of 1.5 to 2.0 µg at/l are reported in the euphotic zone in the central part of the Andaman Sea (Kabanova, 1964).

### 5.10 Plankton :

The plankton biomass (volume) is highest in the Arabian Sea between 10° and 25°N and 50° to 65°E, particularly in the area of Somali and Saudi Arabia coasts (Prasad, 1966, 1969). Average values as high as 54.7 ml/m<sup>2</sup> were observed off Arabia, with Somali showing 15-35 ml/m<sup>2</sup> ± 15 ml all over the south eastern region of the Indian Ocean, in the northern Bay of Bengal and south of Java. The rest of the Indian Ocean showed values less than 15 ml. The seasonal distribution of biomass suggests that areas adjacent to Saudi Arabian coast consistently show very high productivity during the SW monsoon period. Nutrient values were also very high in this area indicating that the Saudi Arabian coast is the richest for secondary production in the northern Indian Ocean (Rao, 1973). The areas of high population density (27000 and above) of copepods are close to the coastal area (Kasturirangan *et al.*, 1973). They are more in the northern Indian Ocean than in the southern region. The largest area of high density population is in the north western border of the Arabian Sea. In the Bay of Bengal, there is a copepod high density region near its head during the SW monsoon season (April 16 to October 15) which spreads out from the area of upwelling in the direction of prevailing current. It disappears during the NE monsoon period. The decapod larvae occur in high numbers off Somali, Indian and Burmese coasts near shore but off Saudi Arabia they appear at a great distance from the shore. They are also more extensively distributed in the SW than in the NE monsoon. In the Central Indian Ocean, south of 10°S they are rare. Larvae of penaeid prawns were concentrated around southern and peninsular India and off Somali Coast. Indian Ocean samples do not contain larval fishes to the extent so as to reveal the breeding grounds of commercially important fishes like sardine and mackerel. The distribution of fish eggs shows that they are consistently rich in areas adjacent to Saudi Arabian coasts and north eastern Bay of Bengal, in all seasons as well as in day and night collections. The emergence of north eastern Bay of Bengal as an area of fish spawning is an important discovery of IIOE. The pelagic molluscs were densely distributed around the Somali coast, the Red Sea, south Java, southwest coast of India and northern part of the Bay of Bengal. The bivalve larvae were also dense around the Somali coast, southern coast of Arabia, southwest coast of India, north of Sumatra and south of Java. Most of the other components of the plankton namely, medusae, polychaets, cladocerans, ostracods, amphipods,

euphausiids, chaetognaths, copepods, salps and doliolids followed almost the same pattern of distribution and abundance as the copepod and fish eggs and larvae, the richest area being Saudi Arabia and Somali coasts (Rao, 1973).

The volume of zooplankton showed higher values over the Bank than off the west coast of Agulhas. The phytoplankton production was lower over the Bank. Presence of large number of Thaliacea in variable sizes and quantities resulted in high volume. They were profusely abundant in numbers swarming over thousands of square kilometres in the central and southern part of the Bank. Their maxima closely followed phytoplankton maxima. The relationship suggests that the Thaliaceans are the important grazers preventing other consumers to establish in the Bank community. *Thalia democratica* and *Doliolum denticulatum* predominated. Sometimes a concentration of copepods, cladocerans or chaetognaths was also met with (Decker, 1973). Among appendicularians *Oikopleura longicauda*, *O. diocia* and *O. rufescens*, as well as *Fritillaria formica* were predominant, but their number varied from year to year. The several species of chaetognaths found in the area are indicators of different water masses that existed in the region.

#### **Primary production :**

Cushing (1971 a, b) has distinguished four categories of primary production in the oceans. They are (1) greater than  $1.0 \text{ g C m}^{-2} \text{ day}^{-1}$  in the major upwelling system, (2)  $0.3\text{-}1.0 \text{ g C m}^{-2} \text{ day}^{-1}$  in lesser systems, (3) less than  $0.3 \text{ g C m}^{-2} \text{ day}^{-1}$  in some minor upwelling systems and (4) less than  $0.1 \text{ g C m}^{-2} \text{ day}^{-1}$  in the open ocean. During SW monsoon a fair portion of Arabian Sea area is highly productive. The average productivity for the whole ocean is  $0.50 \text{ g C m}^{-2} \text{ day}^{-1}$ . The productivity during the NE monsoon is considerably low, the average being  $0.15 \text{ g C m}^{-2} \text{ day}^{-1}$ .

#### **Secondary production :**

The average secondary production during SW monsoon is  $7.3 \text{ g C m}^{-2} \text{ day}^{-1}$  and  $7.0 \text{ g C m}^{-2} \text{ day}^{-1}$  during NE monsoon. The difference is very much less than has been expected from the difference between primary production values of the two seasons. This may be attributed

to poor sampling of secondary production during the NE in the central part as compared with that in SW monsoon

The figures for tertiary production show that off the coast of Arabia, off Zanzibar, off the Malabar coast of India and northern-most part of the Bay of Bengal, values greater than  $40 \cdot 10^5$  tonnes wet weight per  $5^\circ$  square per 180 days. There is an extensive area between Arabia and Madagascar where the production is 20 to  $40 \cdot 10^5$  tonnes wet weight per  $5^\circ$  square per 180 days. There are other patches at the same level in the Bay of Bengal and in eastern Tropical Ocean. A fairly heavy level of production is also observed all over the northern and equatorial parts of the Indian Ocean. In the centre of the southern subtropical anticyclonic gyre the production is very low less than  $5 \cdot 10^5$  tonnes at wet weight per  $5^\circ$  square per 180 days. During the NE monsoon, areas of low production are extensive, still there are dense patches off southern Arabia and East Africa with relatively high bands in the equatorial region. The Bay of Bengal and the eastern tropical ocean appear to be relatively rich but not as rich as during the SW monsoon. A total annual production of about  $3.3 \times 10^8$  tonnes wet weight ( $2.0$  and  $1.3 \times 10^8$  during SW and NE monsoons respectively) is estimated. A greater portion of this quantity lies in the open ocean most of which are inaccessible to exploitation by fishermen.



## 6. BIOGEOGRAPHY OF THE DIFFERENT GENERA AND SPECIES

### 6.1 Distribution of Bothid Larvae :

#### Indian Ocean :

The larvae of bothids were sparsely distributed in the Indian Ocean (Fig. 66), being noted only in 146 out of 1927 stations sampled during the International Indian Ocean Expedition (1960-65). When compared to other taxa, the bothid larvae were few. Out of 146, 85 stations contained larvae up to 5/1000 m<sup>3</sup>, 32 stations 6 to 10 and 17 stations 11 to 20, more than 100 larvae were found in 3 stations while at one station it was more than 300 were noticed.

The larvae of bothids were generally confined to stations close to the shore. In some places, as in the case of stations off the west coast of Australia, west coast of Malaysia, Burma, east and west coasts of India including Sri Lanka (Ceylon), coast of Arabia, Somali and South Africa they were also found a few hundred kilometres away from the shore. The larvae were conspicuously absent in the samples taken from stations situated between 52° and 100°E long and 10° and 45°S lat. Their incidence was high in the Bay of Bengal and the adjoining water bodies. The maximum number was recorded at a station situated in the Malacca Strait which was sampled during night, where the depth was only 60 m. The range of environmental parameters such as temperature, salinity and dissolved oxygen were 29.40-29.50°C, 32.66-34.94 PSU and 3.24-4.45 ml/l respectively. However, the zooplankton biomass at the station was only 160 ml/1000 m<sup>3</sup>. It was noted that the environmental conditions of the majority of stations from where bothid larvae were collected (5/1000 m<sup>3</sup>) had temperature ranging between 11.14°C and 30.30°C, salinity (15.09) 28.69 and 36.57 PSU and dissolved oxygen between 0.17 and 6.69 ml/l.

The larvae appeared in the plankton samples taken both during day and night. However, a preference to darkness was discernible because 56.8 per cent of the samples containing larvae were taken during night (Fig. 66). The number of larvae was found to be more during the NE monsoon period than the SW (Fig. 66). However, the larvae occurred more during the month of April than in other months and the lowest was found in the collections taken during May.

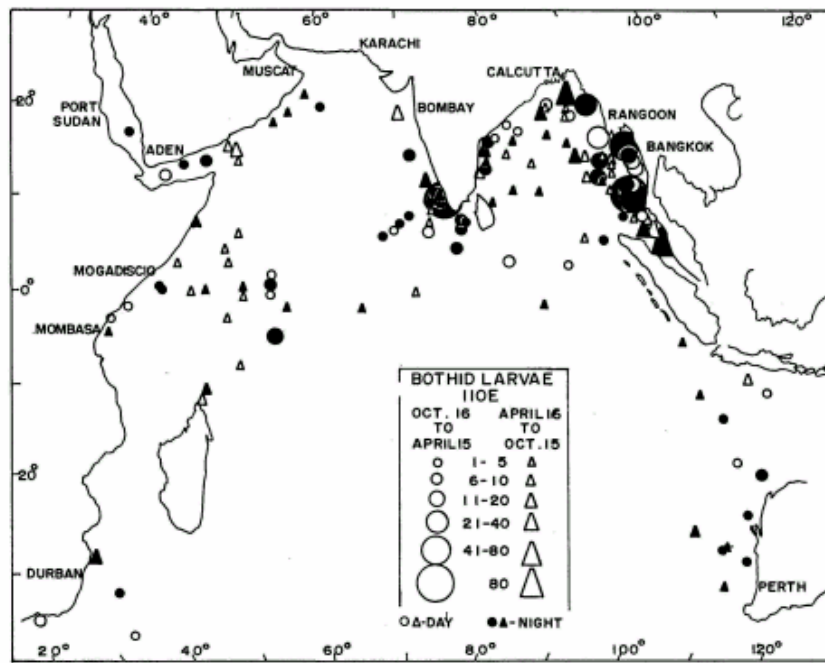


Fig. 66 Seasonal and diurnal variations of bothid larvae in the Indian Ocean.

### Gulf of Thailand and south China Sea :

The larvae of bothids were sparsely distributed in the South China Sea whereas they were found in good numbers in the Gulf of Thailand (Fig. 67), being present in 135 out of 1136 stations sampled during the Naga Expedition (1959-61). Of these 1136 stations, only 580 were considered for checking the quantitative abundance of the bothid larvae since at other stations, the sampling gears and techniques employed were different and the quantity of water filtered during sampling was not available. Hence, these stations were considered only for qualitative assessment and in the distribution maps and tables they are marked as present (+). Out of the 580 quantitative samples, bothid larvae were found only in 82 stations. Of these, 13 stations contained larvae up to 5/1000 m<sup>3</sup>, 15 stations 6-10, 17 stations 11-20, 19 stations 21-40 and 13 stations 41-80. Five stations recorded more than 81 and the maximum 270 was found only at one station.

As in the Indian Ocean, the larvae were confined mostly to the coastal waters, being found in the nearshore stations situated between Bangkok and Seigon. The maximum number of 270 larvae was recorded at a station situated at 10°13'N Lat. and 99°51'E Long., where the temperature, salinity and dissolved oxygen ranged between 30.37 – 30.74°C, 32.55 –32.76 PSU and 4.15-4.34 ml/l respectively. The samples were taken during night and the depth of the station was 43.7 m. The zooplankton biomass was 241 ml/1000 m<sup>3</sup>. From the data, it would appear that the density of distribution was more in the Gulf of Thailand than in the South China Sea. The hydrographical conditions of the stations, having 21-40 larvae per 1000 m<sup>3</sup> ranged from 22.73-31.29°C, 31.53-34.50 PSU and 2.10-5.10 ml/l respectively.

The larvae seemed to prefer darkness since they appeared in 95/135 stations collected during night (Fig. 67). They were found more during April 16 to October 15 period corresponding to the South West monsoon period in the Indian Ocean than in the other half (Fig.67), with a maximum in April, the minimum was in July.

Earlier works on bothid larvae of the Indian Ocean and adjacent waters were highly localised and mostly confined to coastal waters. A comprehensive account on general Ichthyoplankton of the offshore and oceanic regions was not available till the International Indian Ocean Expedition (1960-65) and the Naga Expedition (1959-61).

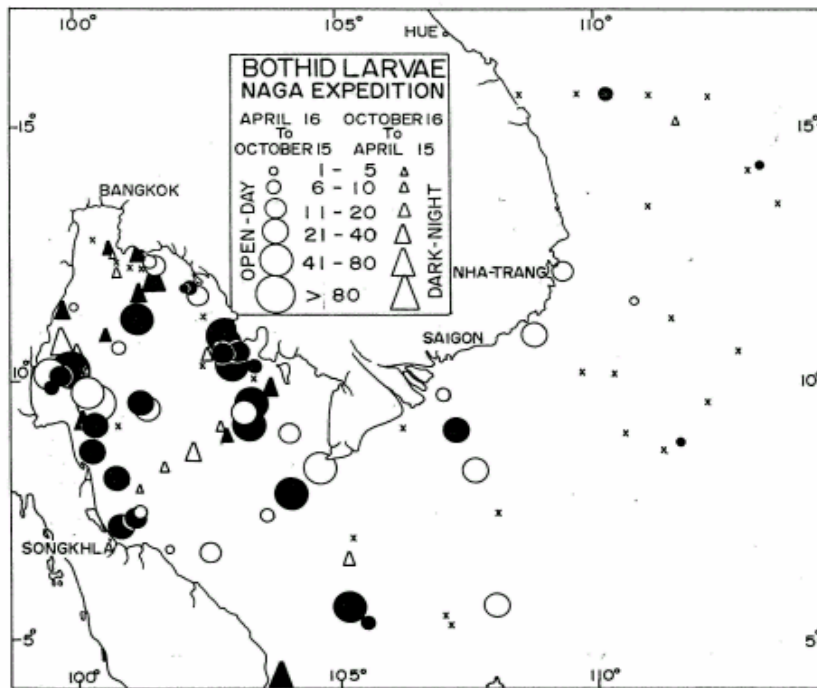


Fig. 67 – Seasonal and diurnal variations of bothid larvae in the Gulf of Thailand and South China Sea.

## 6.2 Species-wise distribution of bothid larvae :

The species-wise distribution of the bothid larvae in different regions of the Indian Ocean, the South China Sea and the Gulf of Thailand was studied and represented in charts. To study the distribution pattern, the index,

$$\frac{\text{Variance}}{\text{Mean}}$$

----- was employed.

### *Crossorhombus valde-rostratus* :

In the samples from the Indian Ocean, the larvae of *C. valde-rostratus* were found only in stations situated in the open ocean (Fig. 68 A). They were

present in the samples from stations off the coast of East Africa, Somali coast, north off Madagascar, in the central part of Bay of Bengal, and north west coast of Australia but were conspicuously absent from the Arabian Sea, and were mostly found in the collections taken during the day time of the SW monsoon period at depths between 997 and 4970 m. Only specimens of the postflexion stage was available in the collections. The salinity ranged between 32.05 and 35.59 PSU. A significant negative correlation was found between larval incidence and dissolved oxygen values ( $R = - 0.5907$ ,  $P < 0.05$ ).

Observations from the Naga samples also indicated that this species showed preference to the open sea (Fig. 68 B). None of the stations from the Gulf of Thailand contained larvae of *C. valde-rostratus*. The depth of its occurrence ranged between 1350 and 5413 m. In the Naga collections, most of the samples (7/8) containing the larvae taken during day time, in the months of March, April, May and September, only the postflexion stage was found. The salinity data alone were available for a few stations, where it varied between 33.22 and 34.69 PSU.

Adults are reported from seas around East Africa, Ceylon, China and Japan.

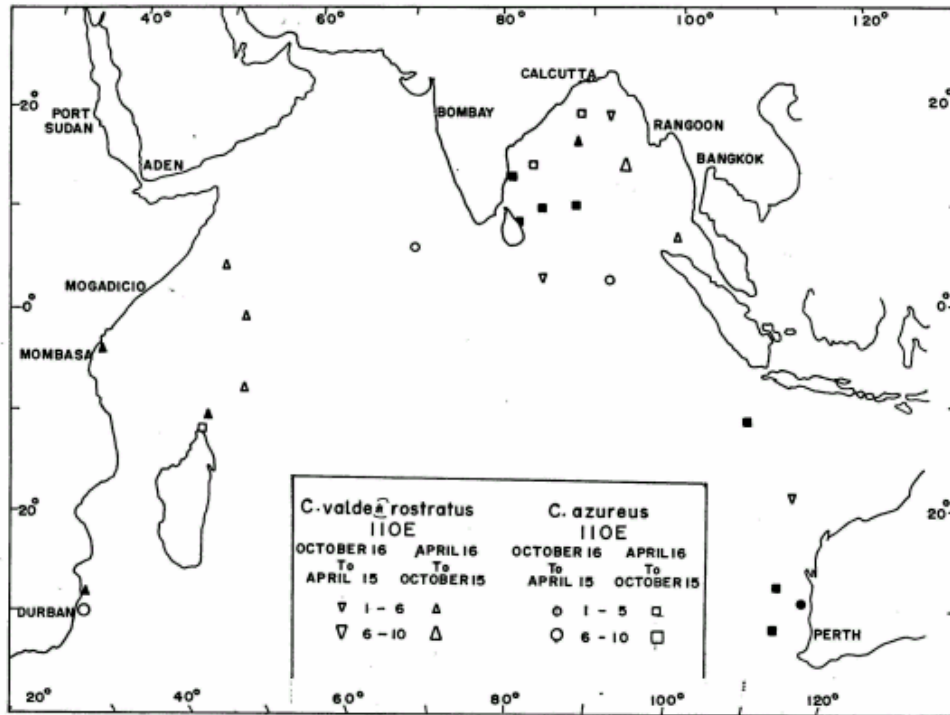


Fig. 68A – Distribution of *Crossorhombus valde-rostratus* and *C. azureus* in the Indian Ocean.

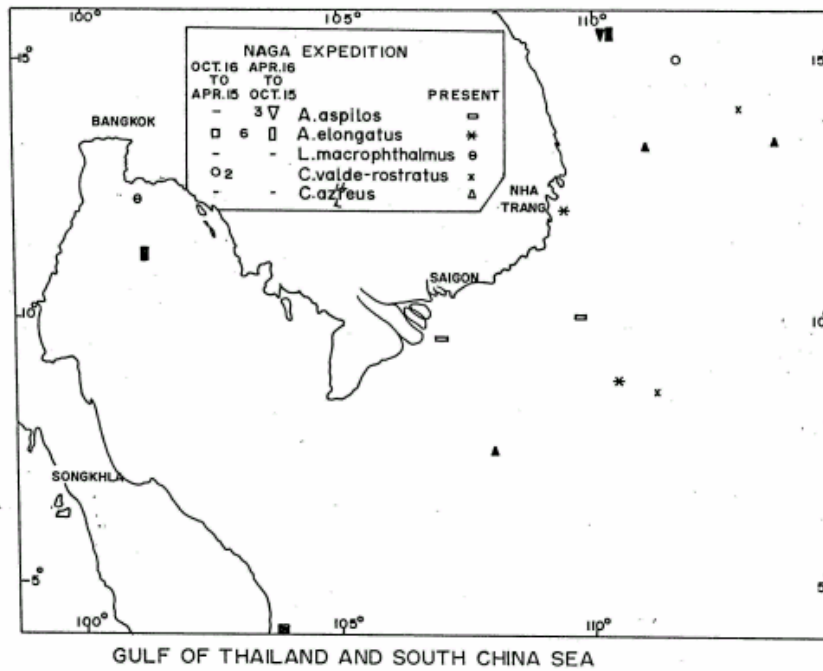


Fig. 68 B - Distribution of *Arnoglossus aspilos*, *A. elongatus*, *Leaops macrophthalmus*, *Crossorhombus valde-rostratus* and *C. azureus*.

*Crossorhombus azureus* :

The larvae of *C. azureus* also exhibit a wide range of distribution, but are mostly confined to the coastal waters of the Indian Ocean along the coast of South Africa, northern tip of Madagascar, east coast of Sri Lanka, east coast of India and south west coast of Australia (Fig. 68 A). They occur in the open ocean at times in depths ranging between 110 and 5504 m. Unlike *C. valde-rostratus*, *C. azureus* preferred night. They appear mostly in samples taken at night (7/13) from stations where the ambient salinity values ranged between 28.49 and 35.41 PSU. Nine out of 13 samples were taken during SW monsoon period, all containing only specimens of postflexion stage. The coefficient of correlation between plankton and postlarvae showed significant positive correlation ( $R = 0.7646$ ,  $P < 0.01$ ).

In the Naga Expedition samples, the larvae of this species was found in the collections from the open sea (Fig. 68 B). As in the case of *C. valde-rostratus* it was absent from the samples taken from the Gulf of Thailand. Confined to the months of March and May it appeared only in the collections during night at depths that ranged between 77 m and 5358 m. No preflexion and flexion stages were present and the few salinity values available ranged between 33.50 and 34.60 PSU. Adults occur along the coasts of south eastern India and Sri Lanka (Ceylon), Indo China, Aru Islands and China (Norman, 1934).

*Engyprosopon cocosensis* :

*Engyprosopon cocosensis* larvae were found in the collections taken from 3 stations off south west coast of India, one station each from off the east coast of India, west coast of Burma, south west and south east coasts of Sri Lanka, and south west coast of Madagascar (Fig. 69 A), with the maximum number from the west coast of Burma, where the depth of haul was only 50 m and sounding was 72 m. At other places the depth of haul varied from 100 to 200 m and the sounding ranged from 120 to 2791 m. They showed no preference for any season (NE or SW) and preferred the coastal seas. The post flexion stage appeared in large numbers in the samples taken during night in 7 out of 8 stations. The salinity ranged between 33.08 and 36.37 PSU, the minimum values being found along the south west coast of Burma and maximum along the west coast of India.

The coefficient of correlation between the number of larvae of *E. cocosensis* with the environmental parameters such as temperature, salinity, dissolved oxygen, phosphate phosphorus and nitrate nitrogen showed that the number of larvae had a negative correlation between salinity ( $R = -0.6781$ ,  $P < 0.05$ ) and phosphate phosphorus ( $R = -0.6675$ ,  $P < 0.05$ ), indicating that when values of these parameters increase, post larvae show a decreasing trend. It is reported that during NE monsoon period (November to January) the low salinity water from the Bay of Bengal passes along the west coast of India (Wyrki, 1973). The larvae of *E. cocosensis* was found during the months of March, July and August from the west coast of India, suggested that these larval forms are not recruited from the Bay of Bengal as the prevailing current in July is from north to south along the west coast. Their incidence at far off stations also suggests that distribution of adults is not continuous but isolated, each clone having their own breeding grounds. The fact that postlarvae were available in the months of March, July, August, October and December indicates protracted breeding of the species.

