IV

REVIEW OF OPEN SEA ENVIRONMENTAL CONDITIONS ALONG INDIAN COAST

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The open sea environment in the east and west coasts of India plays a key role in deciding the future of mussel culture along Indian Coast. A review and analysis of the effects of various factors like wind, wave action, currents, tides, hydrology, upwelling and phytoplankton production are given.

INTRODUCTION

The mussels are gregarious sessile bivalved molluscs with a wide range of distribution occurring in tropical, temperate and boral coasts. They favour damp ledges and platforms rather than verticals. There is a marked increase in number and size toward the submerged lower levels and grow on rocks, shingle and mud flats of mid littoral. Soot-Ryen (1955, *Allan Hancock Pacific Expeditions* **20** : 1-174[1]) considers that there are only three or four valid species of mussels with clear cut characters. All other species according to him are mainly geographical and ecological derivatives. Although one species of mussel may be cosmopolitan in distribution living in wider regimen of salinity and temperature, reproductive behaviour, metamorphosis and survival of larvae and adults of a population living in a particular geographical region are limited within a specific limits. Here too spawning is possible within a still narrower temperature and salinity conditions. Therefore the ecophysiological parameters between ecological races of mussels cannot be considered the same as a general rule. In this context the ecophysiological parameters of each ecological race of mussels are to be studied.

The total absence of mussel population in the south-east coast and the restricted distribution of the brown mussel to the extreme south-west coast cannot be explained easily to causes other than the absence of a combination of environmental parameters in the areas of absence. The presence or absence of a suitable hard substratum alone for the attachment of mussels does not seem to be the only criterion for mussel population thriving in the area. Further, variations in population density between apparently similar sites suggest physical factors alone are not the sole influence. Therefore, an appraisal of other environmental parameters appear to be necessary to understand their full impetus on mussel.

PHYSIOGRAPHY OF INDIAN COAST

The shoreline from Bombay upto Karwar and that of Andaman and Nicobar Islands is irregular and crenulate. The deltaic and estuarine regions are marshy and protuberant and the rest is wavy and at times geometrically straight. In between Karwar and Janjira the coast is indented and rocky with moderate to high cliffs, notches, stacks, promontories, sea coves and embayments with offshore rocky projections. Similar evidences of submergence are also discernable in Andaman and

Nicobar Islands. South of Chilka lake, the regions of Vishakapatnam, Mahabalipuram, south of Tiruchendur, between Cape Comorin and Colachel and upto Quilon are rocky and often with cliffs.

Shelf

In the shallow coastal and shelf waters the amount of organic matter reaching the bottom and thus available to attached forms like mussels is high for three reasons, namely phytoplankton production is higher than the further offshore areas, the distance through which material has to sink and hence the opportunity for it to be consumed in the water column is less and there is lateral transport from the areas of intensely high primary productivity in seaweed beds, coastal marshes and estuaries. The continental shelf is widest in the Gulf of Cambay being more than 400 km and narrowest off the delta of Krishna and Sunderbans, wherein it is less than 30-35 km. The eastern shelf is nearly one third of the width of the west. On the east coast, slope of the shelf is usually 21′ and in the west it ranges from 10′ near Cape Comorin to 1′ in Gulf of Cambay (Ahmed, 1972 *Coastal Geomorphology of India*, Orient Longmans Publish, 222 pp.[2]). The 10 fathom line is usually parallel to the coast while 5 fathom line which is of considerable importance for mariculture show considerable variation. The 5 fathom line generally lies very close to the shore in areas of high cliffs, near promontories and canyons. The Rann of Kutch is a dry swamp for most part of the year. The Gulf of Kutch and Palk Strait are shallow. The shelf is narrow and steeper in the south west coast from Cape Comorin to Trivandrum, wherein it is occasionally less than 30 metres. In east coast the 5 fathom shelf extends for 200 m to 23 km from Hooghly to Mahanadi and further south it is 200 to 1200 metres.

Wind

The four seasons are : 1. Winter—from December to February, 2. Summer or premonsoon—from March to May, 3. South-West Monsoon—from June to September and 4. Postmonsoon in October and November. The bulk of rain is due to the South-West Monsoon which first establishes in the south-west coast of Kerala and progresses northwards upto Bombay and thereafter progresses towards Assam in land. The fifty yearly mean for establishment is May 29 while the earliest and latest dates are May 7 and June 10 (Ramdas, 1974, '*In-Ecology and Biogeography*' *in India* : 99-134, Dr. W. Junk, b.v. publishers, The Hague[3]). The coasts of Kerala, Konkan and Maharashtra which are important as mussel growing areas receive more than 250 cm of rain. The east coast, except the southern most sector also receives considerable rain ranging from 75 to over 125 cm during South West Monsoon. The South-West Monsoon starts retreating by the beginning of September and on further retreat transforms itself into North-East Monsoon during November and December. The rainfall during the North-East Monsoon in the months of September to November is not heavy compared with South-West Monsoon. During this time with the onset of winter, local heat and moisture give rise to tropical cyclones, most of which originate near Andaman Islands and move in westerly, north-westerly direction towards the east coast. The rains lash along with wind the Circar and Coromandal Coasts and the southern districts during October to December. Severe cyclonic storms originating in Arabian Sea and Bay of Bengal in combination with heavy rains occur on an average one or two during the transitional period of April-June and two or three in the postmonsoonal period. Tidal waves may also lash the coastal regions especially on the east coast during this period. (Ramdas, 1974[3]), Mani, (1974, In—'*Ecology and Biogeography in India*' : 135-158., W. Junk b. v. publn. The Hague[4]). Rao and Mahadevan (1958, *Andhra Univ. Mem. Oceanogr.* **2** : 33-47[5]) give a chronological table of storms in east coast during 1937 to 1954.

Wave

In the west coast the most important wave generating winds are the South-West Monsoon and in the east coast it is the North-East Monsoon. The South-West Monsoon strikes the west coast orthogonally and on the Orissa Coast it is roughly parallel or slightly oblique and causes local littoral current. The North-East Monsoon is powerful on the coast south of Krishna delta during mid September to mid April and is mostly transverse to the shore, which stirs up bottom sediments and the water becomes turbid. The size of the wave is due to the velocity and the distance travelled (fetch) by the wave generating wind. Theoretically for a fetch of 5 to 500 km the height of the wave ranges from 0.9 to 6.2 m. Further for a wind of 5 to 20 metre per second the height of the wave could be 1 to 10 m. In India the monsoonal winds blow continuously for a reasonably long duration. Further the South-West Monsoon originates about the north of equator and travels a distance of about 3000 km and the North-East Monsoon about 1500 km before reaching the Indian Coast whereby facilitating a longer fetch (Ahmed, 1972[2]).

Surface Currents

In Indian Ocean the current system is peculiar in the respect that the surface circulation in the North Indian Ocean is subject to alternating monsoons. Herein the system is comparable to that of the Pacific and Atlantic during the North-East Monsoon (November-March/ April). Generally the currents go round Ceylon and so they do not affect drastically the Palk Strait and the Gulf of Mannar and do not enter Gulf of Cambay. The year round general pattern for Bay of Bengal has been worked out in detail (Ganapati and Sarma, 1958, *Andhra Univ. Mem. Oceanogr.* 1 : 168-192[6]). During November-April strong surface current enters into the Bay of Bengal through the Strait of Malaca and forms an anti-clockwise gyral restricted to south-west region, to which water from the equatorial region of the Indian Ocean is also drawn. In December the counter clockwise circulation slowly disappears with the establishment of Westerly Drift. In January in the head of the Bay a clockwise current appears having its southern limit north of 15°N, which spreads later towards south and gets established covering the Bay and remains so until April. For a short duration a counter-clockwise circulation is observable at the head during April which soon fades away. In May with the changing wind pattern deflection of water from the east coast of India south of 15°N in the north-easterly direction results. This East Drift continues upto June and July. Currents along the coast which is of our concern pertaining to the spread of larvae is north to south and turbid during November, December and on the opposite *i.e.* south to north and more transparent during February to May. In January it is transitory. In July/August a counter clock current originates at the head of the Bay having its centre around 'swatch of no ground' and spreads the entire Bay. In the same period off Madras and in the south-west of the Bay clockwise circulation is observable. In September the clockwise circulation off Madras fades off, the anticlockwise gyre still centered near the head is fully established and an anticlockwise circulation in the Gulf of Martaban is formed for a short duration. In addition, a clockwise circulation east of Nicobar group of islands is also present. During October, while the gyre of Gulf of Martaban disappears a counter clockwise circulation appears centered off Madras. Thus there are two anticlockwise and one clockwise currents present in October. In November, clockwise gyre positioned east of Nicobar and the anti-clockwise current centered off Waltair which have by now become weakened fade away, thus resulting in one anticlockwise circulation within the whole of Bay having its centre about 10°N and 85°E.