The larvae of *E. cocosensis* were found in the samples collected during the Naga Expedition from the Gulf of Thailand and the South China Sea. In the Gulf waters they were found only in samples collected from two stations (one in a vertical haul 1 m net and the other a horizontal haul 2 m net) (Fig. 69 B). But most of the larval collections came from the oblique hauls from 400 to surface from the South China Sea. They were also present in 1m vertical hauls but only at three stations. The stations from which larvae of *E. cocosensis* were collected were situated both in coastal and offshore waters up to 250 miles. These findings suggest that this species has an extensive distribution in the Gulf as well as in the ocean. All except a few larvae collected from four stations belonged to the postflexion stage. Preflexion stage was found only at one station and the flexion stage at four stations. The collections containing preflexion and flexion stages were taken during the months of May, June, September and October suggesting a protracted breeding. Sixteen out of 23 samples were taken with 2 m oblique hauls. The larvae were present in 20 out of 23 samples taken during night showing their preference to darkness. The salinity ranged between 31.86 and 34.69 PSU and the soundings varied from 33 to 4318 m, at the stations



from where the larvae were collected. The preflexion stage was contained in the samples from South China Sea far away from the shore, suggesting the adults are distributed both in the inshore as well as in the offshore waters as in the Indian Ocean. However, it appears that the larvae do not prefer the Gulf waters to the same extent as in the case of open ocean.

Adults are reported from the coast of Kerala, Burma, Nicobar and Cocos Islands (Norman, 1934).

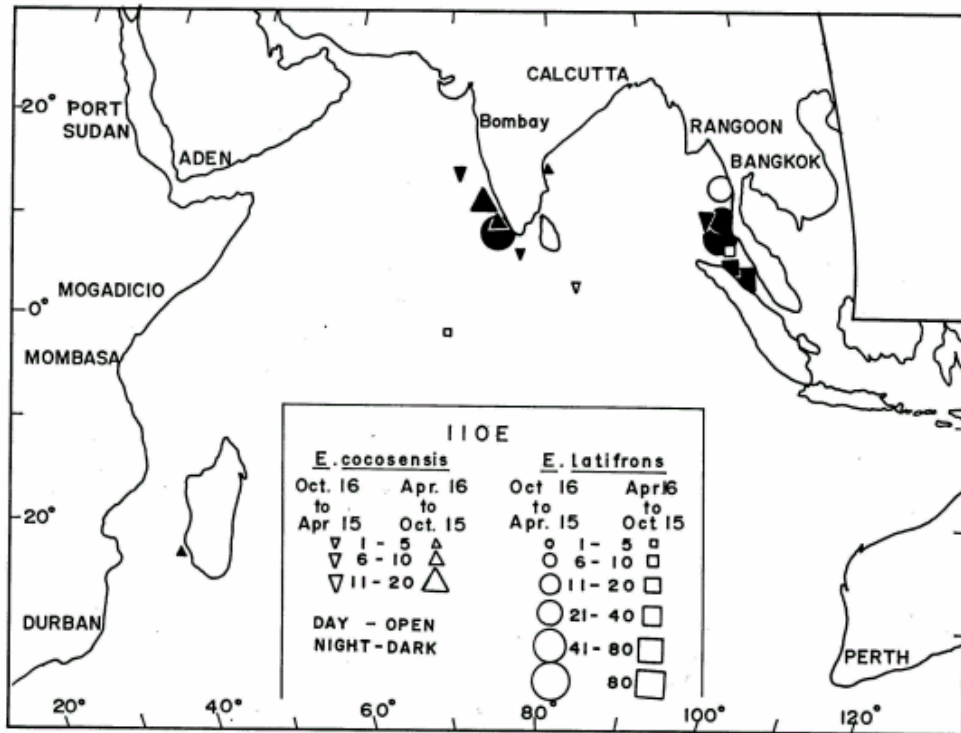


Fig. 69 A- Distribution of *Engyprosopon cocosensis* and *E. latifrons* in the Indian Ocean.

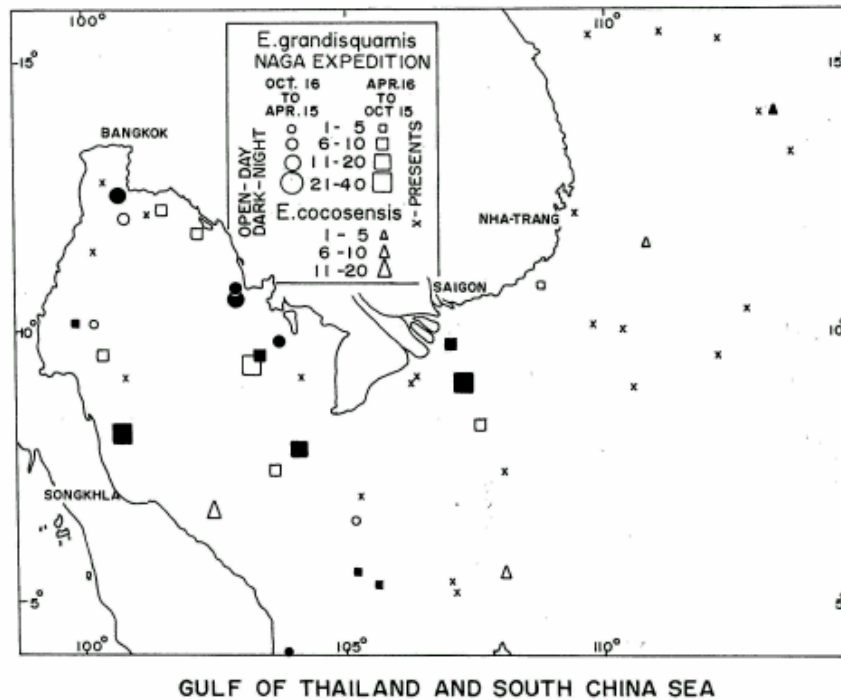


Fig. 69 B- Distribution of *Engyprosopon grandisquamis* and *E. cocosensis* in the Gulf of Thailand and South China Sea.

*Engyprosopon latifrons* :

The larvae of *E. latifrons* in the Indian Ocean were restricted to near shore stations with the exception of one station (Fig. 69 A). Most of the stations were in the Bay of Bengal along the west coast of Burma and Thailand and in the Straits of Malacca as well as along the east coast of Sumatra. Barring one station containing the larvae along the south west coast of India and another in the Central Indian Ocean, the larvae of this species were conspicuously absent from the Arabian Sea and remaining part of the Indian Ocean. All the collections except one contained only the preflexion stage and postflexion stage was totally absent. Five out of eight collections were taken during night and larvae were found equally in both NE and SW monsoon seasons. All except one station was near the shore where the depth varied from 45 to 90 m and the sounding from 50 to 90 m. The offshore station sounding was 3310 m where the plankton was taken from a depth of 200 – 0 m. The salinity ranged 32.27 and 35.37 PSU. The larvae were present in the samples taken during March, June, August, September and November. The flexion stages were contained in the sample

taken from the Strait of Malacca indicating extended breeding. *E. latifrons* does not indicate any significant correlation with hydrographical parameters studied.

The collections from the Gulf of Thailand and the South China Sea indicated that the larvae of *E. latifrons* were found in the samples mostly taken from the shallower regions, ranging in depth from 22 to 96 m. However, they were also found in the 400-0 oblique samples collected from stations where the soundings ranged from 2340m to 3292 m. The larvae were found in eight stations situated near to the eastern bank of the Gulf of Thailand and 13 stations in the South China Sea (Fig. 70 B). In the Gulf they were not represented in samples taken along the western bank. In 16 out of 21 stations the preflexion stage was found whereas flexion and postflexion stages were found only in seven stations, all the three stages being found only in two of the stations. The larvae were collected during the months of January, April, June, and August to October. In all these months the preflexion stage was available suggesting an extensive, protracted breeding. The salinity at the various stations from where the larvae were collected varied between 31.84 and 34.60 PSU and preference to darkness was evident since they appeared in 18 out of 21 samples taken at night.

Adults are reported from Indian Ocean (Norman, 1934).

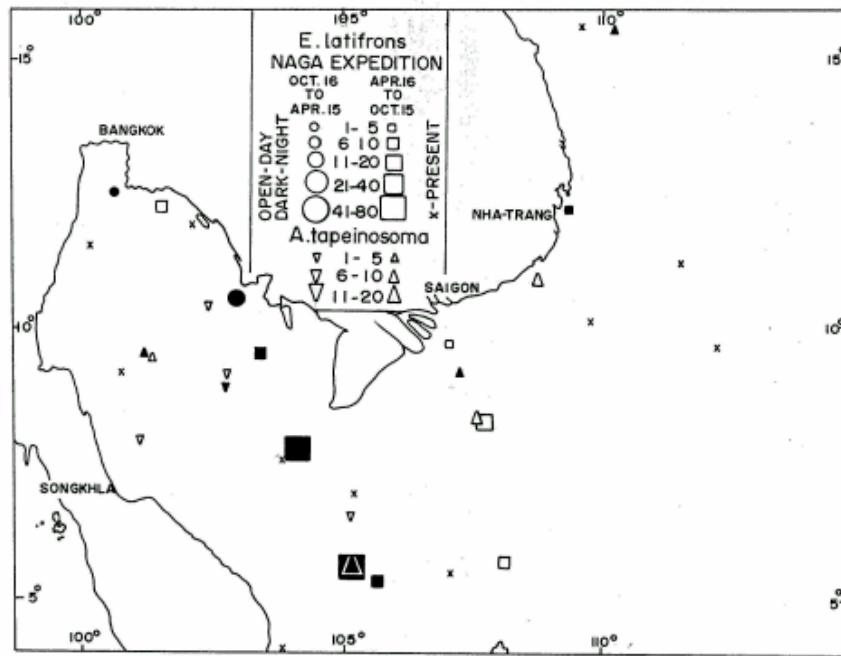


Fig. 70 B – Distribution of *Engyprosopon latifrons* and *Arnoglossus tapeinosoma* in Gulf of Thailand and South China Sea.

*Engyprosopon mogkii* :

The larvae of *E. mogkii* were rare in the Indian Ocean and in the samples from the Naga Expedition from the Gulf of Thailand and the South China Sea. In the Indian Ocean, post flexion stages were found at two stations out of the 1927 stations, one near the Andaman Sea during day and night having depth soundings and the other near the Gulf of Aden during night in 3840 and 3600 m respectively (Fig. 71 A). The salinity ranged between 33.78 and 36.12 PSU. In the samples from Naga Expedition also they were rare (Fig. 71 B) occurring only at three stations in the Gulf of Thailand towards its head and one at a station near the Sulu Sea, (east off South China Sea near the south western arm of Mindano Islands). The sounding at these stations ranged from 27 to 3300 m. While the preflexion and flexion stages were found in the Sulu Sea, in the Gulf of Thailand only the flexion and postflexion stages were present indicating that adults are likely to be confined to the vicinity of shore waters where spawning probably takes place. All the samples were taken at night during April and December. The salinity varied between 30.52 and 33.24 PSU. Adults recorded from the Indian Ocean; Malay Peninsula and archipelago (Norman, 1934).

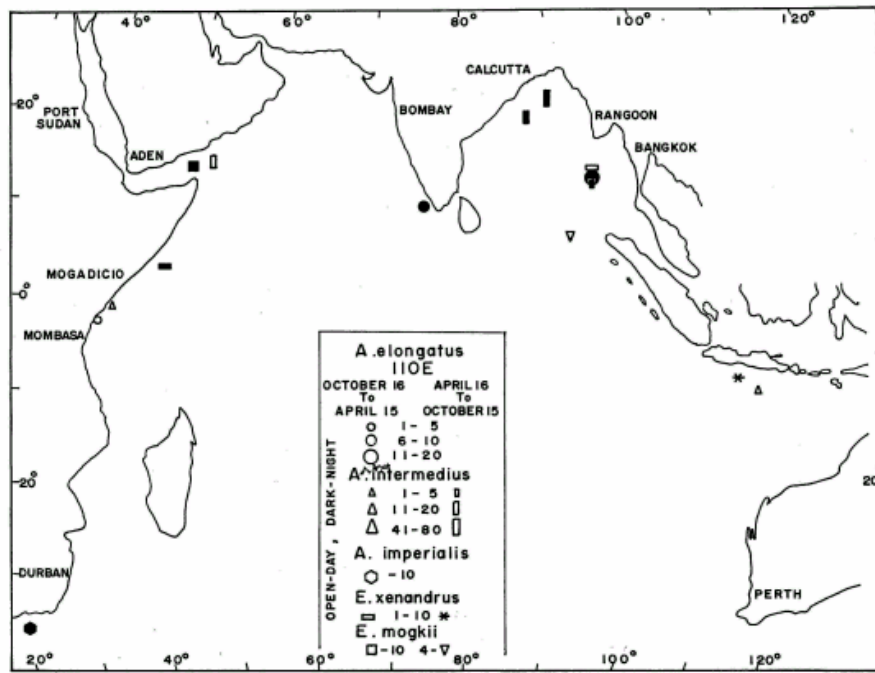


Fig. 71 A – Distribution of *Arnoglossus elongatus*, *A. imperialis*, *Engyprosopon xenandrus* and *E. mogkii* in the Indian Ocean.

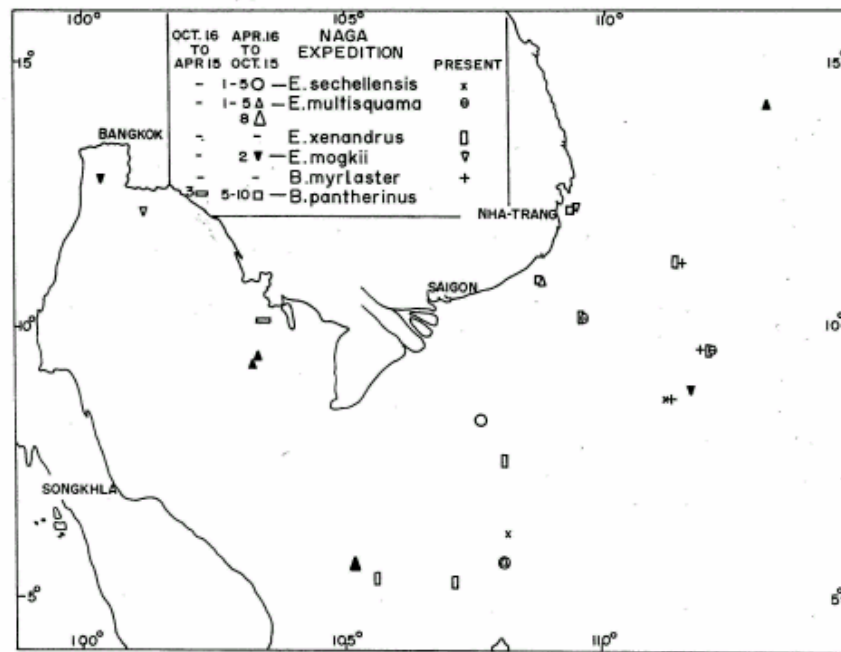


Fig. 71 B - Distribution of *Engyprosopon sechellensis*, *E. multisquama*, *E. mogkii*, *E. xenandrus*, *Bothus myriaster* and *B. pantherinus* in the Gulf of Thailand and South China Sea.

*Engyprosopon grandisquamis*

The larvae of *E. grandisquamis* dominate over other species in the Bay of Bengal. They also occur in the Arabian Sea along the Indian coast, and in the Gulf of Aden. A few were found at a station on the west coast of Australia and in the Malacca Strait (Fig. 72 A), in samples collected during night being present in 12 out of 20 stations. They were found more during the NE monsoon period than in the SW monsoon. Preflexion, flexion and postflexion stages were found in the collections from stations situated both in the nearshore and offshore regions. In the Indian Ocean, preflexion, flexion and postflexion stages were not found in the same place. The preflexion stage was collected at stations from the Malacca Strait, along the north west coast of Australia and the Gulf of Aden. The maximum and minimum salinity values ranged between 32.47 and 36.57 PSU, depth varied from 60 to 3111 m and nearly 50% of the samples were collected from shallow water ranging between 60-200 m.

The coefficient correlation between the number of larvae of *E. grandisquamis* and the environmental parameters such as salinity, temperature, dissolved oxygen, nitrates and phosphates showed highly significant negative correlation with nitrate nitrogen ( $R = -0.7422$ ,  $P < 0.001$ ) with salinity ( $R = -0.6358$ ,  $P < 0.01$ ) and with phosphate phosphorus ( $R = -0.4580$ ,  $P < 0.05$ ) indicating that the larvae prefer lower values.

In the Naga samples also all the three larval stages of *E. grandisquamis* were dominant and found in the samples from both the Gulf region and near the mouth of the Gulf (Fig. 69 B). In the South China Sea, the frequency of the distribution was much less than in the Gulf region. Twenty five out of 36 samples were taken during night. Most of them containing preflexion and flexion stages, 23/36 samples were taken during the period April 16 to October 15. The salinity of these stations varied between 30.52 and 34.66 PSU in the Gulf waters and 32.98 and 34.50 PSU in the South China Sea, the soundings ranged between 22 and 2880 m, all samples except one were taken from depths varying between 22 and 75m.

Adults are found along east Africa, through the Indian Ocean and Archipelago to Australia and Japan (Norman, 1934), in shallow water at a depth

around 20 m from southern Japan (Matsubara, 1979 ; Ochiai, 1981, Amaoka, 1984).

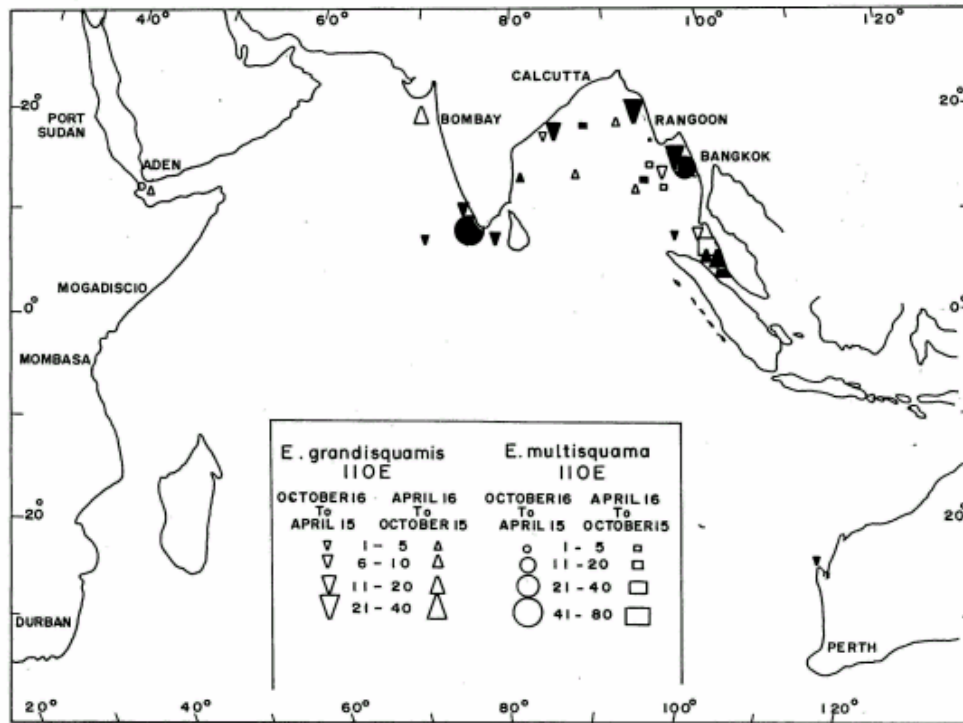


Fig. 72 – Distribution of *Engyprosopon grandisquamis* and *E. multisquama* in the Indian Ocean.

### *Engyprosopon sechellensis*

The larvae of *E. sechellensis* though few in number appeared to be more oceanic than other species, found in stations widely separated from each other in north and south of equator (Fig. 73). They occur also near the shore along the coasts of India, Sri Lanka, Burma (near Cape Negrais region into which river Irravaddy is discharging its contents) and near Sumatra. They appeared in night samples (6/7) in the plankton during the NE monsoon and rarely during SW monsoon period (2/7). The preflexion stage alone occurred at one station near Cape Negrais, at other stations only the postflexion stage was represented. The soundings ranged between 50 and 5200 m.

The larvae, showed negative correlation with dissolved oxygen ( $R = -0.7944$ ,  $P < 0.05$ ), but highly significant positive correlation with nitrate nitrogen ( $R = 1.000$ ,  $P < 0.001$ ). Even though the salinity values ranged between 32.39 and 33.85 PSU at stations where the preflexion stage was

found, these values were minimum when compared to the salinity values at other stations, the maximum value being 36.04 PSU.

The samples revealed that the larvae of *E. sechellensis* were restricted to the South China Sea (Fig. 71 B), the Gulf region being totally devoid of them. Even in the South China Sea they appeared only in two vertical hauls and four oblique hauls. The number of larvae was also few as in the Indian Ocean. Preflexion and flexion stages were absent in the Naga samples and most of the collections were taken at night. The salinity ranged between 33.05 and 34.19 PSU, the larvae were found in stations of shallow water during January, March, June and September and the depth varied between 58 and 2261 m.

Adults are found to occur along the coast of Seychelles (Norman, 1934).

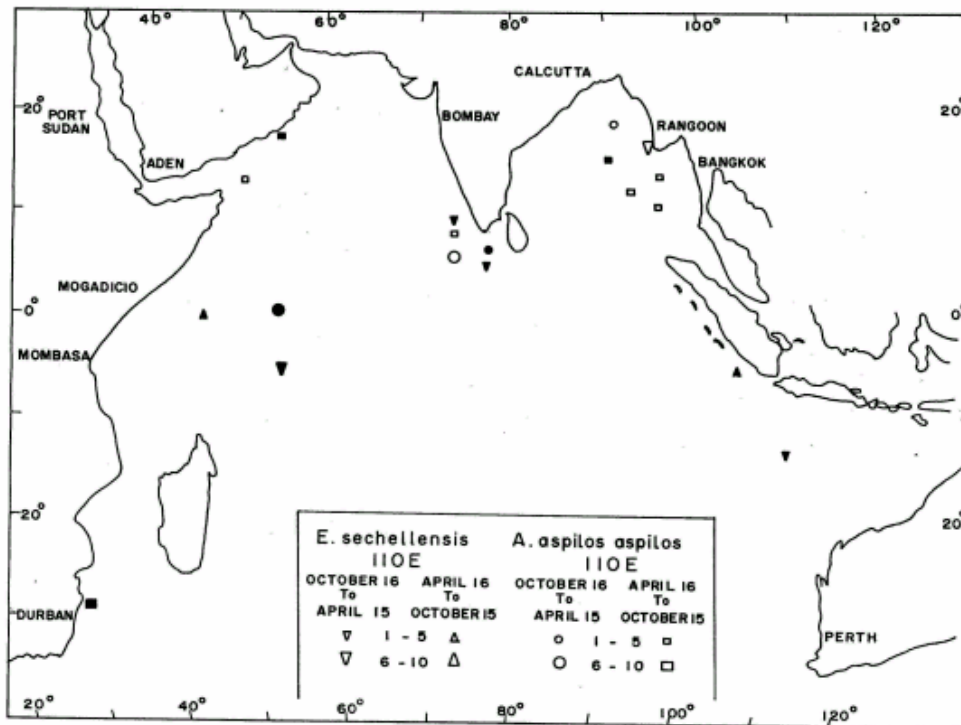


Fig. 73 – Distribution of *Engyprosopon sechellensis* and *Arnoglossus aspilos* in the Indian Ocean.

*Engyprosopon multisquama* :

The larvae of *E. multisquama* showed wide distribution in the east-west direction. Majority of the stations containing these larval forms were situated near the coastal zone mostly in the northern Indian Ocean (Fig. 72 A). Preflexion



and postflexion stages were found in the samples, but in the Indian Ocean, wherever preflexion stage occurred, postflexion stage was absent. No difference was discernible between the day and night samples. More larvae were found in the SW monsoon samples than during the NE monsoon. Larvae of *E. multisquama* were noticed in collections taken near the east coast (Burma and Thailand) from the Bay of Bengal. They were seen more towards Cape Negrais whereas larvae of *E. latifrons* were concentrated towards the south near about the Thailand coast. Samples from the Strait of Malacca, off the coast of Orissa in the Bay of Bengal, south west coast of India and the Gulf of Aden also contain these larvae. The depth varied from 50 to 2297 m. The preflexion stages dominated in the samples at stations located in the Strait of Malacca, off Cape Negrais, south west coast of India and the Gulf of Aden. Postflexion appeared only in the collections from two stations, one near the shore, south off Negrais and the other offshore at a station off Orissa coast. Unlike *E. sechellensis*, the larvae of *E. multisquama* showed significant positive correlation with dissolved oxygen ( $R = 0.7343$ ,  $P < 0.05$ ). The salinity varied from 31.05 to 39.50 PSU at station from where preflexion stages were collected. In the Indian Ocean, preflexion and postflexion stages of *E. multisquama* did not occur simultaneously. Even in the Naga samples they were found in the same haul only once. In the Indian Ocean, preflexion stage was found during August, September, November and December whereas in the Naga samples it was mostly found in April and June and once at a station in September. The minimum range of salinity was same in both Indian Ocean, Gulf of Thailand and South China Sea from where larvae of *E. multisquama* were collected except in the Gulf of Aden where the salinity was unusually high and ranged between 36.58 and 39.59 PSU. In the Gulf of Thailand and South China Sea the larvae were widely distributed (Fig. 71 B) with a preponderance in the night collections (6/8). No larvae were found during October 16 to April 15. The depth ranged from 36 to 40 m in the Gulf of Thailand and 46 to 3549 m in the South China Sea.

The adults live in shallow waters at a depth of around 30 m of the Japanese waters South of Choshi on the Pacific Coast and Yamagata Pref. on the Japan Sea Coast (Amaoka, 1984).

Engyprosopon xenandrus :

Larvae of *E. xenandrus* were found along the Somali coast, Gulf of Aden, Burma coast and Java coast (Fig. 71 A). Of the four stations, preflexion stage was found in two. May and August and postflexion stage in May, September and December. Out of the four samples, three were collected during day time. The larvae dominated in the samples collected mostly from coastal waters. The depth of stations ranged from 245 to 4806 m, the salinity ranged between 32.36 and 35.22 PSU except at a station in the Gulf of Aden where it varied between 36.58 and 39.59 PSU. Highly significant positive correlation was noticed with nitrate nitrogen ( $R = 1.000$ ,  $P < 0.001$ ) and significant positive correlation with phosphate phosphorus ( $R = 0.9713$ ,  $P < 0.05$ ).

In the Naga Expedition samples, the larvae were found in 7 station, all situated in the South China Sea far away from the shore unlike those found in the Indian Ocean (Fig. 71 B). Preflexion and flexion stages were absent, the larvae occurring in the samples taken during night, whereas in the Indian Ocean they were mostly found in day collections. The larvae of this species were confined to the samples taken with 2 m oblique hauls, during the months of March, May, June and September. The salinity varied from 33.05 to 34.59 PSU, and the depth from 60 to 5292 m.

Adults occur in rather deep waters of the Hawaii Islands (Norman, 1934).

Bothus myriaster :

The larvae of *B. myriaster* were found in the coastal waters of Madagascar, Somali coast, and Arabia and off the coast of Somalia, India, Burma and Sumatra (Indonesia) (Fig. 74). Maximum number was recorded along the coast of Arabia and off the coast of Burma. Only the postflexion stage was found in the collections. Of the eight samples, five were collected during the SW monsoon period and larvae dominated in the collections taken during night. The depth of the stations ranged between 196 and 4738 m minimum and the maximum values for salinity were 32.25 and 36.23 PSU. A significant positive correlation were evident between larvae and nitrate nitrogen ( $R = 0.8994$ ,  $P < 0.01$ ).

In the Naga samples, these larvae were present only in night samples from the South China Sea during March, June and September. All the stations were situated far away from the coast (Fig. 71 B). Preflexion, flexion and postflexion stages were present during March, June and September in one of the stations. All the samples containing the larvae were taken during night. The preflexion and flexion stages were found only in September. The depth of the stations ranged between 196 and 4938 m, and the salinity values varied between 33.14 and 34.69 PSU.

Adults are reported from the Indo-China, coast of China, Japan and Formosa (Norman, 1934) and on the shallow sandy bottom at a depth of around 30 m in the Indo-west Pacific region (Amaoka, 1964, 1984 ; Matsubara, 1979 ; Ochai, 1981).

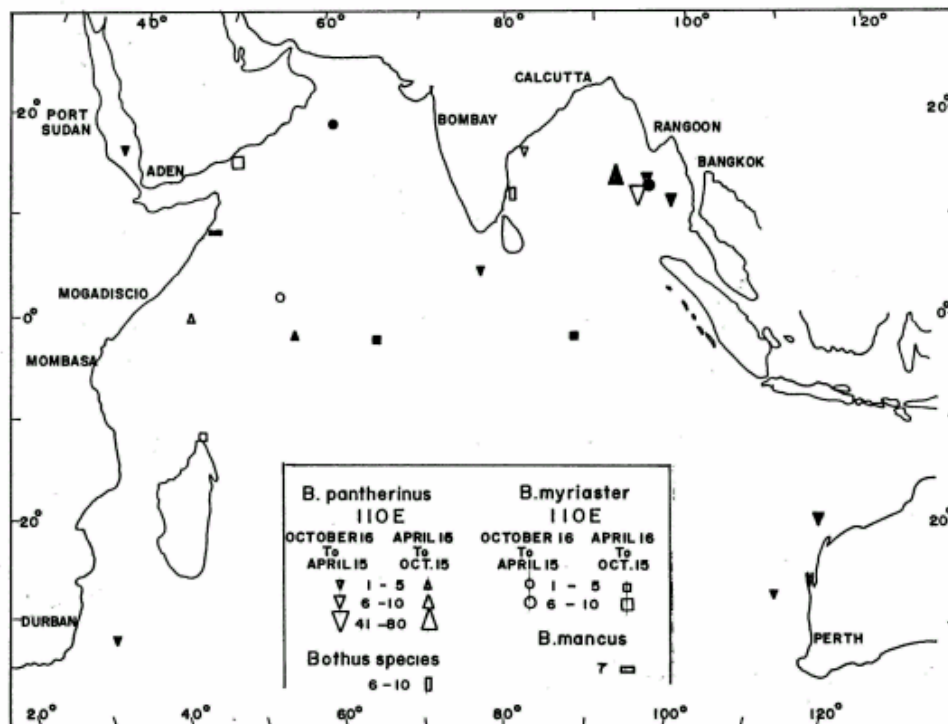


Fig. 74 – Distribution of *Bothus myriaster*, *B. pantherinus*, *B. mancus* and *Bothus* sp. in the Indian Ocean.

*Bothus mancus* :

Seven larvae belonging to the postflexion stage were noticed in the plankton from the Somalia coast during August (Fig. 74). They were not found in

the Naga samples. The station sounding was 96 m and the salinity was around 35 PSU.

Adults occur in the Indian Ocean, through the Malay Peninsula and Archipelago to the Pacific west coast of Mexico (Norman, 1934) tide pools of coral reefs in the tropical and subtropical waters of the Indo-west Pacific region inclusive of southern Japan and Bonin Island (Zama and Fujita, 1977 ; Matsubara, 1979 ; Ochiai, 1981, Amaoka, 1984).

*Bothus pantherinus* :

The larvae of *B. pantherinus* were found distributed extensively both in the coastal and oceanic waters of the Indian Ocean. They were present in the samples taken at stations widely separated from each other, namely off the coast of South Africa, Somali coast, Red Sea, south of peninsular India, both the coasts of the Bay of Bengal and along the north west coast of Australia (Fig. 74). In the Bay of Bengal they were found in more than one station. The number of larvae collected were also maximum from the Bay of Bengal. The depth ranged between 100 and 5658 m. Preflexion and flexion stages were not found in any of the samples. The collections included a few metamorphosed stages at a station south off Peninsular India during December where the depth was 3000 m. The larvae were found in 12 samples of which were taken during the NE monsoon period. The salinity ranged between 32.25 and 35.82 PSU. Significant negative correlation is evident with salinity ( $R = -0.9269$ ,  $P < 0.001$ ), nitrate nitrogen ( $R = -0.8932$ ,  $P < 0.001$ ) and phosphate phosphorus ( $R = -0.5692$ ,  $P < 0.05$ ).

In the Naga samples, the larvae were found in the samples from both inshore and offshore waters, as in the Indian Ocean (Fig.71 B). The depth of stations ranged between 31 and 2250 m, the larval forms included preflexion, and postflexion stages. Metamorphosed stages were also present in the collections taken from the Gulf of Thailand where the depth was only 31 m in the month of February. The larvae were found during January, February, March, June, September in the collections taken mostly during night. The salinity ranged between 33.14 and 34.69 PSU.

Adults are recorded from East Africa and the Red Sea, through the Indian Ocean and Archipelago, to Australia and the Pacific (Norman, 1934), live in the tide pools of coral reefs in the Indo-west Pacific region inclusive of southern Japan (Amaoka, 1984).

*Bothus* sp.

Postlarval stages were found in the collections taken during June from the Bay of Bengal (Fig. 74). The salinity was about 34PSU and the sounding was 183 m. These larvae were not found in the Naga samples.

*Psettina brevirectis* :

Larvae of *P. brevirectis* were totally absent in the Indian Ocean, but in the Naga samples they were present in large numbers. However, these larval stages were confined to the Gulf of Thailand and were conspicuously absent in the samples from the South China Sea (Fig. 75). Even in the Gulf of Thailand they were found concentrated in samples taken from the upper northern and middle portions of the Gulf, but were rarely found in the collections taken towards the southern portion. Confined to night samples (35/47), the larvae appeared almost all the year round except in February, July and October. Larvae belonging to preflexion, flexion, postflexion and metamorphosed stages were available, the preflexion stages being found in all the collections except in September, suggesting protracted breeding of the species. All stages were observed in the same collections taken from certain stations. The salinity ranged between 29.44 and 34.04 PSU, and the depth varied from 18 – 73 m.

Adults are reported from south-eastern India ; *Celebes* in rather deep water (Norman, 1934).

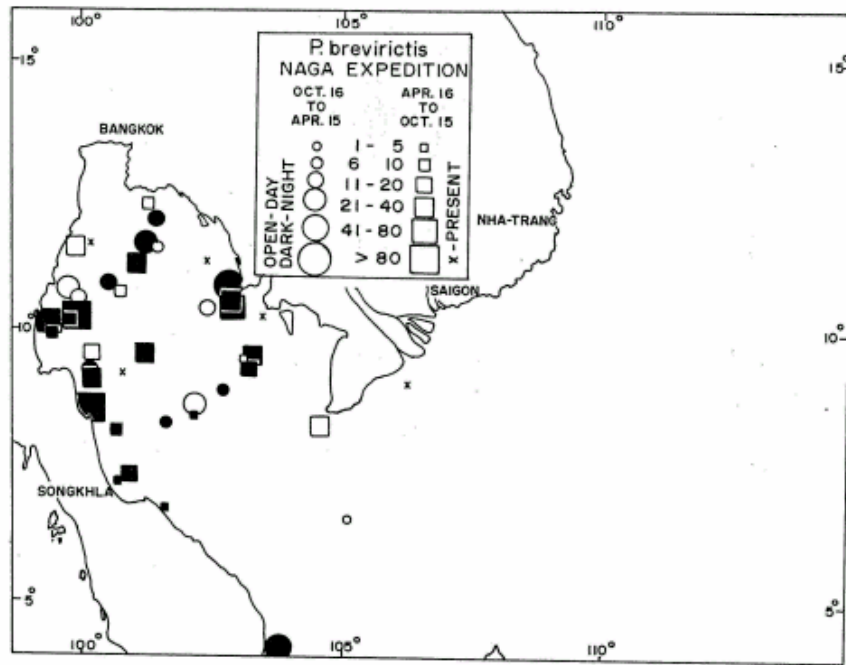


Fig. 75 - Distribution of *Psetina brevirectis* in the Gulf of Thailand and South China Sea.

*Psetina ijimae* :

Larvae of *P. ijimae* were rare in the International Indian Ocean Expedition samples, except in two stations, one in the Strait of Malacca and the other near the north east coast of Sumatra (Indonesia) they were not found in any other stations (Fig. 76 A). The salinity of these stations ranged between 32.40 and 35.03 PSU, and the sounding 60 and 2000 m. Only postflexion stages were found in the collections of September and November.

In the Naga Expedition samples, they were found in the collections taken from the length and breadth of the Gulf of Thailand (Fig. 76 B), occurring more frequently in stations near the shore. Preflexion to metamorphosed stages were present. The larvae of *P. ijimae* were also found in the South China Sea, but not far away from the Gulf region. The larvae dominated in the collections taken during night (37/55). Another peculiarity was that the larvae of this species were found almost throughout the year except in May and July, preflexion stages were found in January, April, June, August, September, October and November suggesting protracted breeding as in the case of *P. brevirectis*. All stages were found in the same collection taken from certain stations. The salinity ranged between 30.23 and 34.50 PSU The depth of stations varied from 18 to 67 m.

Even though the larvae of both *P. brevirictis* and *P. ijimae* were contained in the same sample, the larvae of the former appears to be more salinity tolerant than the latter.

Adults are recorded from southern Japan in rather deep waters (Norman, 1934), around 100 m in the western Pacific (Amaoka, 1984).

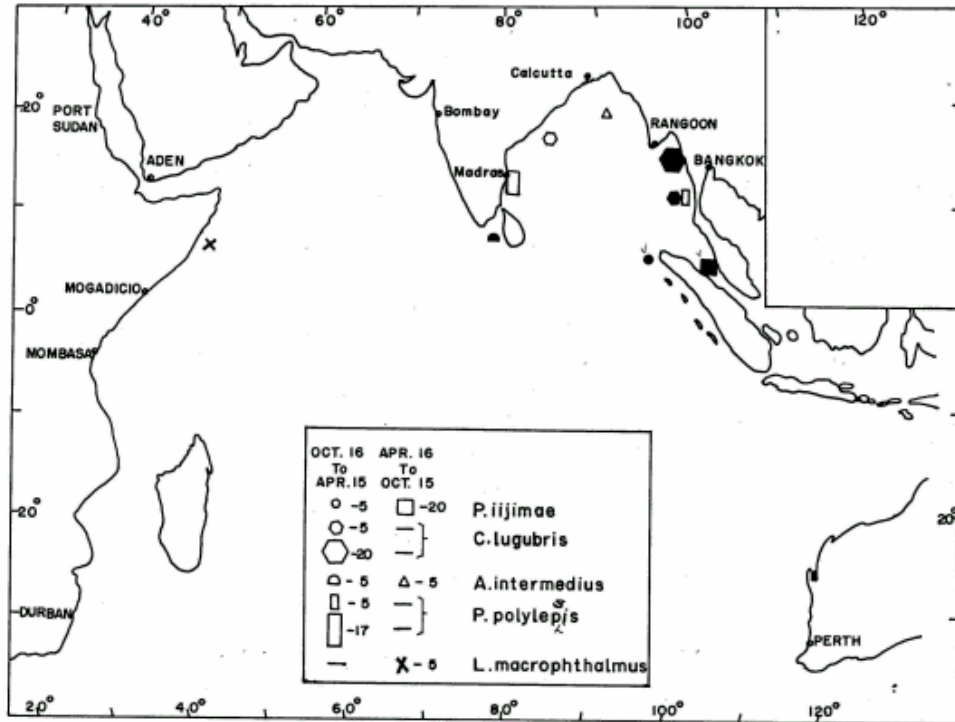
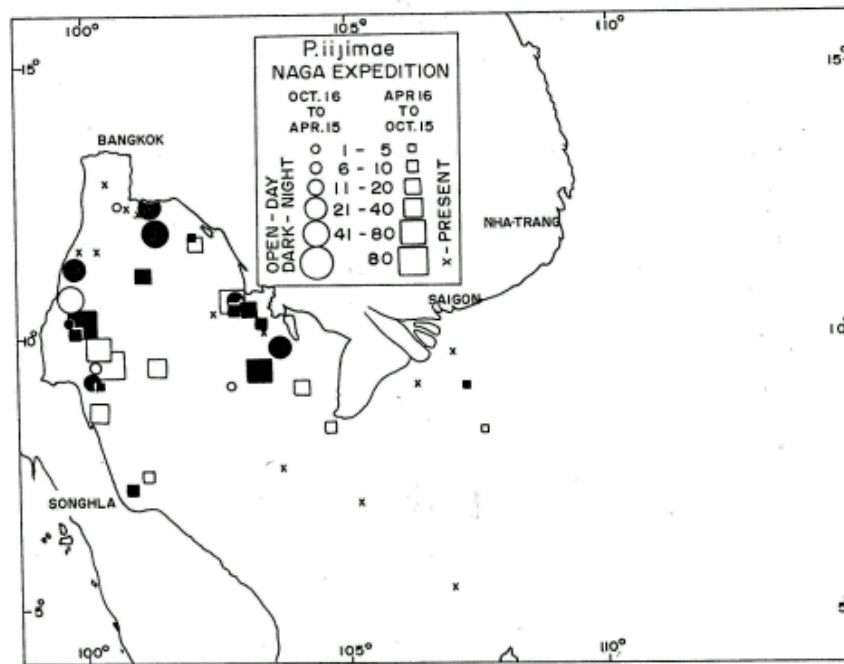


Fig. 76 A – Distribution of *Psettina ijimae*, *Chascanopsetta lugubris*, *Asterorhombus intermedius*, *Parabothus polylepis* and *Laeops macrophthalmus* in the Indian Ocean.



GULF OF THAILAND AND SOUTH CHINA SEA

Fig. 76 B- Distribution of *Psettina iijimae* in the Gulf of Thailand and South China Sea.

*Arnoglossus tapeinosoma* :

The larvae of *A. tapeinosoma* have a wider distribution than all the other species of flat fish larvae so far studied, being found both in the coastal and offshore waters as well as in the southern and northern latitudes occurring in stations located south east off South Africa, east of Somali coast, Persian Gulf, Arabian coast, south of peninsular India, along the east coast of India, off the coast of Burma, Thailand, in the Malacca Strait and along the west coast of Australia (Fig. 70 A). They were conspicuously absent along the west coast of India. Preflexion, flexion and postflexion stages were present in the plankton samples. But most of them belonged to the preflexion stage. The postflexion stage was found only at two stations and the flexion stage at one, both in the Bay of Bengal near Madras coast. Of the 31 samples, 20 were taken during night and larvae were found both in the SW monsoon and the NE monsoon periods. Preflexion stage was found in all months except in May, November and December. The depth of the stations varied from 50 to 5000 m. and salinity ranged between 29.50 and 36.01 PSU. Larvae showed significant positive correlation with temperature ( $R = 0.4266$ ,  $P < 0.05$ ), but highly significant negative correlation was noticeable with salinity ( $R = -0.7059$ ,  $P < 0.001$ ),



phosphate phosphorus ( $R = -0.7164$ ,  $P < 0.001$ ) and nitrate nitrogen ( $R = -0.6405$ ,  $P < 0.001$ ).

In the Naga samples the larvae occurred in samples taken from the Gulf of Thailand and the South China Sea (Fig. 70 B). In the south China Sea, preflexion and postflexion stages were present in stations not far away from the shore. Of the 24 samples 17 were taken at night, larvae being found in all months except in February, July and December, suggesting protracted breeding. The depth of the stations ranged between 22 and 622 m; and the salinity minimum was 29.44 PSU and maximum 34.69 PSU.

Adults are reported from the Persian Gulf to the Malay Peninsula and Archipelago and beyond (Norman, 1934).

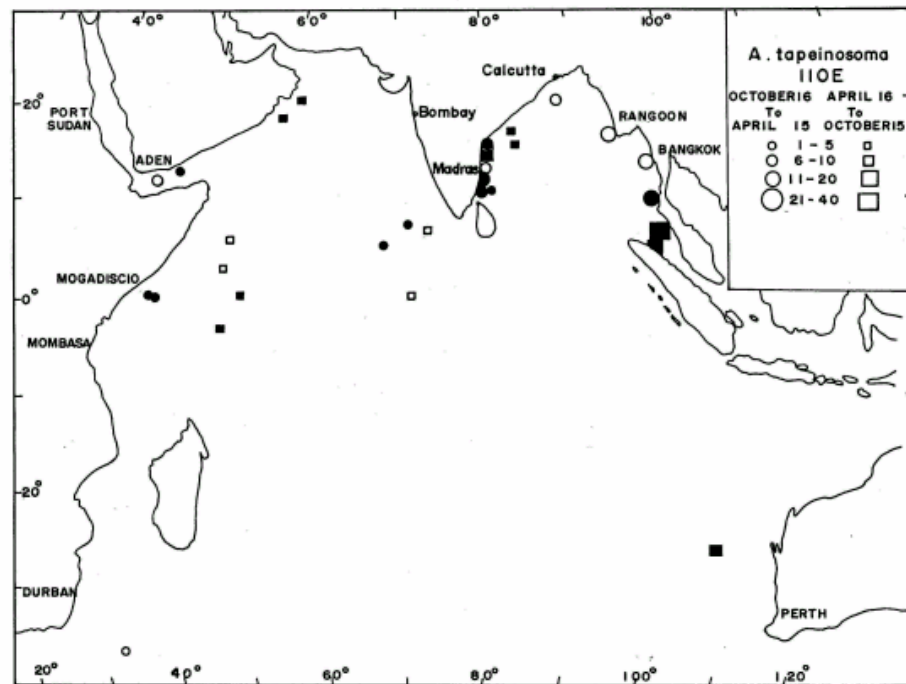


Fig. 70A – Distribution of *Arnoglossus tapeinosoma* in the Indian Ocean.