In the Arabian Sea the circulation is clockwise with a strong southward drift along the west coast of India especially between Calicut and Karwar during South-West Monsoon. With the weakening of South-West Monsoon the current too becomes weak and the northward coastal current associated with sinking occurs along the west coast by December.

Tides

The tides are generally semidiurnal in east coast mixed with preponderance of semidiurnal in the west coast. As usual the range betwen the high and low tides is larger at Spring, *i.e.* close to full and new moon and narrower at neap *i.e.* at first and the third quarter. It is usually maximum at solstices and the diurnal inequality, namely the differences in height of successive highs is generally maximum about the solstices (June and December). The tidal range is near the annual average about equinoxes (March and September), when the diurnal inequality is the minimum. The tidal amplitude is low near the Cape Comorin and it increases with latitude. The amplitude in metres during the spring and neap is as follows : Daman 4.72, 2.16 ; Bombay 3.66 and 1.44 ; Ratnagiri 1.74 and 0.94 ; Vengurla 1.44 and 0.78 ; Karwar 1.44 and 0.67 ; Calicut 0.80 and 0.33 ; Cochin 0.63 and 0.23 ; Quilon 0.61 and 0.24 ; Tuticorin 0.70 and 0.16 ; Madras 1.01 and 0.41 ; Kakinada 1.34 and 0.53 ; Vishakapatnam 1.43 and 0.54 ; and Diamond Harbour (Calcutta) 5.00 and 2.28. In nature, though the zonation of the mussel varies, to a certain extent generalisation resulting in so called ' Mytilus line ' is possible. The upper limit of the ' Mytilus line ' varies in position and form in the beginning of settlement and with growth becomes sharp. In slopy damp surface it is in line with mean high water neap and in vertical wave beaten facets may lie above extreme high water spring. Where such a line exists the main bernacle population is restricted to the upper part of eulittoral zone (Lewis, 1964, *Ecology of rocky shores, Hodder & Stoughton, London* : 323 pp[7]). Immediately below the line the mussel population is dense enough to exclude all barnacles and limpets. A characteristic feature is the tendency of the adult mussels to form discrete, irregularly shaped patches. The general location of the mussels is the eulittoral zone which is below extreme high spring and above extreme low spring. In heavily predated and fished areas presence of mussel beds a few metres below the tide mark is not uncommon. Rao *et. al* (1975, *Indian J. Mar. Sci.*, 4 : 189-197[8]) have recorded *P. viridis* in Dona Paula, Goa 8 m below the level of low water spring.