### *Arnoglossus aspilos*

In the Indian Ocean, the larvae of *A. aspilos* were confined to plankton collected off the coast of Burma, southern tip of Indian peninsula, east coast of South Africa and off Somali coast (Fig. 73). The depth of the station ranged

between 1409 and 4733 m suggesting that the adults of this species lived in deep waters widely separated from each other. The presence of preflexion stages in nine out of 11 stations suggested that they preferred day light. It is not likely that the preflexion stage is not transported through current system from a common breeding ground. The presence of both preflexion and flexion stages at the same station in the same collection also suggests that they are not transported from far off places but from almost the same locality. The postflexion stage was available only in three samples. SW monsoon period appears to favour the spawning of this species. More data are required to confirm the above inferences. The salinity at different stations varied between 32.05 and 35.97 PSU. A significant positive correlation existed with dissolved oxygen ( $R = 0.6753$ ,  $P < 0.05$ ).

In the Naga samples, the larvae of this species were found only at three stations, all situated in the South China Sea (Fig. 68 B). The depth of the stations varied from 22 to 495 m and salinity ranged between 32.98 and 34.58 PSU. Preflexion, flexion and postflexion stages were found ; all were collected during night and in the months of May, June and September (Norman, 1934).

Adults occur in Malay Peninsula and Archipelago.

*Arnoglossus elongatus* :

In the Indian Ocean the larvae of this species were noticed in the plankton taken from 3 stations, one located near Mombassa, one near south west coast of India and the third near Andaman Nicobar Island (Fig. 71 A). Preflexion stage was found in stations except the one along the south west coast of India where only postflexion stages were available. Two of the samples were taken during night, one near the Mombassa coast was taken during day. The larvae were found in the months of March, April and November, the post flexion stages being confined to April. The salinity values ranged between 32.1 and 36.03 PSU, the maximum value was recorded from the south west coast of India, the preflexion stages were noticed in stations where it varied from 32.1 to 35.27 PSU. The depth of the stations ranged from 70 to 4714 m.

In the Naga samples the larvae were contained in the samples taken from the South China Sea and the Gulf of Thailand (Fig. 68 B). Out of the six stations, three were near the shore. Preflexion, flexion and postflexion stages were found in the collections, but all the three were not present in the same sample. Preflexion stage was found only in the Gulf of Thailand and flexion stages from a station in the South China Sea where the sounding was 4590 m. The larvae were found only in the collections taken during night. They were seen in March, May, June and August, the preflexion stage being confined to March and August in areas where the salinity ranged from 32.65 to 32.71 PSU. The salinity of the sampling stations ranged between 32.65 and 34.65 PSU and the depth varied from 46 to 4248 m.

Adults are recorded from Madura Sea, Indo-Australian Archipelago, in deep water (Norman, 1934).

*Arnoglossus intermedius* :

In the Indian Ocean, the preflexion stage of *A. intermedius* was recorded in samples taken from six stations which were separated widely from each other, namely, the Somali coast, Persian Gulf, Bay of Bengal and near Sumatra (Indonesia) (Fig. 71 A). These samples were taken during January 1963, 1965, April 1964, 1965, May 1964 and June 1963. There was no difference between the day and night collections. The depth of the stations ranged from 659 to 5500 m. The minimum salinity recorded at these stations was 32.56 PSU and maximum 36.28 PSU. The larvae of this species were not found in the plankton samples taken from the Gulf of Thailand and the South China Sea.

Adults are reported from Indian Ocean and Archipelago to Australia and the Solomon Islands (Norman, 1934).

*Arnoglossus imperialis*

The larvae were found only from 'Africana' samples and one sample of Natal, restricted to a narrow strip in the Agulhas Bank and also a few samples off the shelf region (Fig. 71 A). The whole area of the cruise is north of the subtropical convergence and mostly north of the warm waters of the Agulhas current that flows in a southwesterly direction. The samples were taken during

January 1963, February 1964, March 1965 and April 1965. The collections were found between 0530 to 1438 hrs. The maximum number of 29 larvae/1000 m<sup>3</sup> was found in the near shore station. The temperature ranged between 12-20°C, the salinity was around 35 PSU and oxygen value ranged between 4.6 to 5.4 ml/l.

Adults are found along the Atlantic coast of Europe and Africa from northern Scotland to Angola; western part of the Mediterranean but not from the Indian Ocean (Norman, 1934).

*Parabothus polylepis*

Postflexion stages were collected from the Bay of Bengal near the coast of Madras in April and at a station diametrically opposite along the Burma coast in March (Fig. 76 A). In both cases the larvae were found only in the day collections, at depths which varied from 84 to 96 m and the salinity between 33 and 34 PSU.

Adults are found to occur off Ceylon (Norman, 1934).

*Asterorhombus intermedius*

Postflexion stages occur in the plankton samples of April from the west coast off Sri Lanka and south east off Calcutta (Fig. 76 A). They were found both during day and night collections, at depths which varied from 1757 to 1922 m and the salinity from 33 to 36 PSU.

Adults are reported from Japanese waters (Amaoka, 1969).

*Laeops macrophthalmus*

The larvae of this species were found in the collections from the Indian Ocean and the Gulf of Thailand. Preflexion stage occurs in the Indian Ocean (Fig. 76 A), east of Somalia coast in the month of August where the depth was around 4980 m and the salinity nearly 35 PSU. The specimens from the Gulf of Thailand belonged to the postflexion stage taken from waters at a depth of 30 m near the head of the Gulf (Fig. 68 B) at night in the month of March.

Adults are reported from the Gulf of Oman through the Indian Ocean to Burma in deep water (Norman, 1934).

*Chascanopsetta lugubris*

The larvae were collected only from the Indian Ocean from the Bay of Bengal off the coast of Orissa and along the coast of Burma (Fig. 76 A) taken during April and March respectively. They were found both during day and night, the depth of the station varied from 380 to 2779 m and the salinity ranged between 33 and 35 PSU.

Adults are recorded from off south east Africa, Gulf of M, Bay of Bengal, Japan in deep water (Norman, 1934), in the Indo-west Pacific inclusive of southern Japan (Amaoka, 1984).

### **6.3 Occurrence and abundance at species level (Biodiversity)**

Generally the abundance of a species in an ecosystem is an indication of its success in the community structure. Some forms though relatively less in number contribute much to the food of man and hence becomes a significant factor. Fish larvae contributing only a very small percentage of the total plankton has thus become an important group as they relate to the fishery resources of a particular region or season. In spite of the fact that flat fishes comprise only a very small fraction among fishes and their larval forms become very insignificant when the total biomass of the plankton is considered, they deserve special consideration as they occupy two ecological niches benthic and planktonic.

The larvae of bothids collected during the IIOE and Naga Expedition were from 146 out 1927 and 135 out 1136 stations respectively. The numerical abundance varied from 0 - 320 per collection. Even through about 70 species of adult bothids are recorded from the Indo-Pacific region, only 23 species belonging to 9 genera were present in the Indian Ocean and 15 species coming under 5 genera from the Gulf of Thailand and South China Sea making a total of 24 species.

The distribution of 24 species of bothid larvae are given in Table 26. Distribution maps include the total number of bothid larvae from IIOE during

1960-65 as well as from Naga Expedition during 1959-61 from Gulf of Thailand and South China Sea.

In the Indian Ocean the most abundant group of bothid larvae was that of *Engyprosopon grandisquamis* contributing 23.2 per cent of the total for IIOE. But in the Gulf of Thailand and South China Sea, the maximum number was contributed by *Psettina brevirictis* which formed 43.04 per cent of the total. In the Indian Ocean this species was not even represented by a single larva. *Crossorhombus valde-rostratus*, *Arnoglossus tapeinosoma* and *Engyprosopon latifrons* occurred next in abundance to *E. grandisquama*, contributing to 14.8, 12.8 and 11.94 per cent respectively. *E. cocosensis*, *E. multisquama* and *Bothus pantherinus* contributed only 8.5, 7.28 and 6.47 per cent respectively leaving five still less abundant species such as *Arnoglossus intermedius*, *Crossorhombus azureus*, *Arnoglossus aspilos*, *E. sechellensis* and *Bothus ovalis* together contributing 17.24 per cent of the total number of larvae. The other 11 species account for 9.4 per cent indicating their sparse occurrence.

In the Gulf of Thailand and South China Sea larvae of *Psettina iijimae* contribute 33.39 per cent. The larvae of *E. grandisquamis* which showed maximum abundance in the Indian Ocean was reduced to 8.9 per cent the third rank in the order of abundance followed by *E. latifrons* (7.1 per cent). The remaining 12 species together contributed only 7.6 per cent.

The Bay of Bengal appears to be favourable for the growth and distribution of Bothid larvae because 20 out of 22 species found in the Indian Ocean are represented in the Bay. Numerically also the larvae were maximum in the Bay of Bengal when compared with other regions of the Indian Ocean. 69.3 per cent of the Bothid larvae were contained in the plankton taken from the Bay of Bengal. In the Arabian Sea even though there were 18 species, the number was considerably low being only 23.1 per cent. The south West and South East Indian Ocean regions had eight species differing species composition each making only 7.5 per cent of the bothid larval collections. This low number could be due to the

inadequate sampling of the area or because the larvae of bothids are rare in oceanic region.

The Naga Expedition samples showed that the number of species was less in the Gulf of Thailand (11 Species) than in the South China Sea (16 species). Numerically, the Gulf waters had 84.5 per cent but only 15.5 per cent in the South China Sea. This unevenness might be due to the inadequate sampling or the preference of the species to neritic waters as is seen in the case of the Southern Indian Ocean.

The volume of water filtered during the collection of samples is an important factor that determines the true representation of the species of the stratum sampled. McGowan (1971) has shown that for collecting fish larvae the amount of water to be filtered in order to include all species was in excess of 10000m<sup>3</sup>. But only 200 m<sup>3</sup> of water was filtered from the majority of stations during IIOE and mostly less than 1000m<sup>3</sup>, during Naga Expedition. Hence, due allowances have to be given for the said factors.

Variation in the number of fish larvae in some of the collections might be due to the patchiness or predation or both. The uneven distribution of larvae could also be due to the tendency of adult fishes releasing clumps of eggs as well as choice of food for larvae after hatching. Factors determining the composition of species may be directly caused by predation patterns of the different trophic levels in the plankton. Lebour (1923) showed that as chaetognaths preyed upon fish larvae, their vertical distribution overlapped with that of fish larvae.

Cushing (1966, 1967) has stated that coincidence of food supply with larval distribution is important and probably critical for their survival. The role of hydrographic parameters in the distribution of fish larvae cannot be ignored.

#### **6.4 Seasonal variation :**

The Indian Ocean is characterised by its peculiar seasonal variation, particularly in its northern hemisphere. This has a bearing on the abundance and distribution of zooplankton biomass. The seasons identified are the SW

Monsoon (April 16 to October 15) and the NE Monsoon (October 16 to April 15), which exert their influence at least up to 10°S. In order to study the effect of seasonal variation in the distribution and abundance of bothid larvae, the zooplankton collected during different years of the expedition were pooled together and examined (Fig. 66).

The total number of bothid larvae contained in the zooplankton samples collected from the Indian Ocean was only 1977. Of this 1032 (52.2%) were collected from 72 stations during October 16 to April 15 period (NE Monsoon) and the remaining from 74 stations during April 16 to October 15 (SW Monsoon) period. Numerically the bothid larvae were slightly higher during NE than SW monsoon period, however they were widely distributed during the SW monsoon period. A similar pattern of distribution was also observed in the copepod Scolecithricidae (Gopalakrishnan, Ph.D. Thesis unpublished, 1982). 45.9% of the stations containing bothid larvae were situated in the Bay of Bengal, 38.4% in the Arabian Sea, 8.9% in SE Indian Ocean and 6.8% in SW Indian Ocean. In the Bay of Bengal there was no appreciable difference in the number of the larvae in the collections taken during the SW monsoon period. 50.4% of the larvae were found in 53.7% of the samples during the above mentioned period and 49.6% of the larvae were found in 46.3% of the samples during NE monsoon indicating almost equal preference to both the seasons.

Even though bothid larvae were found in the South West Indian Ocean in very small numbers, they showed some preference to SW monsoon period because 60% of the larvae of the region were found in 60% of the stations during this period whereas in the South East Indian Ocean 52.7% of the larvae were found in 46.2% of the stations.

In the Naga Expedition, of the 2486 bothid larvae 70.7% were collected from 54 stations during April 16 to October 15 period corresponding to the SW monsoon period of the Indian Ocean. The remaining were collected from 28 stations during the other season (Fig. 67).

In the Gulf of Thailand, 69.2% of the larvae were contained in the plankton taken from 60.3% of the stations during April 16 to October 15 period



whereas in the South China Sea, 75.7% of the larvae were present in 82.4% of the stations during the above period.

In general it may be noted that bothid larvae prefer April 16 to October 15 period both in the Gulf of Thailand and South China Sea. This was the case with the Southern Indian Ocean, whereas there was no preference for a particular period in the Bay of Bengal while the Arabian Sea region showed some preference to October 16 to April 15 period.

*Arnoglossus tapeinosoma*, a dominant species in the Arabian Sea even though found to occur in both seasons a preference was shown to the NE monsoon season. *Engyprosopon multisquama*, *E. latifrons*, *E. grandisquamis* and *Arnoglossus aspilos* which come next in order of abundance also exhibited a pattern of distribution as in *A. tapeinosoma*. *E. cocosensis*, *Bothus myriaster*, *B. pantherinus*, *A. intermedius*, *Crossorhombus valde-rostratus* on the other hand showed some preference to SW monsoon period.

In the Bay of Bengal, the dominant species was *E. grandisquamis*. The larvae of this species were found to occur in both seasons, preference being shown to SW monsoon season, the percentage being 69.3. The larvae of *E. cocosensis*, *A. tapeinosoma* and *B. pantherinus* dominated during the NE monsoon period, their percentages being 53.5, 62.1 and 83.9 respectively.

It is seen that *E. cocosensis* on the whole showed preference to SW monsoon period and *E. xenandrus* to NE monsoon period, whereas all other species did not show such clear cut preferences. The preference of certain larvae to NE monsoon in the Arabian Sea and SW monsoon in the Bay of Bengal may be due to their reaction to rainy season.

The variation in the occurrence of larvae is associated with the seasonal cycles in oceanic and neritic ecosystems. Sournia (1969) and Blackburn *et al.* (1970) report that there is very little evidence for predominant maxima and minima associated with the seasonal events in the tropical ocean. But in the Northern Indian Ocean, the influence of monsoon is predominant. The annual variation in the concentration of the larvae in the Arabian Sea and the Bay of

Bengal changed directly with southerly (cyclonic circulation) and a northerly (counter cyclonic) transfer of water during changing monsoon. The distribution of larvae in the equatorial area is governed by the eastward drift and the westward flow. The concentration of fish larvae in the oceanic waters is the outcome of the southward surface drifts along the south west coast during the late premonsoon to early postmonsoon period, causing the currents to carry some kind of translocation of larvae during the major part of the spawning period. According to Peter (1982) during the SW monsoon period high concentrations of fish larvae were seen as large patches along the coastal areas. This extended to offshore areas considerably. The premonsoon (spring transition – March-April) recorded relatively very high concentration of larvae along with south west coast of India and in the western and northern Bay of Bengal extending to oceanic regions. But George (1979) found relatively poor abundance in fish larvae and eggs during January to April in the monsoon during 1970-75 along the south west coast of India. The NE monsoon also recorded good catches of larvae especially from the west coast of India. During the period November to March with the onset of northerly current with the postmonsoon condition (i.e. after the SW monsoon and during the NE monsoon) prevailing very high concentration of oxygen due to photosynthetic activity, plankton bloom following upwelling, and gradual rise in the sea temperature resulting in from the recession of upwelling processes, provide the fish fauna with favourable environmental conditions along the south west coast of India. This is found applicable to explain the distribution of bothid larvae as they were dominant during NE monsoon period (October 16 to April 15) in the Arabian Sea with the maximum number of larvae occurring along the south west coast of India during that period. The maximum plankton biomass always coincided with the peak period of upwelling followed by larval abundance brought about by the prevailing upwelled water from the mesopelagic region to the surface.

## **6.5 Monthly variation**

In the Indian Ocean the distribution of bothid larvae was not uniform in all months (Fig. 77 A). When an average minimum number of five was recorded of October, the maximum number of 32 was found in September. In November, the average number was 26. In December, January and February, the number dropped to 6. But the March values were higher than those of November, being

28, thereafter the number was lowered to 12 in April, and May, 10 in August and 7 in June and July. In the Gulf of Thailand and South China Sea (Fig. 77 B), the maximum average number of 41 was noticed in August, 37 in April, 28 in November, 27 in January and 25 in March and June. Thereafter the number dropped considerably to 10 in May, 4 in February, and 2 in September. A very high value of 48 was noticed in October, which was an exception.

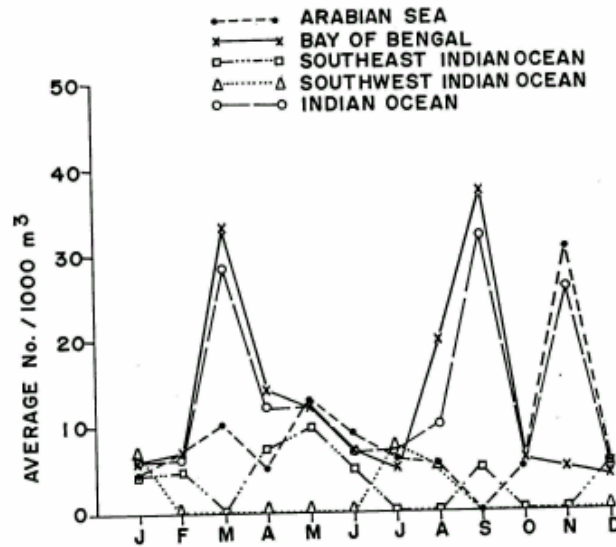


Fig. 77 A – Monthly variation of bothid larvae in different water bodies.

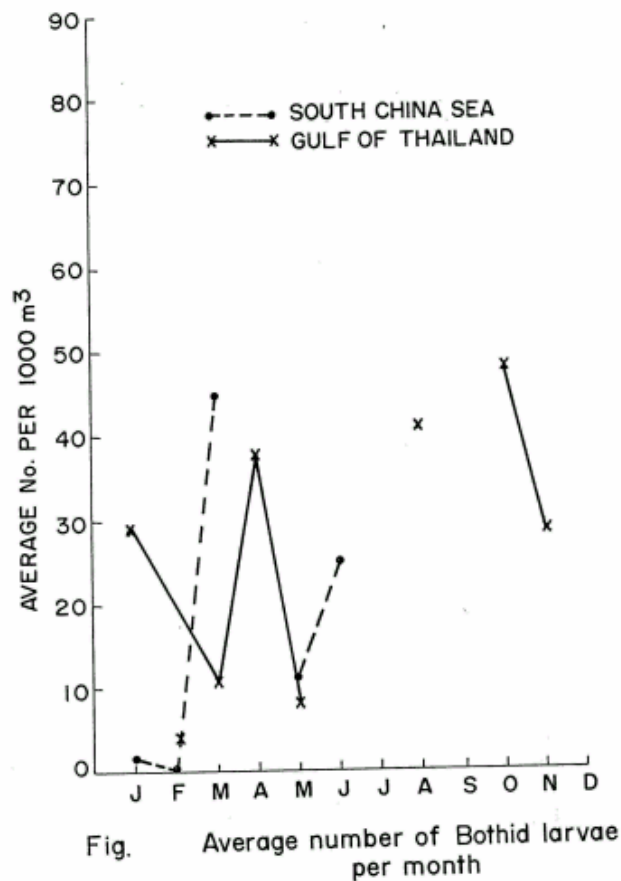


Fig. 77 B – Monthly variation of bothid larvae in different water bodies.

The value indicated that the distribution pattern of bothid larvae in the Indian Ocean and Gulf of Thailand and South China Sea samples were quite different from each other, both in numerical abundance as well as their dominance in different months.

The fluctuation in the number of larvae were also distinct in different months in different regions of the Indian Ocean. When the average number of 32, the highest for the Arabian Sea was noticed in the month of November, it was 37 in the Bay of Bengal in the month of September. In the Arabian Sea the number dropped to 10 in March, 9 in June, 7 in February, 6 in July and December, 5 in October, April and January and 0 in September, in the Bay of Bengal, the fluctuation in the number decreased to 33 in March, 20 in August, 14 in April, 13 in May, 7 in February and June, 6 in January and October, 5 in July and November and 4 in December. In the Bay of Bengal the larvae were found in all months.

In the South West Indian Ocean, the larvae were found only in three months, 8 each in January and July and 5 in August.

In the South East Indian Ocean, it was 10 in May, 8 in April, 6 in December and 5 each in January, February, June and September.

The Gulf of Thailand recorded a different picture. A maximum of 48 was noticed in October and a minimum of 4 in February. Their number was 29 in January, 11 in March, 38 in April, 8 in May, 41 in August and 28 in November. The stratum was not sampled for the months of June, July and September.

There was also considerable difference between the number of larvae in the South China Sea and the Gulf of Thailand. In South China Sea an average number of 45 was noticed in March, followed by 25 in June, 11 in May and 2 each in January and September. No larvae were found in the months of February and November. The collections were not taken during April, July and August.

It may be noted that the maximum number of bothid larvae were found during the NE monsoon period in the Arabian Sea, when larvae of other species of fishes were maximum during the SW monsoon period (Peter, 1973). Similarly, in the Bay of Bengal when fish larvae other than those of bothids were maximum during NE monsoon period the bothids were maximum during SW monsoon period (Peter, Ph.D. Thesis, 1982, unpublished).

## **6.6 Day and night variation**

The distribution pattern of bothid larvae collected during International Indian Ocean Expedition and Naga Expedition showed that they are found more during night than day in both series of collections (Fig. 66 & 67). A detailed analysis of the data revealed that in the Arabian Sea the maximum number of larvae (111 per 1000 m<sup>3</sup>) were contained in the plankton samples taken at night from SW coast of India. The distribution of the grade 11-20 larvae was found equally distributed during day and night. The lowest grade 1-5 was found more in the samples taken at night. 60.7% of the samples and 69.6 % of the larvae were confined to the collections taken at night.

Eleven species of bothid larvae were found dominant in the night samples from the Arabian Sea. Of these the larvae of *Engyprosopon cocosensis*, *E. mogkii* and *E. sechellensis* were found during night and *E. latifrons*, *E. grandisquamis*, *E. multisquama*, *E. xenandrus*, *Arnoglossus elongatus*, *A. tapeinosoma*, *Bothus pantherinus* and *B. myriaster* were present only in the day collections whereas *A. aspilos* though present both during day and night were found more during day.

In the Bay of Bengal even though there was not much difference between the number of collections containing bothid larvae 73.7% of the larvae were present in the samples taken at night. *Psettina iijimae*, *Arnoglossus elongatus*, *A. intermedius* and *B. myriaster* were found only during night. *E. cocosensis*, *E. latifrons*, *E. grandisquamis*, *Crossorhombus azureus* and *Arnoglossus tapeinosoma* though present both during day and night showed preference to darkness. *E. mogkii*, *E. sechellensis* and *E. xenandrus* were present only during day, but all of them were contained in one and the same collection, hence difficult to assess their preference. *E. multisquama*, *C. valde-rostratus*, *A. aspilos* and *B. pantherinus* showed definite preference to day time though they were found in collections taken both during day and night.

In the South West Indian Ocean the distribution of samples containing larvae were equal but 53.3% of the larvae were found in the night. *A. aspilos*, *A. imperialis* and *B. pantherinus* were found only during night whereas *E. cocosensis*, *C. azureus*, *A. elongatus* and *B. myriaster* were found during day. *C. valde-rostratus* though found during day and night showed preference to darkness.

The South East Indian Ocean showed a different picture. 74.3% of the larvae were contained in 76.9% of the stations which were taken at night. *E. grandisquamis*, *E. sechellensis*, *C. azureus*, *A. aspilos*, *B. pantherinus* were found only in the plankton samples collected at night whereas *E. xenandrus*, *C. valde-rostratus* and *A. intermedius* were found only during day time.

69.3% of the bothid larvae from 55.5% of samples collected from the Gulf of Thailand were confined to the plankton samples taken during night. The larvae of *E. mogkii* and *A. elongatus* were present only during night and *E. cocosensis*, *E. multisquama* and *B. pantherinus* were found only during day. *E. latifrons*, *E. grandisquamis*, *P. brevirectis* though found during day and night showed preference to day time. *P. iijimae* and *A. tapeinosoma* appears to have no such preference in the Gulf waters.

In South China Sea 62.4% of the larvae from 52.9% of stations were found occurring in the plankton samples taken at night. 52.9% of the stations which contained bothid larvae were collected during night. *E. mogkii*, *E. xenandrus*, *C. azureus*, *A. aspilos*, *A. elongatus* and *B. myriaster* were found only during night. *C. valde-rostratus*, *B. pantherinus* were found during day. *E. cocosensis*, *E. latifrons*, *E. grandisquamis*, *E. multisquama*, *P. brevirectis* and *A. tapeinosoma* though found in the samples both during day and night showed decided preference to darkness whereas *P. iijimae* attracted towards light and *E. sechellensis* did not show any preference at all.

In general, *E. latifrons*, *E. grandisquamis*, *P. brevirectis* and *A. tapeinosoma* showed preference to darkness, irrespective of the area of collection. All other species exhibited different degree of preference to day or night in different regions. This may be due to the ecological factors prevailing in such regions which may have influence in their growth and distribution.

According to Mc Laren (1963) the adaptive value of vertical migration may depend upon the lower temperature generally found in deeper waters. The vertical migration of zooplankton, according to Hutchinson (1967) is most likely to avoid visual predation, having a residence away from surface by day. Mc Alister (1969) suggested that vertical migration may give additional advantage of better utilisation of growth potential of the zooplankton as well as permitting the unimpeded growth of plant during day light hours. Kerfoot (1970) argued that vertical migration or orientation in the water column as “unavoidable correlate of the use of light as a frame of reference” optimised the transfer of phytoplankton production to zooplankton biomass.

The above explanation of adaptive values of vertical migration by zooplankton are difficult to explain in terms of individual fitness. Copepods in general exhibit remarkable diurnal variation in spatial abundance (Gopalakrishnan, 1982, unpublished thesis). Fish larvae indicated nocturnal abundance more than double of that during day (Peter, 1982, unpublished thesis). Light appears to be an important factor in the process of feeding of anchoveta larvae as the guts were empty or had less food in the larvae collected during night (Mendiola, 1974).

The fish larvae also behaves in the same manner like many other planktonic organisms in their diel variation. Several authors have reported the occurrence of more number of fish larvae in the collections taken during night than day samples. Silliman (1943) and Ahlstrom (1954) have observed lesser number of Pacific sardines *Sardinops caerulea* in day catch. Bridger (1956) reported a larval catch as high as seven times in the case of clupeids and four times in the case of pilchards during night than day. Ahlstrom (1959) has also stated that no consistent difference could be noted in the larvae of *Trachurus symmetricus* in California and Baja California waters between day and night. However, Ahlstrom (1971) has recorded marked differences in the day and night occurrences of scombrid larvae, with high numbers in the night during ESTROPAC surveys. In 1978 he has also observed the occurrence of larvae of gomostomid more by 2.9 to 3.4 times at night than day. When Klawe (1963) has reported fewer number of *Auxis* larvae during night than day, Ueyanagi (1969) did not find any difference between the number of tuna larvae collected during day and night. Schnack and Hempel (1971) have noted that when catches were more, the numbers were more during night but when the catches were small, the larvae were equal in both day and night collections. Silas (1974) observed nocturnal abundance of *Rastrelliger kanagurta* along south west coast of India. But Boonprakob and Debtaranon (1974) recorded large number of postlarvae of *Rastralliger neglecta* congregating 5-10 m during day sinking to greater depths from dusk to night exhibiting some kind of positive phototropism. In the case of bothid larvae, a preference to darkness was observed in most of the species studied.



The avoidance of the net by the larvae, the diurnal vertical migration and their photo taxis reaction exhibited by several groups could be the possible reason for the high count of larvae in the night hauls. According to Ahlstrom (1959) and Hartmann (1970) several kinds of fish larvae performed diurnal vertical migration. In this study the samples collected from 200-0 m contained both pelagic and bathypelagic species during day hauls. So the effect of vertical migration in such sampling is comparatively less. The possibility of bathypelagic forms from greater depths migrating to upper layers cannot be ruled out. It is also reported that towing speeds less than 100 cm per sec. cause increased avoidance of the sampler by the larvae (UNESCO Report, 1975). Lalithambika Devi (1972) has reported that most of the fish releases eggs during night. Hence importance of sampling during night cannot be ignored while conducting ichthyoplankton surveys.

#### **6.7 Latitudinal abundance and distribution**

Considering the latitudinal variation, the maximum number of bothid larvae was found at 9°N (379 larvae) followed by 4°N (331). A notable numerical and specific decrease was found near the equator as well as towards the southern latitudes (Table 26 a). The maximum number of species (9) was encountered from 12 to 14°N. From 2°S and beyond the distribution was restricted to one or two species. Even though the dominant species varies in different latitudes. *Engyprosopon grandisquamis* and *A. tapeinosoma* outnumber others in the Indian Ocean (Table 27 a). Comparing the numerical abundance of bothid larvae of the Indian Ocean with that of the Gulf of Thailand and the South China Sea, it seems that the latter is more favourable with a maximum at 10° (859) followed by 9° (560) and 11° (245) (Table 26 b). The species-wise distribution also showed a maximum at 10° (13) followed by 8°-9° (11 each), 7° and 11° (10 each). The minimum number of larvae was noticed from 19° to 22° for one or two species. In the Gulf waters *Psettina brevirectis* and *Psettina ijimae* were the dominant species (Table 27 b).

Table 26. Larvae of Bothid species, total number and frequency of occurrence.

Species	Arabian sea		Bay of Bengal		SW Indian ocean		SE Indian ocean		South china sea		Gulf of Thailand	
	Total Number	Frequency of occurrence	Total number	Frequency of occurrence	Total Number	Frequency of occurrence	Total Number	Frequency of occurrence	Total Number	Frequency of occurrence	Total Number	Frequency of occurrence
1 <i>Parabothus polylepis</i>	0	0	30	2	0	0	0	0	0	0	0	0
2 <i>Crossorhombus valde-rostratus</i>	10	2	28	5	20	4	5	1	2	2	1	0
3 <i>Crossorhombus azureus</i>	5	1	34	7	15	2	19	4	4	4	1	0
4 <i>Engyprosopo coccosensis</i>	36	4	128	3	5	1	0	0	27	5	5	1
5 <i>E. latifrons</i>	49	2	187	6	0	0	0	0	82	6	6	5
6 <i>E. mogkii</i>	10	1	4	1	0	0	0	0	2	1	1	+
7 <i>E. grandisquamis</i>	39	5	414	14	0	0	5	1	52	8	8	15
8 <i>E. sechellensis</i>	27	4	20	1	0	0	9	2	8	3	3	0
9 <i>E. multsquama</i>	71	2	73	6	0	0	0	0	15	4	4	10
10 <i>E. xenandrus</i>	9	2	5	1	0	0	10	1	4	1	1	0
11 <i>Bothus myriaster</i>	25	4	15	2	5	1	0	0	+	0	0	0
12 <i>B. mancus</i>	7	1	0	0	0	0	0	0	0	0	0	0
13 <i>B. pantherinus</i>	18	4	93	5	5	1	12	2	16	2	2	3
14 <i>Bothus</i> sp.	0	0	10	1	0	0	0	0	0	0	0	0
15 <i>Asterorhombus intermedius</i>	4	1	3	1	0	0	0	0	0	0	0	0
16 <i>Psetina brevivittis</i>	0	0	0	0	0	0	0	0	99	3	3	35
17 <i>P. ijimae</i>	0	0	25	2	0	0	0	0	14	3	3	802
18 <i>Arnoglossus tapeinosoma</i>	77	15	161	14	5	1	10	1	41	7	7	20
19 <i>A. aspiros</i>	35	6	25	5	10	1	0	0	3	1	1	0
20 <i>A. elongatus</i>	11	2	20	1	0	0	0	0	9	2	2	6
21 <i>A. intermedius</i>	19	2	66	3	0	0	4	1	0	0	0	0
22 <i>A. imperialis</i>	0	0	0	0	10	1	0	0	0	0	0	0
23 <i>Laeops macrophthalmus</i>	5	1	0	0	0	0	0	0	0	0	0	0
24 <i>Chascanopsetta lugubris</i>	0	0	30	3	0	0	0	0	0	0	0	0

Table 26 a - Latitudinal distribution of Bothid larvae in the Indian Ocean

Station	Latitude (°N)	Longitude (°E)	Parabotus polylepis	C.rossorhombus valde-rostratus	C. azureus	ngyrosopon coccoensis	E. latifrons	E. mogkii	E. grandisquama	E. sechellensis	E. multisquama	E. xenandrus	Bothus myraster	B. mancus	B. pantherinus	Bothus sp.	Asteroglossus intermedius	Psetta brevifrons	P. filifera	Argnoglissus tapinosoma	A. asplios	A. elongatus	A. intermedius	A. imperialis	Laeops macrothalimus	Chascaopsetta lugubris
	0		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
AR 22	00 03'	55 03'																		5						
AR 25	00 00'	48 55'										5			5											
KI 300	00 00'	73 00'																		5						
Me 147	00 17'	45 48'																		4						
Me 148	00 00'	46 03'																		5						
Me 176	00 30'	57 49'																		8						
	1																									
Me 178	01 32'	57 57'											5													
	2																									
AR 31	02 59'	53 02'																								
OS 11/4	02 36'	90 08'		4																5						
	3																									
VI 5289	03 01'	84 00'		3		3																				
	4																									
DI 5543	04 12'	52 35'		5																						
KI 527	04 00'	99 49'					60		240																	
Um 1-3	04 26'	77 56'								3					3											
	5																									
AB 168	05 52'	52 56'																		5						
KI 105 A	05 32'	70 00'																		4						
KI 528	05 00'	98 00'					17		17											19						
Ko 3	05 00'	94 00'																								
VI 5227	05 06'	91 33'						4																		
	6																									
AB 327	06 51'	75 02'																		5						
DI 5548	06 34'	51 00'																						5		
Ka 20	06 23'	78 01'				3																				
KI 104 A	06 21'	71 00'			5																					
KI 520	06 00'	98 30'							11																	
KI 521	06 05'	98 59'																								
Um 1-2	06 04'	77 46'									33															

(26 a - Contd.)

Station	Latitude (°N)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
AB 16	07 31'	96 11'							5																	
AB 18	07 41'	97 59'							8																	
AR 40	07 05'	49 39'										7														
KI 102	07 52'	72 58'																			5					
KI 103	07 00'	71 41'							5																	
KI 517	07 00'	97 02'		5																						
KI 518	07 07'	98 21'					10																			
KI 680	07 12'	78 34'															4									
Um 1-1	07 39'	78 09'							7																	
BF 27 B	08 54'	76 04' 30'				27																				
KI 311	08 00'	75 00'																				5				
PI 20	08 32'	81 32'			5																					
BF 25	08 48'	76 21'				40																				
BF 26	08 51'	76 12'				80																				
AB 20	09 13'	97 51'					60																			
AB 21	09 54'	97 42'				120	20																			
KI 314	09 24'	75 48'				10																20				
KI 677	09 11'	75 54'																					6			
Va 2004	09 00'	76 22'					44				67															
Va 2008	09 04'	74 40'								5																
BF 16	09 34' 30"	75 48'				27																				
AB 22	10 37'	97 34'																								
AB 23	10 39'	96 36'	13																							
KI 334	10 08'	94 35'													10											5
KI 363	10 00'	87 00'			5																					
KI 366	10 00'	84 00'			5																					
KI 666	10 13'	75 39'							9																	
AB 28	11 49'	92 53'																								
AB 29	11 23'	93 31'													53											
KI 258	11 00'	74 33'				15																	20			
KI 315	11 30'	92 00'							5																5	
KI 594	11 01'	80 12'																								
KI 686	11 01'	80 21'																							6	
PI 7	11 01'	93 42'																							3	
																								5		



(26 a - Contd.)

Station	Latitude (°N)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	15																									
AB 43	15 08'	94 04'																								
DI 5010	15 01'	52 36'								20			10													
KI 406	15 00'	90 00'																			5					
KI 575	15 36'	81 01'																			6					
KI 718	15 02'	84 07'																			5					
	16																									
AB 92	16 40'	83 58'																			5					
KI 407	16 00'	88 00'		5																						
KI 572	16 31'	82 53'							4																	
Me 73	16 37'	41 09'												5												
	17																									
AB 64	17 48'	84 02'							20																	
AB 66 B	17 07'	84 33'																								5
DI 5038	17 18'	57 09'																			5					
	18																									
AB 54	18 24'	90 45'																			5					
DI 5062	18 39'	58 31'		5																						
KI 727	18 04'	90 06'							4																	
KI 728	18 56'	90 12'																								
PI 16	18 15'	87 48'									5															
VA 1801	18 30'	71 15'							13																	15
	19																									
AB 49	19 32'	92 52'							40																	
KI 433	19 00'	88 00'			5																					
KI 553	19 37'	87 19'																								
AB 198	19 17'	62 29'											5													
	20																									
DI 5067	20 13'	60 20'																								
KI 729	20 00'	90 18'																			5					46

(26 a - Contd.)

Station	Latitude (°S)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
AB 166	00 24'	54 33'		5																						
AR 24	00 05'	50 56'								5																
Me 174	00 28'	57 55'																		4		5				
	1																									
AB 115	01 07'	71 00'					5																			
Dm 29	01 43'	87 23'											5													
DI 5355 B	01 52'	67 49'											5													
Me 155	01 27'	42 34'																								4
	2																									
AB 150	02 00'	59 59'												5												
	3																									
AB 420 A	03 07'	40 39'																								
AR 43	03 00'	53 00'																								5
	4																									
DI 5292 B	04 56'	58 04'								14																
	5																									
DI 5514 A	05 38'	42 48'																								
PI 43	05 46'	102 24'		5						5																
	6																									
0																										
	7																									
0																										
	8																									
DI 5500 B	08 02'	54 02'		5																						
	9																									
Dm 132	09 46'	109 36'										10														
	10																									
DI 5505 A	10 43'	50 23'		5																						
)S 30	10 41'	112 12'																								4
	11																									
Dm 156	11 23'	104 50'																								4





(26 a - Contd.)

Station	Latitude (°S)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OS 4	13 13 51'	107 32'								4																
OS 4	14, 15, 14 00'	16, 17 118 00'	4							4																
GA 26	18 18 30'	110 00'		5																						
OS 10	20 20 00'	112 51'												7												
AB 366	23 23 13'	43 13'				5																				
Dm 31	24 24 06'	112 22'							5																	
Dm 5	26 26 03'	106 54'																		10						
Dm 148 GA 5	27 27 37'	110 25'			5																					
AB 359	28 28 35'	32 40'		5																	10					
Dm 5 7A	29 29 06'	113 48'			5																					
Na 143	29 58'	31 06'			10																					
Na 147	30 31 31 47'	34 09'																								
Dm 54	32 32 00'	1 11 50'			5																					
	33																									

Na 177	34 34 59'	21 32'																				10				
Na 152	35 36 19'	34 09'																				5				

Table 26 b - Latitudinal distribution of Bothid larvae in the Gulf of Thailand and South China Sea.

Station	Latitude	Longitude	<i>Crossorhombus valde-rostratus</i>	<i>C. azureus</i>	<i>Engypsopon cocconsis</i>	<i>E. latifrons</i>	<i>E. mogkii</i>	<i>E. grandisquama</i>	<i>E. sechellensis</i>	<i>E. multisquama</i>	<i>E. xenandrus</i>	<i>Bothus mylaster</i>	<i>B. pantherinus</i>	<i>Psetina brevirctis</i>	<i>P. ijilmae</i>	<i>Argnogllossus asplios</i>	<i>A. elongatus</i>	<i>A. tapelinosoma</i>
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S1A 34	04 00' 30	104 02' 30						6		6				63			6	+
S1A 34	04 00' 30	104 02' 30																
S4 35 B	05 18' 10	107 12' 20			+						+							
S6 35 A	05 27' 30	107 08' 20			+	+		+										
S6 38	05 20' 40	105 45' 15				8		2										
S6 38	05 20' 40	105 45' 15			+						+							+
S6 39	05 39' 00	105 23' 15			8	46		4		8								12
S5 U13	06 52' 30	101 45' 00												4				
S1A 85	06 35' 06	105 19' 24						5						5				5
S1B 63	06 52' 00	121 52' 24					6	6						26				
S3 13	07 54' 00	101 11' 30																3
S4 32	07 36' 45	108 10' 00		+	+				+				+					
S5 4	07 32' 00	103 41' 30						7										
S5 4 A	07 39' 00	103 51' 45				+		+										
S5 5	07 55' 00	104 14' 00				53		13										3
S5 14 B	07 28' 30	101 02' 45												20				
S5 15	07 20' 30	100 54' 30												15				
S7 32 A	07 33' 45	101 10' 30												8				
S8 41	07 00' 15	105 27' 40			+			+										+
S3 11	08 37' 00	102 21' 30												28				
S3 12	08 16' 00	101 46' 00												9				
S4 24 B	08 58' 05	110 36' 05			+													+
S5 16	08 03' 20	100 42' 20						31						8				
S5 17	08 39' 45	100 14' 45																
S6 23	08 51' 00	111 50' 00				2												
S6 31	08 18' 30	107 47' 50				12		7	2					2				7
S6 42	08 19' 00	104 47' 40												31				
S7 30	08 31' 30	102 22' 30												4				
S8 23B	08 46' 00	111 19' 30	+						+				+					
S9 15	08 57' 00	102 53' 18												8				4

(26 b - Contd.)

Station	Latitude (°N)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S3 7	09 06' 00	104 14' 00													+			
S3 8	09 52' 00	103 50' 30						9							27			
S3 10	09 01' 50	102 51' 00													5			2
S3 16	09 07' 00	100 47' 45			+									+				+
S4 U24	09 58' 00	103 27' 45													63			
S5 U7	09 49' 30	100 09' 15													27			
S5 U9	09 05' 30	100 16' 45													5			
S5 7	09 01' 30	104 14' 37													16			
S5 9B	09 31' 36	103 30' 00				10		10		5				19				
S5 10	09 24' 30	103 21' 15								5				19	36			
S5 19	09 30' 06	101 20' 30												26				3
S5 29 A	09 54' 18	99 30' 00												9				
S6 29	09 45' 10	107 04' 00				3		3										+
S6 29	09 45' 10	107 04' 00				+									+			2
S6 30	09 02' 00	107 25' 00						22							2			2
S7 18 G	09 33' 30	100 17' 50						7						14	117			3
S7 22	09 28' 00	101 21' 15													25			
S7 28	09 23' 30	103 24' 00						29						5				
S8 U2	09 03' 00	106 26' 00												+	+			
S8 U2	09 03' 00	106 26' 00												+	+			
S8 20 B	09 36' 40	112 10' 40				+								+				
S8 12	09 30' 00	100 15' 30																
S8 12	09 30' 00	100 15' 30													6			
S8 13	09 10' 12	100 15' 18												11	11			
S8 71	09 25' 36	121 51' 30		4														
NH 40	10 07' 30	137 27' 30																
S1 23	10 40' 45	103 01' 30		+														
S3 19	10 23' 00	102 30' 00				18		12						6	12			
S3 20	10 41' 15	103 03' 00												12				2
S3 25	10 50' 00	100 30' 45						9						126				
S3 26	10 27' 45	99 56' 30												11				
S3 28	10 40' 00	99 35' 30												15				
S4 19	10 32' 30	112 53' 20												24	47			
S5 22 A	10 46' 00	103 03' 15																
S5 22 C	10 42' 48	103 09' 24													45			
S5 22 D	10 40' 00	103 05' 15													20			
S5 22 E	10 49' 12	102 58' 00													58			
S5 27	10 38' 55	100 33' 00													13			
S5 28 A	10 13' 00	99 51' 00						3							8			
S5 28 B	10 08' 50	99 39' 40													165			
S6 25 B	10 01' 15	110 24' 15													9			
S6 28	10 55' 30	108 55' 30																
S7 17 B	10 18' 45	99 47' 45																9
S7 18 A	10 05' 35	99 24' 35																
S7 24	10 19' 50	102 25' 50																
S7 26	10 12' 00	103 32' 30																
S8 26 A	10 02' 15	109 48' 00				+												
S9 10	10 12' 48	103 23' 00													+			
S9 10	10 12' 48	103 23' 00													+			



(26 b - Contd.)