Hydrology

The Bay of Bengal is surrounded on all the three sides by land and nine major rivers totally empty about

1300 million acre feet of freshwater per year into it along with huge quantity of silt. Therefore salinity at surface and in the coastal regions is brought low. The salinity in the head of the bay varies from 17-24‰ and at times during monsoon it may go still low. The yearly average salinity is 30-33‰ (Pannikar and Jayaraman, 1966, *Proc. Indian Acad. Sci.*, **64** (5) : 231-240[9]). In the coastal waters off Waltair it is maximum—34.7‰ during March to May and minimum during October, November, 24.4‰. (Ganapati and Rao, 1959, *J. mar. biol. Ass. India*, **1** (2) : 224-227[10]). At times it may go as low as 21.81‰ during December (Mojumdar 1967, *J. mar. Biol. Ass. India*, **9**(1) : 164-172[11]), depending on the intensity of North-East Monsoon. In the north at Saugor the salinity is high during March to June and lowest (17.47‰) in October. In Madras, surface salinity ranges between 19.25‰ in November to 28.13‰ in June while at 8 fathoms 34.63‰ in March and 26.24‰ in November. Mandapam area receives little rain during South-West Monsoon and further the influence of drainage from the north is also minimum. Therefore the salinity is high during August, September 36.02-36.47‰ and minimum during December, January, 27.47‰-29.50‰. The salinity minimum is ascribable to the only rainy season which is during the middle of October to November and the influx of low saline water from the north due to the change in current system with the onset of North-East Monsoon. (La Fond, 1958, *Andhra Univ. Mem. Oceanogr.*, **2** : 12-21[12]). Further during South-West Monsoon high saline water enters from south due to currents which contributes to rise in salinity (Jayaraman, 1954, *Indian J. Fish.*, **1** : 345-364[13]).

In Saugor Island the waters are warmest during August to October averaging about 29.0°C and coolest during January to March (23.2°C). In Waltair sea, surface is warmer during June to September (29.5°C) and cool in January, February (24.92°C). The temperature in the coastal water of Madras ranges from 26.2-29.4°C. It is usually high during April-June and again during September-October (29.2-29.4°C) and cooler during December. Since temperature plays a vital role in the reproduction of molluscs, the short period within which mercury drops is noteworthy. In the far south at Mandapam the surface water is warmest during April, May (29.0-29.7°C) falls by one or two degree in the following months and again it is elevated during August to October (28.1°C). January is the coolest (25.2°C) (La Fond, 1958[12]).

The dissolved oxygen in the surface water of Madras ranges between 2.5-5.0 ml/l, while at Waltair and Mandapam 2.96 to 5.59 ml/l and 3.5 to 4.6 ml/l respectively. In Bay of Bengal silicates are usually high while inorganic phosphate is low. Andaman Sea water is reported to be rich in phosphate, probably due to volcanic activity. In Waltair, inorganic phosphate is higher during December, January (1.66 μg-at P/l) and low in March, April (0.27 μg-at P/l). The average maximum for silicate in Waltair is 29.91 μg-at Si/l during September, October and minimum, 7.0 μg-at Si/l during January, March, (Ganapati and Rao, 1959[10]).

Though hydrology of Arabian Sea has been studied in detail the main emphasis had been on vertical profile. Since mariculture of the molluscs is done very close to the shore information about the chemistry and temperature of the coastal waters is needed most. The near shore waters are influenced by the monsoonal drainage and currents. In the west coast upwelling is very close to the shore and oceanic conditions have been observed to be prevalent close to the shore.

The surface temperature shows a bimodal fluctuation and the sea is generally warmer in the south. The maxima and minima vary for different years. Five yearly average for Karwar region show that the yearly temperature range is 24.0 to 32.6°C, with maximum in April/May and minimum in August/September. Primary and secondary peaks generally occur in May and November respectively while in August and January primary and secondary low occur (Noble, 1968, *J. mar. biol. Ass. India*, **10** (2) : 197-223[14]). The physiology of maturity and spawning in molluscs are influenced by spurt in fall and rise of temperature. The difference between the mean monthly temperatures for the following months are above one degree ; February-March + 1.15°C; March-April + 1.35°C; May-June − 1.81°C; and July-August − 1.39°C. (Calculated from Noble, 1968[14]).