Station	Latitude (°N)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S3	23 11 31' 00	101 38' 00												8				
S3	29 11 17' 00	99 39' 00													40			
S4	17 11 11' 05	111 33' 50				+												
S5	U3 11 26' 00	99 53' 15												21				
S5	23A 11 45' 00	102 23' 30													6			
S5	23B 11 49' 00	102 17' 00													5			
S5	24 11 53' 00	102 10' 00													+			+
S5	24 "	"				+									+			+
S7	8B 11 30' 30	100 02' 30						+										
S7	13 11 53' 45	102 12' 09						6							13			
S7	15 11 11' 00	101 10' 00												30	13		6	
S7	42 11 13' 00	102 32' 25			2									+				
S8	17 11 37' 40	110 56' 40																
S9	30 11 36' 12	101 12' 36												23				
S9	31 11 59' 30	101 21' 36												13	59			
S9A	4A 11 48' 47	102 18' 16					+								+			
S9A	5 11 59' 24	102 11' 06													+			
S9A	10 11 30' 00	99 47' 12													+			
S3	31 12 04' 30	100 46' 00						6										
S3	32 12 24' 00	101 19' 15													38			
S5	34 12 24' 00	101 23' 45												7				
S6	15 12 09' 00	109 24' 45				3							6					
S6	15 12 09' 00	109 24' 45			+													3
S7	11 12 22' 00	101 25' 00				7												+
S9A	13 12 21' 18	101 31' 55						7										
S9A	13A 12 18' 15	101 22' 18					+								+			
S9A-	14 12 19' 15	100 43' 40													+			
S9A	18A 12 49' 25	100 20' 00				+									+			
S10	U1 12 33' 36	100 46' 30				3												
S10	U77 12 32' 50	100 41' 30						12										5

(26 b - Contd.)

Station	Latitude (°N)	Longitude (°E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	13																		
S4 8	13 30' 00	113 38' 07		+	+														
S4 10 B	13 26' 45	111 07' 55		+														+	
	14																		
S4 6	14 48' 00	113 04' 00	+	+	+		+												
S6 8	14 12' 00	113 17' 00		2	2					2									
S11B 91	14 01' 48	119 58' 48		4	8				4	4									
S11C 2	14 53' 54	119 51' 30																	+
	15																		
S6 3	15 42' 00	110 20' 00														3	3	3	3
S6 5 A	15 38' 00	112 18' 00	+																
S8 5 AI	15 40' 05	112 09' 05			+														
S10 U31	15 41' 00	108 39' 18											+						
S10 7	15 06' 12	111 45' 18	2																
	16																		
S6 34	16 16' 00	108 06' 40			7	10			2	2									
	19																		
S11C 34	19 53' 00	124 15' 18	+																
S11C 00	19 46' 06	139 55' 12	+																
	20																		
S11C 46	20 28' 48	127 24' 06		+															
S11C 53	20 51' 54	129 04' 00	+																
	21																		
S11C 80	21 52' 42	136 38' 54	+	+															
S11C 90	21 15' 00	138 04' 30		+															
	22																		
S11C 71	22 19' 42	134 46' 45		+															
S11C 71	22 19' 42	134 46' 45		+															

**Table 27 a - Latitudinal distribution of bothid larvae in the Indian Ocean**

Latitude (°N)	Total (No.)	Species (No.)	Dominant species	Other species
0	37	4	<i>Arnoglossus tapeinosoma</i> (19)	<i>A. aspilos</i> (8), <i>Engyprosopon xenandrus</i> (5), <i>Bothus pantherinus</i> (5).
1	5	1	<i>Bothus myriaster</i> (5)	---
2	9	2	<i>Arnoglossus tapeinosoma</i> (5)	<i>Crossorhombus azureus</i> (4)
3	6	2	--	<i>C. valde-rostratus</i> (3), <i>E. cocosensis</i> (3).
4	331	6	<i>E. grandisquamis</i> (240)	<i>E. latifrons</i> (60), <i>Psettina iijimae</i> (20), <i>C. valde-rostratus</i> (5), <i>E. sechellensis</i> (3), <i>B. pantherinus</i> (3),.
5	71	5	<i>A. tapeinosoma</i> (28)	<i>E. latifrons</i> (17), <i>E. grandisquamis</i> (17), <i>P. iijimae</i> (5), <i>E. mogkii</i> (4).
6	96	7	<i>E. multisquama</i> (33)	<i>A. tapeinosoma</i> (27), <i>A. aspilos</i> (12), <i>E. grandisquamis</i> (11), <i>C. valde-rostratus</i> (5), <i>Laeops macrophthalmus</i> (5), <i>C. azureus</i> (3).
7	56	6	<i>E. grandisquamis</i> (25)	<i>E. latifrons</i> (10), <i>B. mancus</i> (7), <i>C. valde-rostratus</i> (5), <i>A. tapeinosoma</i> (5), <i>Asterorhombus intermedius</i> (4).
8	157	3	<i>E. cocosensis</i> (147)	<i>C. azureus</i> (5), <i>A. aspilos</i> (5),
9	379	6	<i>E. cocosensis</i> (157)	<i>E. latifrons</i> (124), <i>E. multisquama</i> (67), <i>A. tapeinosoma</i> (20), <i>A. elongatus</i> (6), <i>E. sechellensis</i> (5).
10	52	6	<i>Parabothus polylepis</i> (13)	<i>C. azureus</i> (10), <i>B. pantherinus</i> (10), <i>E. grandisquamis</i> (9), <i>A. aspilos</i> (5), <i>Chascanopsetta lugubris</i> (5).
11	112	7	<i>B. pantherinus</i> (53)	<i>A. elongatus</i> (20), <i>E. cocosensis</i> (15), <i>A. tapeinosoma</i> (9), <i>E. grandisquamis</i> (5), <i>A. aspilos</i> (5), <i>A. intermedius</i> (5).
12	111	9	<i>A. tapeinosoma</i> (23)	<i>E. grandisquamis</i> (20), <i>A. latifrons</i> (20), <i>B. myriaster</i> (10), <i>B. pantherinus</i> (10), <i>Bothus sp.</i> (10), <i>E. multisquamis</i> (9), <i>A. aspilos</i> (5), <i>E. xenandrus</i> (4).



(27 a - Contd.)

13	95	9	<i>A. tapeinosoma</i> (28)	<i>Parabothus polylepis</i> (17), <i>B. pantherinus</i> (15), <i>E. mogkii</i> (10), <i>C. azureus</i> (5), <i>E.</i> <i>grandisquamis</i> (5), <i>E. multisquama</i> (5), <i>E. xenandrus</i> (5), <i>A. aspilos</i> (5).
14	143	9	<i>E. grandisquamis</i> (40)	<i>E. multisquama</i> (25), <i>Chascanopsetta lugubris</i> (20), <i>A.</i> <i>intermedius</i> (15), <i>E. cocosensis</i> (13), <i>C. valde-rostratus</i> (10), <i>A.</i> <i>tapeinosoma</i> (10), <i>C. azureus</i> (5), <i>B.</i> <i>pantherinus</i> (5).
15	66	4	<i>A. tapeinosoma</i> (31)	<i>E. sechellensis</i> (20), <i>B. myriaster</i> (10), <i>A. aspilos</i> (5).
16	19	4	--	<i>C. valde-rostratus</i> (5), <i>B. pantherinus</i> (5), <i>A. tapeinosoma</i> (5), <i>E. grandisquamis</i> (4).
17	30	3	<i>E. grandisquamis</i> (20)	<i>A. aspilos</i> (5), <i>Chascanopsetta</i> <i>lugubris</i> (5).
18	55	7	<i>A. grandisquamis</i> (17)	<i>A. intermedius</i> (15), <i>C. valde-</i> <i>rostratus</i> (5), <i>E. multisquama</i> (5), <i>A.</i> <i>tapeinosoma</i> (5), <i>A. aspilos</i> (5), <i>Asterorhombus intermedius</i> (3).
19	59	4	<i>E. grandisquamis</i> (40)	<i>A. tapeinosoma</i> (9), <i>C. azureus</i> (5), <i>B. myriaster</i> (5),
20	51	2	<i>A. intermedius</i> (46)	<i>A. tapeinosoma</i> (5)
(°S)				
0	19	4	--	<i>C. valde-rostratus</i> (5), <i>E.</i> <i>sechellensis</i> (5), <i>A. elongatus</i> (5), <i>A.</i> <i>tapeinosoma</i> (4).
1	19	3	<i>B. myriaster</i> (10)	<i>E. latifrons</i> (5), <i>A. intermedius</i> (4).
2	5	1	<i>B. pantherinus</i> (5)	
3	10	2		<i>A. tapeinosoma</i> (5), <i>A. elongatus</i> (5).
4	14	1	<i>E. sechellensis</i> (14)	
5	10	2	--	<i>C. valde-rostratus</i> (5), <i>E.</i> <i>sechellensis</i> (5)
8	5	1	<i>C. valde-rostratus</i> (5)	
9	10	1	<i>E. xenandrus</i> (10)	
10	9	2	<i>C. valde-rostratus</i> (5)	<i>A. intermedius</i> (4)
11	14	2	<i>C. azureus</i> (9)	<i>B. myriaster</i> (5)
13	4	1	<i>E. sechellensis</i> (4)	
14	8	2		<i>C. azureus</i> (4), <i>E. sechellensis</i> (4).

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18	5	1	<i>C. valde-rostratus</i> (5)	
20	7	1	<i>B. pantherinus</i> (7)	
23	5	1	<i>E. cocosensis</i> (5)	
24	5	1	<i>E. grandisquamis</i> (5)	
26	10	1	<i>A. tapeinosoma</i> (10)	
27	10	2		<u><i>C. azureus</i> (5), <i>B. pantherinus</i> (5).</u>
28	15	2	<i>A. aspilos</i> (10)	<u><i>C. valde-rostratus</i> (5)</u>
29	15	1	<i>C. azureus</i> (15)	
31	5	1	<i>B. pantherinus</i> (5)	
32	5	1	<i>C. azureus</i> (5)	
34	10	1	<i>A. imperialis</i> (10)	
36	5	1	<i>A. tapeinosoma</i> (5)	

**Table 27 b - Latitudinal distribution of bothid larvae in the Gulf of Thailand and South China Sea.**

Latitude (°N)	Total (No.)	Species (No.)	Dominant species	Other species
4	75	3	<i>Psettina brevirectis</i> (63)	<i>Engyprosopon grandisquamis</i> (6), <i>Arnoglossus elongatus</i> (6).
5	88	7	<i>E. latifrons</i> (54)	<i>A. tapeinosoma</i> (12), <i>E. cocosensis</i> (8), <i>E. multisquama</i> (8), <i>E. grandisquamis</i> (6), <i>E. xenandrus</i> (+), <i>P. ijimae</i> (+)
6	57	4	<i>P. brevirectis</i> (35)	<i>E. mogkii</i> (6), <i>E. grandisquama</i> (11), <i>A. tapeinosoma</i> (5).
7	130	10	<i>E. latifrons</i> (53)	<i>P. brevirectis</i> (35), <i>E. grandisquamis</i> (20), <i>P. ijimae</i> (16), <i>A. tapeinosoma</i> (6), <i>C. azureus</i> (+), <i>E. cocosnesis</i> (+), <i>E. sechellensis</i> (+), <i>E. xenandrus</i> (+), <i>B. pantherinus</i> (+).
8	186	11	<i>P. brevirectis</i> (90)	<i>E. grandisquamis</i> (38), <i>P. ijimae</i> (31), <i>E. latifrons</i> (14), <i>A. tapeinosoma</i> (11), <i>E. sechellensis</i> (2), <i>C. valde-rostratus</i> (+), <i>E. cocosensis</i> (+), <i>B. myriaster</i> (+), <i>E. pantherinus</i> (+), <i>A. elongatus</i> (+).
9	560	11	<i>P. ijimae</i> (313)	<i>P. brevirectis</i> (130), <i>E. grandisquamis</i> (80), <i>E. latifrons</i> (13), <i>E. multisquama</i> (10), <i>A. tapeinosoma</i> (10), <i>C. valde-rostratus</i> (4), <i>E. cocosensis</i> (+), <i>E. xenandrus</i> (+), <i>B. myriaster</i> (+), <i>B. pantherinus</i> (+).
10	859	13	<i>P. brevirectis</i> (527)	<i>P. ijimae</i> (255), <i>E. grandisquamis</i> (32), <i>E. latifrons</i> (18), <i>E. pantherinus</i> (13), <i>A. tapeinosoma</i> (11), <i>E. multisquama</i> (3), <i>C. azureus</i> (+), <i>E. cocosensis</i> (+), <i>E. sechellensis</i> (+), <i>E. xenandrus</i> (+), <i>B. myriaster</i> (+), <i>A. aspilos</i> (+).

(27 b - Contd.)

11	245	10	<i>P. iijimae</i> (136)	<i>P. brevirectis</i> (95), <i>E. grandisquamis</i> (6), <i>A. elongatus</i> (6), <i>E. cocosensis</i> (2), <i>E. latifrons</i> (+), <i>E. mogkii</i> (+), <i>E. xenandrus</i> (+), <i>B. myriaster</i> (+), <i>A. tapeinosoma</i> (+).
12	97	9	<i>P. iijimae</i> (430)	<i>E. grandisquamis</i> (25), <i>E. latifrons</i> (13), <i>P. brevirectis</i> (7), <i>B. pantherinus</i> (6), <i>A. tapeinosoma</i> (3), <i>E. cocosensis</i> (+), <i>E. mogkii</i> (+), <i>A. elongatus</i> (+).
13	+	3	<i>C. azureus</i> (+)	<i>E. cocosensis</i> (+), <i>A. elongatus</i> (+).
14	24.	8	<i>E. cocosensis</i> (10)	<i>E. azureus</i> (4), <i>E. sechellensis</i> (4), <i>E. xenandrus</i> (4), <i>E. multisquama</i> (2), <i>C. valde-rostratus</i> (+), <i>E. grandisquamis</i> (+), <i>A. tapeinosoma</i> (+).
15	11	6		<i>A. aspilos</i> (3), <i>A. elongatus</i> (3), <i>A. tapeinosoma</i> (3), <i>C. valderostratus</i> (2), <i>E. cocosensis</i> (2), <i>B. pantherinus</i> (+),
16	21	4	<i>E. latifrons</i> (10)	<i>E. cocosensis</i> (7), <i>E. sechellensis</i> (2), <i>E. grandisquama</i> (2).
19	+	1	<i>C. valde-rostratus</i> (+)	
20	+	2		<i>C. valde-rostratus</i> (+), <i>C. azureus</i> (+).
21	+	2		<i>C. valde-rostratus</i> (+), <i>C. azureus</i> (+).
22	+	1	<i>C. azureus</i> (+).	

## 6.8 Frequency of occurrence :

Both in the IIOE and Naga Expedition samples, the frequency of occurrence of bothid larvae was more in the lower density range (Table 28) as in the case of other fish larvae (Peter, 1982). In the Arabian Sea the lower density of larvae of 1 to 5 per 1000m<sup>3</sup> had the highest frequency of occurrence of 38. This was followed by the next density range of 6-10 per 1000 m<sup>3</sup> with 13 occurrences. The highest density, i.e. above 81 had only one occurrence with 111 larvae.

In the Bay of Bengal the frequency of occurrence of the larvae was also maximum in the lowest density range (Table 28). In the 1-5 larvae per 1000 m<sup>3</sup> range there were 30 occurrences. The next high density of 6-10 has 14 occurrences, 11-20 had 12 occurrences, 21-40 had 4 occurrences and 41-80 had 5 occurrences. The range above 81 had only 2 occurrences of 160 and 320 per 1000 m<sup>3</sup>.

In the South West Indian Ocean and South East Indian Ocean lowest range had 6 and 10 and 6-10 had 3 each respectively with an exception of one occurrence of 15 larvae in South West Indian Ocean.

The frequency distribution was also similar in the South China Sea and Gulf of Thailand lowest density range being 4 and 8 respectively. The next range of 6-10 had 3 and 12 and 11-20 had 3 and 14 respectively, whereas 21-40 had 4 and 14 and 41-80 range had 3 and 10. The numbers above 81 had 5 occurrences of 270, 138, 135, 270, 98 and 81 larvae each in Gulf of Thailand.

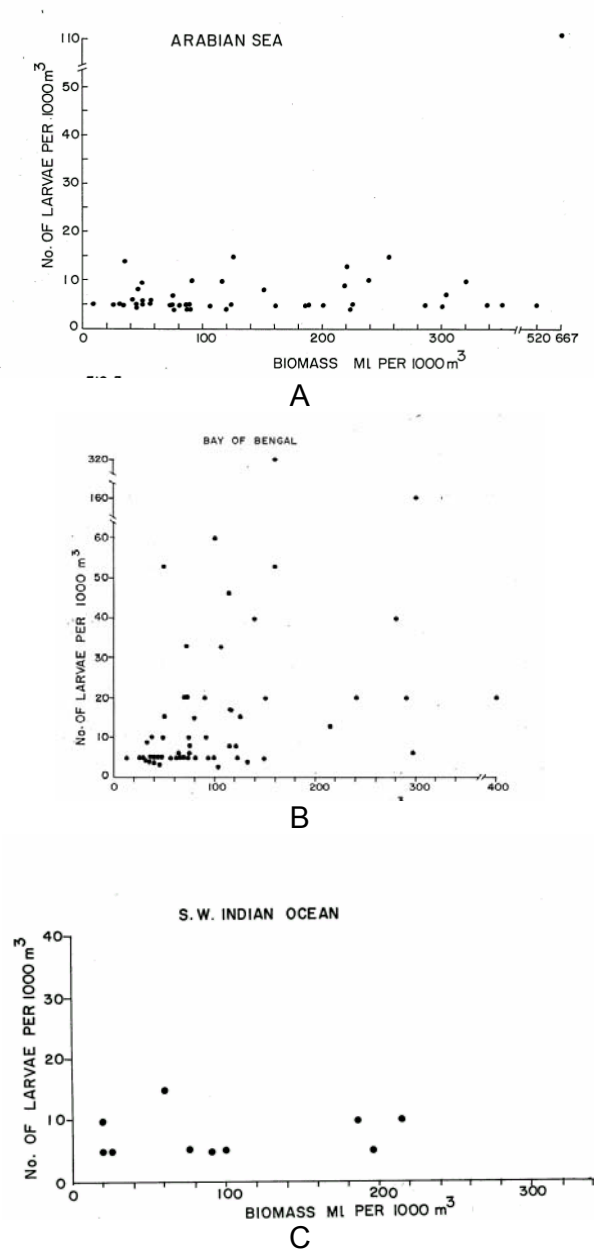
The effect and pattern of the prevailing current is one of the important factors that facilitates the distribution of the larvae. Since the fish larvae are capable of free swimming to some extent they can resist water movements but not with strong currents. The fish larvae being the least protected member of the plankton community fall an easy prey to the predators. This may also contribute to their low density together with natural mortality.

Table 28 - Relationship between number of larvae/ 1000 m<sup>3</sup> and frequency of occurrence.

Class Interval	Frequency of occurrence					
	Arabian Sea	Bay of Bengal	SW Indian Ocean	SW Indian Ocean	South China Sea	Gulf of Thailand
1-5	38	30	6	10	4	8
6-10	13	14	3	3	3	12
11-20	4	12	1	0	3	14
21-40	0	4	0	0	4	14
41-80	0	5	0	0	3	10
Above 81	1	2	0	0	0	5

## 6.9 Larval abundance in relation to zooplankton biomass

The total number of bothid larvae in each sample were plotted against the volume of the plankton from the corresponding station. It was found that there is no direct relationship between the volume of the plankton and the number of larvae. (Fig. 78 A-D).



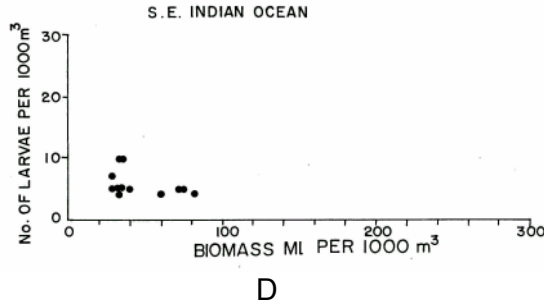


Fig. 78 - Bothid larvae in relation to zooplankton biomass in A- Arabian Sea, B-Bay of Bengal, C-Southwest Indian Ocean, D-South east Indian Ocean.

In the Arabian sea, the maximum number of larvae (10/1000 m<sup>3</sup>) was recorded in highest volume of plankton (667.7 ml/1000 m<sup>3</sup>). But the next lower was 15 from a zooplankton biomass of 2.25 ml/1000 m<sup>3</sup> and equal number from 125 ml/1000 m<sup>3</sup>.

In the Bay of Bengal, the maximum number was 320/1000 m<sup>3</sup> from the zooplankton biomass of 160 ml/1000 m<sup>3</sup>. The next lower numbers were 160, 60 and 53 from zooplankton biomass of 300 ml, 100ml and 50ml respectively.

In the South West Indian Ocean the maximum number was 15 for a zooplankton biomass of 60 ml/1000 m<sup>3</sup> and in the South Eastern Indian Ocean it was 10 for a zooplankton biomass of 37.5 and 33.8 ml/1000 m<sup>3</sup>.

In the Gulf of Thailand, a maximum number of 270/ 1000 m<sup>3</sup> was recorded from a zooplankton biomass of 241 ml/1000 m<sup>3</sup>. 138 and 135 were the next numbers from a biomass of 619 ml/1000 m<sup>3</sup> and 418 ml/1000 m<sup>3</sup> respectively. In the South China Sea the maximum number was 78 from a zooplankton biomass of 296 ml/1000 m<sup>3</sup> (79 A&B).



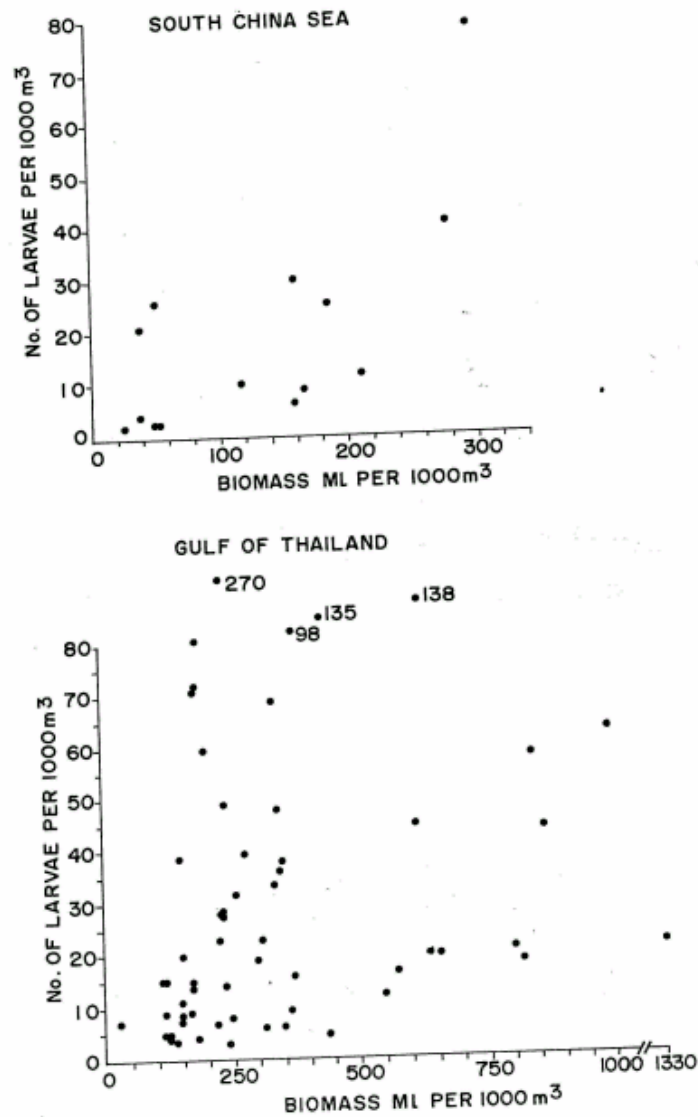


Fig. 79 – Bothid larvae in relation to zooplankton biomass in A- South China Sea, B-Gulf of Thailand

It may be noted that the maximum number of larvae has been collected not from samples having maximum biomass. It varied suggesting that there is no direct relationship between the zooplankton biomass and the number of flat fish larvae.

Strasburg (1960) has reported an inverse relationship between larvae of skip jack and yellow fin tuna and zooplankton biomass, Ali Khan (1972) also found the same inverse relationship in the samples taken from Gulf of Aden. Nakamura and Matsumoto (1966) have stated that large number of fish larvae were contained in low or moderate volume of zooplankton. Peter (1969)

indicated that when the plankton volumes were high, the number of larvae were not proportionately higher or vice-versa. Peter (1982) further observed that the maximum number of larvae were not found in samples of larger biomass, but from samples which were neither high nor low. However, George (1979) has reported a positive correlation from the coastal waters of South West Coast of India.

In the case of bothid larvae there was no correlation between the number and the zooplankton biomass. The presence of predators like medusae, ctenophores, ostracods, chaetognaths, and others may affect the number of fish larvae in the plankton collected. Lebour (1923) has shown that chaetognaths feed on fish larvae. Fraser (1969) has reported that fish larvae form an important food item of medusae belonging to *Aurelia*, *Cyanea* group. Lillelund and Lasker (1971) have stated that heavy predation occurs on sardine larvae by copepods. Nellen (1973) has shown that ostracods also feed on fish larvae. Semi digested larvae were found in the guts of chaetognaths and ctenophores.

The inconsistent and irregular relationship between the number and the biomass could also be due to the type of gear used, region, time, nature and duration of sampling.

Ahlstrom (1961) could not find any relationship between year class strength of sardines and high plankton productivity. Lillelund (1965) found that the biotic factors are more associated with the abundance than abiotic. Steele (1964) has concluded that prediction of fishery resources required more knowledge on the food web structure.

#### **6.10 Biodiversity in relation to ecological factors**

The incidence and distribution of bothid larvae in the Indian Ocean, the Gulf of Thailand and the South China Sea during seasons and different regions appear to be related to the prevailing temperature, salinity, dissolved oxygen and nutrients.

In the Arabian Sea the temperature varied from 11°C to 30°C at stations from where bothid larvae were collected. The upper limit of tolerance to temperature in most cases was found to be around 30°C (Table 29).

The salinity values ranged from 15-40PSU (Table 29). Tolerance to salinity differed in different species of bothid larvae. When larvae of *Arnoglossus tapeinosoma* were found in regions where salinity values varied between 15 and 36PSU, those of *Crossorhombus azureus*, *Bothus pantherinus*, *B. mancus* and *Laeops macrophthalmus* preferred only a very narrow range (34.81 to 35.40PSU). *Engyprosopon mogkii* preferred 35.54 to 36.14 PSU whereas *E. sechellensis*, *C. valde-rostratus*, *Asterorhombus intermedius* and *Arnoglossus imperialis* were found in a salinity range of 35-36PSU. *E. cocosensis*, *A. aspilos*, *A. elongatus* and *B. myriaster* were found at stations where the salinity was 34-36PSU. Other species had no common range. But *E. multisquama* and *E. xenandrus* were also found to occur at stations where the upper limit of salinity was 40PSU (Table 30 a).

In the Arabian Sea, dissolved oxygen values varied from 0.29 to 9.57 mg/l (Table 29). Larvae of *C. valde-rostratus*, *E. latifrons*, *E. multisquama*, *E. xenandrus*, *B. mancus*, *A. elongatus* and *L. macrophthalmus* were collected from regions where dissolved oxygen ranged between 2.86 and 7.14 mg/l. In the case of *E. grandisquamis* the range was 0.86 to 7.86 mg/l and in *B. pantherinus* it was 3.57 to 9.57 mg/l (Table 30 a).

The phosphate phosphorus values ranged from 0.10 to 2.45 µmols and nitrate nitrogen values ranged from 0.1 to 42.9 µmols (Table 29).

In the Bay of Bengal *E. grandisquamis* and *B. pantherinus* were found at stations where the temperature varied maximum from 11°-30°C. *A. elongatus* preferred the minimum range of 27°-29°C. In the Bay of Bengal, larvae of bothids were not found where the temperature was above 30°C and below 11°C.

The salinity recorded for the Bay of Bengal for stations from where bothid larvae were collected ranged between 32 and 33PSU for *A. elongatus*, 32 and 34PSU, for *E. latifrons* and *E. sechellensis*, 32 and 35PSU for *C. valde-rostratus*,

*E. xenandrus*, *B. pantherinus* and *B. myriaster*, 33 and 35PSU for *E. cocosensis*, *Asterorhombus intermedius*, *P. iijimae*, and *Chascanopsetta lugubris*, 34-35 PSU for *E. mogkii* and *Bothus* sp. and 27-35 PSU, for *A. tapeinosoma* (Table 30 a ).

The dissolved oxygen values ranged from 0.29 to 7.86 mg/l (Table 29).

The phosphate phosphorus values varied from 0.01 to 2.43  $\mu$ mol and nitrate nitrogen from 0.1 to 25.6  $\mu$ mol (Table 29).

In the south west Indian Ocean *A. imperialis* tolerated a maximum range of temperature 12° to 20°C. For *A. tapeinosoma*, the range was between 18° and 21°C (Table 30 b).

The range of salinity variation was small, the maximum being 36PSU and minimum 35 PSU. The larvae of *C. azureus*, *C. valde-rostratus*, *A. aspilos*, *A. imperialis* and *B. myriaster* were found in waters where the salinity was around 35 PSU, those of *A. tapeinosoma* and *B. pantherinus* around 36 PSU whereas larvae of *E. cocosensis* were found in water having a salinity range between 35 and 36 PSU (Table 30 b).

The dissolved oxygen values were found to vary between 3.43 and 7.71 mg/l. This range was tolerated by *C. valde-rostratus*, but *A. imperialis* preferred the narrowest range from 6.57 to 7.7 mg/l.

The phosphate phosphorus values showed a variation from 0.11 to 2.20  $\mu$ mol and nitrate nitrogen values were found to vary from trace to 23.4  $\mu$ mol.

In the southeast Indian Ocean, the temperature ranged between 13 and 29°C. *A. intermedius* appears to tolerate 15 and 29°C the widest range and the narrowest range of 19 to 27°C by *C. valde-rostratus*.

The salinity values ranged between 34 and 36 PSU. *A. intermedius* was found in waters having a salinity range between 34 and 35 PSU, *E. sechellensis* and *C. valde-rostratus* were more selective and found only where salinity is

35 PSU. *C. azureus* and *B. pantherinus* preferred a salinity that ranged between 35 and 36 PSU.

The data on dissolved oxygen values were so few that it was not possible to make a comparative assessment.

Nutrients showed the minimum values in the southeast Indian Ocean where 0.06 to 1.31 and 0.0 to 17.8  $\mu\text{mols}$  for phosphate phosphorus and nitrate nitrogen respectively (Table 29).

In the South China Sea, the temperature varied considerably. The maximum ranges recorded were 9 and 31°C. Larvae of *E. cocosensis* were found in these waters. The larvae of *P. brevirictis* were found where the temperature variation was minimum (28.84° and 28.89°C).

The salinity variations were comparatively small in the South China Sea being only 32-35 PSU. Larvae of *E. cocosensis*, *E. latifrons*, *E. grandisquamis*, *E. sechellensis*, *E. multisquama*, *E. xenandrus*, *C. valde-rostratus*, *A. aspilos*, *A. tapeinosoma*, *B. pantherinus* and *B. myriaster* were found in these water masses. The larvae of *C. azureus*, *E. mogkii* and *A. elongatus* were found in water bodies where the salinity ranged between 34 and 35 PSU (Table 30 c).

The dissolved oxygen values varied from 2.57 to 7.14 mg/l. *E. mogkii* was found where the range of variation was minimum (4.86 to 6.7 mg/l).

In the Gulf of Thailand, the temperature of the water column did not show much variation. The maximum variation recorded was 26° to 31°C. Larvae of *E. xenandrus*, *P. ijimae* and *A. tapeinosoma* were found in waters having the above range of temperature. *A. elongatus* larvae however, preferred the narrowest range (28.54° to 28.58°C).

The salinity values varied between 29 and 34PSU. Larvae of *E. xenandrus* and *A. tapeinosoma* were found in waters with the above mentioned salinity range. As in the case of temperature, *A. elongatus* preferred waters with very narrow range of salinity (32.65-32.71 PSU). The larvae of *E. cocosensis*,

*E. latifrons* and *E. multisquama* were found in waters with salinity ranging between 32 and 34 PSU, whereas *E. grandisquamis* and *P. iijimae* were found in areas where the salinity range was between 31 and 34 PSU and between 30 and 34 PSU respectively (Table 30 c).

Larvae of *P. brevirectis* were found in waters where the dissolved oxygen values showed maximum variation (1.71 to 6.71 mg/l), whereas *A. elongatus* and *E. multisquama* preferred water bodies with minimum variation (6.14 to 6.29 mg/l).

The distribution pattern of different species in relation to environmental parameters such as temperature, salinity, dissolved oxygen and nutrients were statistically analysed.

Among the different species studied *Crossorhombus valde-rostratus* showed a significant negative correlation between the larvae and dissolved oxygen values ( $r = - 0.5907$ ,  $p < 0.05$ ). *Engyprosopon sechellensis* also showed the same trend ( $r = - 0.7944$ ,  $p < 0.05$ ) whereas *E. multisquama* and *Arnoglossus aspilos* showed significant positive correlation with dissolved oxygen ( $r = 0.7343$ ,  $p < 0.05$  and  $r = 0.6753$ ,  $p < 0.05$  respectively) indicating that larvae of *C. valde-rostratus* and *E. sechellensis* exhibit a decreasing trend when concentration of dissolved oxygen increases while the other two species show an increasing trend.

While studying the coefficient of correlation between temperature and bothid larvae only *Arnoglossus tapeinosoma* responded to it showing significant positive correlation with temperature ( $r = 0.4266$ ,  $p < 0.05$ ).

The coefficient of correlation between the larvae and salinity showed that *E. cocosensis*, *E. grandisquamis*, *B. pantherinus* had negative correlation ( $r = - 0.6781$ ,  $p < 0.05$ ;  $r = - 0.6358$ ,  $p < 0.01$  and  $r = - 0.9269$ ,  $p < 0.001$  respectively). Larvae of *Arnoglossus tapeinosoma* showed highly significant negative correlation with salinity ( $r = - 0.7059$ ,  $p < 0.001$ ) indicating that these larvae show an increasing trend when salinity decreases.

The larvae of *E. cocosensis*, *E. grandisquamis*, *B. pantherinus* showed the same pattern with phosphate phosphorus ( $r = - 0.6675$ ,  $p < 0.05$  ;  $r = - 0.4580$ ,  $p < 0.05$ , and  $r = - 0.5692$ ,  $p < 0.05$  respectively). Here also *A. tapeinosoma* showed highly significant negative correlation ( $r = - 0.7164$ ,  $p < 0.001$ ) where as larvae of *E. xenandrus* only showed significant positive correlation with phosphate phosphorus ( $r = 0.9713$ ,  $p < 0.05$ ).

The coefficient of correlation between the number of larvae and nitrate nitrogen showed highly significant negative correlation of *E. grandisquamis* and *A. tapeinosoma* ( $r = - 0.7422$ ,  $p < 0.001$  and  $r = - 0.6405$ ,  $p < 0.001$ ) *B. pantherinus* also showed negative correlation ( $r = - 0.8932$ ,  $p < 0.001$ ). *E. sechellensis* ( $r = 1.000$ ,  $P < 0.001$ ) and *E. xenandrus* ( $r = 1.000$ ,  $p < 0.001$ ) showed highly significant positive correlation. *B. myriaster* also presented significant positive correlated ( $r = 0.8994$ ,  $p < 0.01$ ) (Table 31).

Biogeographical distribution of zooplankton – fish larvae – depend on specific environmental factors such as light, temperature, salinity, dissolved oxygen, nutrients, wind, currents, productivity, predation and other biotic components. Even though many fish larvae tolerated a wider range of temperature (eurythermal) some of them were stenothermal. Similarly, euryhaline and stenohaline species were also present. Bary (1963) defines such plankton distribution in terms of their temperature and salinity tolerance (T-S-P diagram). Over large areas, temperature is important in limiting species distribution, which in sub areas, where temperature variation is small, salinity variation restricts the distribution. According to Hoagman (1974), white fish larvae preferred temperature between 12°-17°C, Irvin (1974) noted that this temperature tolerance increased during development up to metamorphosis at which point it corresponded closely with that of juvenile fish in *Solea solea*. Uda (1961) determined the optimum temperature range for 21 species of fish and Rae (1957) has shown that there is a correlation between average wind strength and brood strength of haddock. A very general relationship between zooplankton abundance and tuna catch was brought out by Blackburn (1965, 1969) even though tuna generally occur in waters warmer than 20°C, where zooplankton abundance is less. When temperature was taken into account it was evident that the 20° isotherm determined the overall range of tuna, while

zooplankton concentration determined the distribution of tuna within the animal's temperature range. In general, the prediction of abundance on single or multiple component, this correlation has not been successful. According to Bapat (1955) the maximum spawning activity of fishes of the Gulf of Mannar was during low salinity and temperature periods.

Matsumoto (1959) reported favourable surface temperature ranging from 23.5-29.0°C for *Auxis* of the Dana collections from the Pacific and the Atlantic. Jones and Kumaran (1963) reported maximum number of tuna larvae collected from the Indian Ocean during the "Dana Expedition" where the temperature ranged from 26° to 29°C. In the Gulf of California, Klawe (1963) recorded an optimum temperature of 27°C for *Auxis* larvae. Richard *et al.* (1971) reported the widest temperature range of 21.6 to 30.5°C for *Auxis* larvae and temperature higher than 24°C for the larvae of yellow fin, big eye and skip jack tunas in the Gulf of Guinea and off Sierra Leone. In the case of bothid larvae the temperature was found to be ranging between 9° and 31°C and the salinity between 15 and 40 PSU.

Critical thermal maximum (CTM), oxygen consumption, survival, and behaviour of larval fish were examined by Hoss *et al.*, (1974) as a function of magnitude of temperature change, exposure time and salinity for five species : Atlantic menhaden (*Brevoortia tyrannus*), spot (*Leiostomus xanthurus*), pin fish (*Lagodon rhomboides*) and flounders (*Paralichthys dentatus*, *P. lithostigma* and *P. albigutta*).

Geographical regularities of developments in serially related forms are expressed by similar trends of changes from the tropics to the poles. Such changes are independently formed under the influence of temperature factor (Rass, 1973).

Lalithambika Devi (1977) has reported that highly significant negative correlation exists between number of flat fish larvae and salinity as well as dissolved oxygen.



From the results it is seen that the South China Sea recorded a wider range of variations in temperature (9° to 31°C) than those of the Arabian Sea (11° to 30°C), Bay of Bengal (11° to 30°C), south west Indian Ocean (12° to 26°C), south east India Ocean (13° to 29°C) and Gulf of Thailand (26° to 31°C). In the case of salinity the maximum range was found in the Arabian Sea (15-40 PSU), compared to the Bay of Bengal (27-36 PSU), the Gulf of Thailand (29-34 PSU), south China Sea (32-35 PSU), south east Indian Ocean (34-36 PSU) and south west Indian Ocean (35-36 PSU). In the case of dissolved oxygen values the maximum variation was found in the Arabian Sea (0.29-9.57 mg/l) compared to the Bay of Bengal, followed by the Gulf of Thailand, south China Sea, south west Indian Ocean and south east Indian Ocean. Despite these variations, almost all species of bothid larvae described in the report were present in all these areas under discussion. It may be noted that in general *A. tapeinosoma* tolerated a wide range of temperature, dissolved oxygen and salinity whereas *A. elongatus* larvae were found in regions where the fluctuation in these factors was minimum.

Thus, the results suggest that some species of larvae have the capacity to survive in low oxygen concentrations to which the adults are likely to be exposed when living amidst the bottom deposit.

**Table 29 - Range of hydrographic parameters in the Indian Ocean, South China Sea and Gulf of Thailand.**

	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (mg/l)	Phosphate phosphorus (µmols)	Nitrate nitrogen (µmols)
Arabian Sea	11 - 30	15 - 40	0.29 - 9.57	0.10 - 2.45	0.1 - 42.9
Bay of Bengal	11 - 30	27 - 36	0.29 - 7.86	0.01 - 2.43	0.1 - 25.6
Southwest Indian Ocean	12 - 26	35 - 36	3.43 - 7.71	0.11 - 2.20	Trace- 23.4
Southeast Indian Ocean	13 - 29	34 - 36	5.14 - 7.71	0.06 - 1.31	0.0 - 17.8
South China Sea	9 - 31	30 - 35	2.57 - 7.14	No data	
Gulf of Thailand	26 - 31	29 - 34	1.71 - 7.14	No data	

**Table 30 a - Range of temperature, salinity, dissolved oxygen parameters in the distribution of bothid larvae of the Arabian Sea and Bay of Bengal.**

Species	Arabian Sea			Bay of Bengal		
	Range of			Range of		
	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (ml/l)	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (ml/l)
<i>P. polylepis</i>	---	---	---	21-29	33-34	1.9-5.1
<i>C. valde-rostratus</i>	14-28	35-36	1.8-5.0	13-29	32-35	0.2-5.0
<i>C. azureus</i>	16-29	35	0.9-4.6	13-30	29-35	0.2-4.9
<i>E. cocosensis</i>	13-29	34-36	0.3-5.1	13-29	33-35	0.3-4.9
<i>E. latifrons</i>	14-29	34-35	2.0-4.7	24-30	32-34	2.0-4.9
<i>E. mogkii</i>	15-26	36	0.6-5.0	13-28	34-35	0.6-4.7
<i>E. grandisquamis</i>	15-30	33-37	0.6-5.5	12-30	32-36	0.2-5.5
<i>E. sechellensis</i>	13-29	35-36	0.6-4.8	26-29	32-34	2.0-5.0
<i>E. multisquama</i>	23-29	34-40	1.9-4.6	12-29	31-35	0.5-4.9
<i>E. xenandrus</i>	14-27	35-40	1.9-4.9	11-28	32-35	0.6-4.5
<i>B. myriaster</i>	11-30	34-36	0.4-5.1	12-29	32-35	0.5-4.7
<i>B. mancus</i>	11-23	35	2.2-4.8	---	---	---
<i>B. pantherinus</i>	14-28	35	2.5-6.7	12-30	32-35	0.2-4.9
<i>Bothus</i> sp.	---	---	---	25-30	34-35	----
<i>A. intermedius</i>	14-29	35-36	0.9-4.9	15-29	33-35	0.2-5.3
<i>P. brevirictis</i>	---	---	---	---	---	---
<i>P. iijimae</i>	---	---	---	---	---	---
<i>A. tapeinosoma</i>	13-30	15-36	0.2-5.4	14-30	27-35	0.2-5.4
<i>A. aspilos</i>	13-28	34-36	0.3-4.7	12-29	31-35	0.2-5.0
<i>A. elongatus</i>	15-30	34-36	1.5-5.0	27-29	32-33	4.3-5.2
<i>A. intermedius</i>	---	---	---	---	---	---
<i>A. imperialis</i>	12-26	35-36	0.4-4.9	---	---	---
<i>L. macrophthalmus</i>	16-24	35	2.3-4.6	---	---	---
<i>C. lugubria</i>	---	---	---	12-30	33-35	0.6-4.9

**Table 30 b - Range of temperature, salinity, dissolved oxygen parameters in the distribution of bothid larvae of the South west and Southeast Indian Ocean.**

Species	SW Indian Ocean			SE Indian Ocean		
	Range of			Range of		
	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (ml/l)	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (ml/l)
<i>P. polylepis</i>						
<i>C. valde-rostratus</i>	13-26	35	2.4-5.1	19-27	35	3.6-4.8
<i>C. azureus</i>	17-24	35	3.0-4.8	13-21	35-36	5.0-5.4
<i>E. cocosensis</i>	19-23	35-36	3.5-5.0			
<i>E. latifrons</i>						
<i>E. mogkii</i>						
<i>E. grandisquamis</i>						
<i>E. sechellensis</i>				17-27	35	---
<i>E. multisquama</i>						
<i>E. xenandrus</i>						
<i>B. myriaster</i>	17-24	35	3.0-4.8			
<i>B. mancus</i>						
<i>B. pantherinus</i>	17-23	36	4.3-4.9	16-26	35-36	---
<i>Bothus sp.</i>						
<i>A. intermedius</i>						
<i>P. brevirictis</i>						
<i>P. iijimae</i>						
<i>A. tapeinosoma</i>	18-21	36	4.4-4.9			
<i>A. aspilos</i>	17-22	35	4.0-5.1			
<i>A. elongatus</i>						
<i>A. intermedius</i>				15-29	34-35	---
<i>A. imperialis</i>	12-20	35	4.6-5.4			
<i>L. macrophthalmus</i>						
<i>C. lugubria</i>						

**Table 30 c - Range of temperature, salinity, dissolved oxygen parameters in the distribution of bothid larvae of South China Sea and Gulf of Thailand.**

Species	South China Sea			Gulf of Thailand		
	Range of			Range of		
	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (ml/l)	Temperature (°C)	Salinity (PSU)	Dissolved oxygen (ml/l)
<i>P. polylepis</i>						
<i>C. valde-rostratus</i>	10-28	33-35	1.8-4.7			
<i>C. azureus</i>	10-28	34-35	2.1-4.8			
<i>E. cocosensis</i>	9-31	33-35	2.0-5.0	26-29	32-34	3.3-4.4
<i>E. latifrons</i>	10-29	33-35	1.9-4.7	29-31	32-34	3.5-4.5
<i>E. mogkii</i>	21-29	34-35	3.4-4.7			
<i>E. grandisquamis</i>	10-29	33-35	2.3-4.7	28-31	31-34	3.2-5.0
<i>E. sechellensis</i>	10-29	33-35	1.8-4.8			
<i>E. multisquama</i>	11-30	33-35	2.0-5.0	30-31	32-34	4.3-4.3
<i>E. xenandrus</i>	10-29	33-35	1.9-4.8			
<i>B. myriaster</i>	10-28	33-35	1.8-4.5			
<i>B. mancus</i>						
<i>B. pantherinus</i>	10-28	33-35	1.8-4.8			
<i>Bothus</i> sp.						
<i>A. intermedius</i>						
<i>P. brevirictis</i>	29	32-33	4.3	26-31	29-34	1.2-4.7
<i>P. iijimae</i>	23-29	32-33	4.1-4.6	26-31	30-34	2.9-5.0
<i>A. tapeinosoma</i>	14-39	33-35	2.4-4.9	29	33	4.0
<i>A. aspilos</i>	14-30	33-35	2.4-4.9			
<i>A. elongatus</i>	10-30	34-35	2.3-4.9	29	33	4.4
<i>A. intermedius</i>						
<i>A. imperialis</i>						
<i>L. macrophthalmus</i>						
<i>C. lugubria</i>						

**Table (31) - Correlation of bothid larvae with environmental parameters**

Species	Parameters	Correlation coefficient
<i>Crossorhombus valde-rostratus</i>	Dissolved oxygen	Significant negative correlation. (r = - 0.5907, p < 0.05).
<i>Engyprosopon cocosensis</i>	Salinity	Negative correlation (r = - 0.6781, p < 0.05).
“	Phosphate phosphorus	Negative correlation (r = - 0.6675, p < 0.05).
<i>E. grandisquamis</i>	Salinity	Significant negative correlation (r = - 0.6358, p < 0.01).
“	Nitrate nitrogen	Highly significant negative correlation (r = - 0. 7422, p < 0.001).
“	Phosphate phosphorus	Significant negative correlation (r = - 0.4580, p < 0.05).
<i>E. sechellensis</i>	Dissolved oxygen	Negative correlation

		( $r = -0.7944$ , $p < 0.05$ ).
“	Nitrate nitrogen	Highly significant positive correlation ( $r = 1.000$ , $p < 0.001$ ).
<i>E. multisquama</i>	Dissolved oxygen	Significant positive correlation ( $r = 0.7343$ , $p < 0.05$ ).
<i>E. xenandrus</i>	Nitrate nitrogen	Highly significant positive correlation ( $r = 1.000$ , $p < 0.001$ ).
“	Phosphate phosphorus	Significant positive correlation ( $r = 0.9713$ , $p < 0.05$ ).
<i>Bothus myriaster</i>	Nitrate nitrogen	Significant positive correlation ( $r = 0.8994$ , $p < 0.01$ ).
<i>B. pantherinus</i>	Salinity	Negative correlation ( $r = -0.9269$ , $p < 0.001$ ).
“	Nitrate nitrogen	Negative correlation ( $r = -0.8932$ , $p < 0.001$ ).
“	Phosphate phosphorus	Negative correlation ( $r = -0.5692$ , $p < 0.05$ ).
<i>Arnoglossus tapeinosoma</i>	Temperature	Significant positive correlation ( $r = 0.4266$ , $p < 0.05$ ).
“	Salinity	Highly significant negative correlation ( $r = -0.7059$ , $p < 0.001$ ).
“	Phosphate phosphorus	Highly significant negative correlation ( $r = -0.7164$ , $P < 0.001$ ).
“	Nitrate nitrogen	Highly significant negative correlation ( $r = -0.6405$ , $p < 0.001$ ).
<i>A. aspilos</i>	Dissolved oxygen	Significant positive correlation ( $r = 0.6753$ , $p < 0.05$ ).

## 6.11 Statistical inferences

Coexistence on species, pattern of distribution and dependence of bothid larvae with prevailing hydrographic parameters are studied by statistical methods. The coexistence is studied with the help of the matrix of correlation using Pearson's formula (Snedecor and Cochran, 1967).

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{n \cdot s_x \cdot s_y}$$

where  $\bar{x}$  and  $\bar{y}$  are the means,  $s_x$  and  $s_y$  are the standard deviations of  $x$  and  $y$  respectively and  $n$  represents the number of pairs of observations. The significance of  $r$  is tested using student's 't'

$$t' = \frac{r \sqrt{n-2}}{\sqrt{1-r^2}}$$

The degrees of freedom of 't' is  $n - 2$ . The matrix of correlation is presented in Table 32. Significant positive correlation implies coexistence between species and negative correlation means that species cannot coexist. The expressions a, b and c in the Tables represent the significance at 5%, 1% and 0.1% levels respectively.

The results show that highly significant positive correlation ( $P < 0.001$ ) exists between *E. cocosensis* and *E. latifrons* between *E. latifrons* and *E. multisquama*, *Psettina ijimae* and *Arnoglossus tapeinosoma* as well as between *P. brevirictis* and *P. ijimae*. Highly significant positive correlation also exists between *P. brevirictis* and *A. elongatus*. The correlation is significant ( $P < 0.5$ ) in the case of *E. grandisquamis* and *E. latifrons*. This suggests that interspecific competition is not very rigorous and the above species can be found together at a given time and place.

Highly significant negative correlation at 0.1 per cent level as observed between *E. latifrons* and *P. brevirictis* as well as between *E. Grandisquamis* and *P. brevirictis*, *P. ijimae*, *Arnoglossus elongatus* and *A. tapeinosoma*. Highly significant negative correlation ( $P < 0.001$ ) was also found between *P. brevirictis* and *A. tapeinosoma*. The negative correlation at 5 per cent level was

seen between *P. ijimai* and *A. tapeinosoma*. The results indicate that the above species will have rigorous interspecific competition, may be for food.

The dependence of bothid larvae with hydrographical parameters is evaluated by multiple regression analysis using the mathematical model.

$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$  where  $x_1, x_2, x_3, x_4$  represents temperature, salinity, dissolved oxygen and zooplankton respectively and  $y$  the bothid larvae.

The significance of multiple regression is tested by ANOVA technique. The relative importance of each hydrographical parameter with the bothid larvae is worked out using the formula.

$$b_1 \frac{x_1^2}{y^2}$$

Where  $b_1$  is the regression coefficient of the 1st parameter,  $x_1^2$  is the sum of squares of deviation of the 1<sup>st</sup> variable from its mean and  $y^2$  is the sum of squares of deviation of the abundance of bothid larvae from its mean. The values are presented in Tables 32, 33 and 34.

The multiple regression equation connecting larvae of bothids with maximum and minimum temperature, salinity, dissolved oxygen and zooplankton are given in Table 32 and the relative importance of each of the parameters to the abundance of bothid larvae is represented in Table 33.

While considering the maximum and minimum values, the statistical analysis showed that dissolved oxygen is the most effective parameter regulating the abundance of bothid larvae in the Arabian Sea followed by temperature, zooplankton and salinity. In the case of the Bay of Bengal, the minimum values showed the same trend as in the Arabian Sea but the maximum values a different picture. The relative importance of salinity, temperature and zooplankton followed by dissolved oxygen. The same relation is maintained in the South West Indian Ocean for both maximum and minimum as well as for the minimum values for the Gulf of Thailand. In the Gulf of Thailand, for the case of



maximum values, the zooplankton came next in importance to dissolved oxygen followed by salinity and temperature.

In the Arabian Sea as well as in the South West Indian Ocean the bothid larvae showed significant negative correlation ( $P < 0.05$ ) with maximum dissolved oxygen and significant positive correlations ( $P < 0.01$ ) with minimum values in the Arabian Sea but not significant in the South West Indian Ocean. This may be due to the small sample size of the South West Indian Ocean. The results suggest that the larvae have the capacity to survive in low oxygen concentrations to which the adults are likely to be exposed when living amidst the bottom deposits. In the Bay of Bengal and the South China Sea there was no significant correlation with maximum values but the minimum values showed highly significant positive correlation in the Bay of Bengal ( $P < 0.001$ ) and in the South China Sea ( $P < 0.05$ ). Significant positive correlation ( $P < 0.001$ ) was seen in the Gulf of Thailand for both maximum and minimum values, suggesting that while the Bay of Bengal and the South China Sea followed the Arabian Sea, the Gulf of Thailand behaved differently in the case of maximum values. This might be attributable to the shallowness of the Gulf waters or some other as yet unknown prevailing condition.

In the case of temperature, the Arabian Sea and the South West Indian Ocean showed negative correlation with maximum temperature, significant in the case of the South West Indian Ocean ( $P < 0.05$ ), and positive correlation with minimum. In the Bay of Bengal and the South China Sea both maximum and minimum values showed negative correlation but it was significant with maximum values in the Bay of Bengal ( $P < 0.05$ ) whereas in the South China Sea it was significant with minimum values ( $P < 0.05$ ). In the Gulf of Thailand the relationship was positive in both cases but not statistically significant.

In the case of salinity, the maximum values in the Arabian Sea, Bay of Bengal and South China Sea, showed positive correlation. In the Bay of Bengal, the minimum values showed highly significant positive correlation ( $p < 0.001$ ) whereas it was only significant ( $P < 0.01$ ) in the South China Sea. In the Arabian Sea it was not statistically significant. In the South West Indian Ocean maximum values showed highly significant negative correlation ( $P < 0.001$ ), in

the Gulf of Thailand also it was negative but less ( $P < 0.01$ ). The minimum values showed significant positive correlation in the South West Indian Ocean ( $P < 0.05$ ). In the Gulf of Thailand highly significant positive correlation existed ( $P < 0.001$ ).

The zooplankton values showed that negative correlation existed only in the South West Indian Ocean whereas in all other places it was positive statistically nonsignificant correlation for maximum values except in the Bay of Bengal and where it was significant ( $P < 0.01$ ). All the minimum values showed positive correlation of which those of the Arabian Sea and the Bay of Bengal showed highly significant correlation ( $P < 0.001$ ) and the South China Sea was significant at 1 per cent level.

It is observed that in the Arabian Sea and the Bay of Bengal a significant part of the variability is explained by the multiple regression for maximum and minimum values (Table 35) and for minimum values in the South China Sea whereas a significant part of the variability is not explained by the fitted model in other regions. The unexplained variability may be due to the unaccounted factors such as current, turbidity, depth, stratification and others. The present observation is in agreement with the finding of Iyer and Lalithambika Devi (1977). It is therefore, recommended that when expeditions for the future are planned the above mentioned factors should find a relevant place in the schedule for data collection and analysis.

Table 32 - Coexistence of bothid larvae in South China Sea and Gulf of Thailand. (Corrected two places of decimal after fixing the significance level).

	E.coco-sensis	E.lati-frons	E.mogkii	E.grandi-squamis	E.seche-llensis	E.multi-squama	E.xena-nidrus	P.brevi-rictris	P.lijimae	C.azureus	C.valde-rostratus	A.asplios	A.elong-atus	A.lapeino-soma	B.panth-erinus	M.myri-aster
E.coco-sensis	1.00															
E.lati-frons	1.00 <sup>c</sup>	1.00														
E.mogkii	0.00	0.00	1.00													
E.grandi-squamis	0.00	0.22 <sup>a</sup>	0.00	1.00												
E.seche-llensis	0.00	0.00	0.00	0.00	1.00											
E.multi-squama	0.00	0.87 <sup>c</sup>	0.00	0.02	0.00	1.00										
E.xena-nidrus	0.00	0.00	0.00	0.00	0.00	0.00	1.00									
P.brevi-rictris	0.00	1.00 <sup>c</sup>	0.00	-0.43 <sup>c</sup>	0.00	0.00	0.00	1.00								
P.lijimae	0.00	-1.00 <sup>c</sup>	0.00	-0.54 <sup>c</sup>	0.00	0.00	0.00	0.79 <sup>c</sup>	1.00							
C.azureus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00						
C.valde-rostratus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00					
A.asplios	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00				
A.elong-atus	0.00	0.00	0.00	-1.00 <sup>c</sup>	0.00	0.00	0.00	1.00 <sup>c</sup>	0.00	0.00	0.00	0.00	1.00			
A.lapeino-soma	0.00	0.97 <sup>c</sup>	0.00	-0.89 <sup>c</sup>	0.00	0.00	0.00	-0.54 <sup>c</sup>	-0.20 <sup>a</sup>	0.00	0.00	0.00	0.00	1.00		
B.panth-erinus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
M.myri-aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

a = P < 0.05

b = P < 0.01

c = P < 0.001

**Table 33 - Dependence of bothid larvae with hydrographical factors.**

Arabian Sea	Max.	$y = - 8.8875 + 2.0022x_1 - 0.09241x_2 - 3.0232x_3 + 0.0686x_4$
Arabian Sea	Min.	$y = - 3.6526 + 1.3516x_1 - 0.5094x_2 - 0.1618x_3 + 0.0548x_4$
Bay of Bengal	Max.	$y = 838.0163 + 8.3579x_1 - 29.0824x_2 - 12.1505x_3 + 0.0930x_4$
Bay of Bengal	Min.	$y = - 47.8644 + 4.4739x_1 - 0.3332x_2 - 4.6346x_3 + 0.0702x_4$
SW Indian Ocean	Max.	$y = 425.0659 - 1.2160x_1 - 11.6295x_2 + 3.9952x_3 - 0.0106x_4$
SW Indian Ocean	Min.	$y = 240.9669 + 0.2219x_1 - 6.9761x_2 + 2.4956x_3 - 0.0088x_4$
South China Sea	Max.	$y = 361.0748 + 0.7005x_1 - 11.3727x_2 + 2.2947x_3 + 0.1244x_4$
South China Sea	Min.	$y = - 729.2581 + 4.2821x_1 + 21.3859x_2 - 22.2686x_3 + 0.1759x_4$
Gulf of Thailand	Max.	$y = - 37.8524 - 0.3684x_1 + 4.1832x_2 - 13.1548x_3 + 0.0186x_4$
Gulf of Thailand	Min.	$y = - 268.0377 + 3.3224x_1 + 6.2063x_2 + 1.3355x_3 + 0.0090x_4$

Y = bothid larvae ;  $x_1$ ,  $x_2$ ,  $x_3$  &  $x_4$  = Temp. (°C) ; Salinity (PSU) ; Dissolved oxygen (ml/l) and zooplankton biomass (ml/1000 m<sup>3</sup>).

**Table 34. - Relative importance of hydrographic parameters in the Multiple Regression.**

Region		Temp.	Sal.	DO	Zoo
Arabian Sea	Max.	0.8896	0.1739	198.7000	0.4951
"	Min.	1.0721	0.1515	6.0572	0.2253
Bay of Bengal	Max.	6.5415	10.4179	1086.7881	5.0322
"	Min.	0.8135	0.0771	62.1010	0.5651
SW Indian Ocean	Max.	1.0756	1.6807	185.7799	0.0224
"	Min.	0.0184	1.7896	58.3812	0.0097
South China Sea	Max.	0.3049	2.0166	172.6091	2.1299
"	Min.	0.5684	2.5836	561.9177	1.0103
Gulf of Thailand	Max.	0.2752	0.5933	2691.0797	0.7134
"	Min.	2.2997	2.9616	250.6327	0.3167

**Table 35 – ANOVA Table of Multiple Regression of Bothid larvae with hydrographical parameters.**

	Sources	SS	d.f.	MS	F	VER%
Arabian Sea Maximum	Total	217.5049	52	4.1828	7.01 <sup>c</sup>	32.49
	Regression	81.9558	4	20.4890		
	Deviation	135.5491	48	2.8239		
Arabian Sea Minimum	Total	670.4184	52	12.8927	8.47 <sup>c</sup>	36.48
	Regression	277.3521	4	69.3380		
	Deviation	393.0663	48	8.1889		
Bay of Bengal Maximum	Total	43.2982	60	0.7216	6.35 <sup>c</sup>	26.29
	Regression	13.5134	4	3.3784		
	Deviation	29.7848	56	0.5319		
Bay of Bengal Minimum	Total	1956.6583	60	32.6110	4.98 <sup>o</sup>	20.95
	Regression	513.0356	4	128.2590		
	Deviation	1443.6225	56	25.7790		
SW Indian Ocean Maximum	Total	25.1512	9		<1	N.S
	Regression	7.7692	4	1.9423		
	Deviation	17.3828	5	3.4764		
SW Indian Ocean Minimum	Total	93.3098	9		<1	N.S
	Regression	24.4533	4	6.6133		
	Deviation	66.8565	5	13.3713		
South China Sea Maximum	Total	19.3270	13		2.92	N.S
	Regression	10.9236	4	2.7309		
	Deviation	8.4034	9	0.933		
South China Sea Minimum	Total	171.7436	13	13.2110	4.32 <sup>a</sup>	50.51
	Regression	112.9042	4	28.2261		
	Deviation	58.8394	9	6.5377		
Gulf of Thailand Maximum	Total	72.6013	52	1.3962	<1	N.S
	Regression	1.4302	4	0.3576		
	Deviation	71.1711	48	1.4827		
Gulf of Thailand Minimum	Total	86.2663	52		<1	N.S
	Regression	3.0279	4	0.7570		
	Deviation	83.2384	48	16.6477		

SS = Sum of squares; d.f = degree of freedom; MS = Mean square; F = Variance ratio; VER = Variability explained by the regression; a = p < 0.05;

C = P < 0.001. N.S. = Not significant

## 7. SUMMARY

1. A systematic account is furnished on the larvae of flat fishes (bothid larvae) of the Indian Ocean. The distribution and relative abundance of the larvae are described and discussed in relation to the prevailing environmental factors.
2. The scope and purpose of the subject are indicated and the need for promoting taxonomic studies which have been shunted to remote corner by the modern approaches in biological sciences has been advocated particularly in the light of new investigations on the vent fauna. The progress in the study of systematics of larval fishes is improving consequent on the availability of more and more plankton materials through expeditions and offshore routine cruises of Research Vessels. However, the information on the larvae of flat fishes especially those of bothids is more confusing than clear owing to the paucity of material and inadequate literature on the subjects.
3. Larvae of bothids collected during the International Indian Ocean Expedition (1960-65) from the Indian Ocean and the Naga Expedition (1959-61) from the South China Sea and the Gulf of Thailand were worked out by serial method of linking backwards from identifiable stages. Whenever possible, the larval material was studied in three series. Morphometrics were taken with the first series. Second series was used for differential staining for cartilages and bone using enzyme digestion for removing flesh. Morphological details were studied with the third series. Three stages were recognised to describe the larval stages depending on the flexion of the notochord. Distribution and abundance of larvae were represented in charts. Statistical analysis were done to assess the correlating factors.
4. Bothid larvae belonging to 24 species coming under the genera of *Parabothus*, *Crossorhombus*, *Engyprosopon*, *Bothus*, *Asterorhombus*, *Psettina*, *Arnoglossus*, *Laeops* and *Chascanopsetta* are studied, out of which 16 species are described and reported for the first time. Larvae belonging to *Engyprosopon cocosensis*, *E. latifrons*, *E. mogkii*, *E. grandisquamis*, *E. sechellensis*, *E. multisquama*, *E. xenandrus*, *Bothus myriaster*, *B. pantherinus*, *Psettina brevirictis*, *P. iijimae*, *Arnoglossus tapeinosoma*, *A. aspilos*, *A. elongatus* and *A. imperialis* are

described in detail since most of the developmental stages of the above mentioned species are available.

5. A review is provided on the environmental characteristics of the Indian Ocean in the second part which explains the zoogeography and diversity.
6. The larvae of bothids occurring in the coastal waters in places far apart from each other suggest the absence of special breeding grounds. The larvae are found in the plankton mostly during night, with a preponderance during October to April in the Indian Ocean. In the Gulf of Thailand and the South China Sea their incidence was high during April to October.
7. In the Indian Ocean as well as in the Gulf of Thailand and the South China Sea, the preflexion stages occur during different months indicating protracted breeding. The occurrence of preflexion stages in coastal and offshore regions suggests discontinuous distribution of adults.
8. Even in coastal areas the larvae are found in isolated regions suggesting that the prevailing currents have only marginal influence in the distribution of these species even though bothid larvae have extended larval life. In some species, a highly significant negative correlation is found with dissolved oxygen which suggests that the larvae are conditioned for a life in the sea bottom where the oxygen concentration is affected by decaying organic matter.
9. Of the 24 species described, 23 belonging to nine genera are found in the Indian Ocean whereas in the Gulf of Thailand and the South China Sea, only 15 species belonging to 5 genera are noticed, suggesting that the diversity of species is more in the Indian Ocean than in the other regions studied. Of the different species examined, the larvae of *Engyprosopon* is found to dominate the Indian Ocean, among them *E. grandisquamis* outnumbered others. While in the Gulf of Thailand and the South China Sea larvae of *Psettina ijimae* are the most abundant group.



10. Among the different species studied, *E. cocosensis* is found preferring April to October period and *E. xenandrus* the other period. Other species apparently do not exhibit such clear cut preference.
11. The distribution of larvae during the different months showed regional variations.
12. Irrespective of the area of collection some species such as *E. latifrons*, *E. grandisquamis* and *A. tapeinosoma* exhibited preference to darkness.
13. The frequency distribution of bothid larvae in general suggested that low density group is more frequent in both IIOE and Naga samples.
14. No direct correlation is noticeable between larvae and zooplankton biomass.
15. The upper limit for tolerance to temperature is 30°C. The salinity tolerance varies with different species. In general, *A. tapeinosoma* tolerates a wide range of temperature, salinity and dissolved oxygen, whereas *A. elongatus* occurs only in waters where fluctuations are minimum.
16. Highly significant positive correlation is noticeable between *E. cocosensis* and *E. latifrons*, between *E. latifrons* and *E. multisquama*, *P. iijimae* and *A. tapeinosoma* as well as between *P. brevirectis* and *P. iijimae*, suggesting that interspecific competition is not very rigorous and the species could coexist. Highly significant negative correlation is seen between *E. latifrons* and *P. brevirectis* as well as between *E. grandisquamis* and *P. brevirectis*, *P. iijimae*, *A. elongatus* and *A. tapeinosoma* indicating possible competition for food. The dependence of bothid larvae is clearly discernible in the case of dissolved oxygen, in the Indian Ocean. But no dependence is noticeable in the Gulf of Thailand and the South China Sea with regard to hydrographic parameters examined. In general it would appear that examination of some more parameters such as current, turbidity, stratification and others would enable a better understanding of the correlation factors.

## 8. Bibliography

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