Salinity is unimodal, high during summer (April-May) and low during the South-West Monsoon. In certain years during December-January a slight fall has been observed particularly south of Calicut. Since North-East Monsoon is little felt here this low has been attributed to north-west coastal current which brings in low saline water from the south-east coast of India, Subramanyan, (1959, *Proc. Indian Acad. Sci.* **50** B(4) : 189-252[15]). The near maximum salinity along west coast is 38.4‰ in May and at times salinity values as high as 40.8‰ also been recorded off Bombay. Further there is a tendency for salinity values to increase towards north, which may be due to the high saline Red Sea water entering and the low precipitation level in the bordering, north-west, north and north-east arid regions. Further due to the coastal currents during the South-West Monsoon the drainage from the rivers are usually pushed south along the coast, while to the northern coast currents bring high saline waters.

Dissolved oxygen is usually 3.45 to 5.13 ml/l along the west coast. It is usually high during rainy season and very low while upwelled waters move towards the coast. The inorganic phosphate along the coastal waters along the west coast is bimodal. The values are high during February-April and June-October. In waters off Bombay average value is 0.21-0.35 μg-at P/l while values around 1.15 μg-at P/l also been recorded. In Calicut it may go as high as 1.92 μg-at P/l and usually ranges 0.13 to 1.68 μg-at P/l. At Karwar it varies between 0.12-2.42 μg-at P/l and at times 4.17 μg-at P/l also has been observed. Unlike phosphate, silicates show a unimodal seasonal fluctuation. In Bombay, silicates are usually high during January-March, in Karwar July-August and at Calicut July-September. Silicates are usually very high near river months—260.0 μg-at Si/l near Korapuza river mouth (Rao and George, 1959, *J. mar. biol. Ass. India*, 1(2) : 212-223[16]) and near Kali river it is 149.25 μg-at Si/l, Noble, (1968).[13] Generally silicates are above 5.0 μg-at Si/l at Calicut and over 1.2 μg-at-Si/l in Karwar Coast.

Upwelling and production of phytoplankton

Upwelling is a phenomenon in which deeper oxygen deficient, colder, and nutrient rich water comes up. This is a very important factor ecologically not only because it enriches the euphotic zone, whereby production is geared up along the marine trophic levels, but also the cold water has greater dissolving power of carbonate sediments, whereby upwelling introduces an abnormal rise in calcium carbonate compensation depth. This is a factor of importance for shell bearing organisms like mussels wherein calcium carbonate is a major component.

Outside the limits of the Indian Coastal waters upwelling has been reported during the North-East Monsoon between 50°E and 110°E around mean latitude of 7°S and further north of equator upwelling zones are scattered and are at 5°N to 6°N around 58°E to 70°E. During South-West Monsoon along the Somali Coast of Africa, at about 9°N, strong upwelling occurs wherein, like the Peruvian upwelling, surface temperature drops as low as 13-14°C.

During pre-and early South-West Monsoon season upwelling occurs extensively along the west coast of India, with the maximum intensity in Calicut-Karwar regions. La Fond is of the view that off Godavari delta in the Andhra Coast around March-May upwelling occurs while sinking of the surface water happens during September-November period (La Fond, 1954, *Andhra Univ. Mem. Oceanogr.*, 1 : 94-101 and 117-121[17]). Further there are evidences to show upwelling East of Andaman group of islands.

Primary production along the west coast of India is high and is comparable with any other high productive area, while that of the east coast is not so. Average production in the west coast within 50 m depth is estimated to be 1.19 gC/m^2/day. Off Alleppey, during the postmonsoon period, production ranges from 0.38-1.11 gC/m^3/day. In the wadge Bank the highest value recorded for the Indian coastal region is 4.55 gC/m^2/day while at a station 38 m deep it was 2.09 gC/m^2/day. In Gulf of Mannar and Palk Bay there are two peaks of production, one in April-May and another in October. On an average the estimated production is 3.0gC/m^2/day. The annual production works out to about 230gC/m^2/year for eastern shelf while that of the west coast within 50 m depth it is 434 gC/m^2/year. An extensive treatment of production levels has been given by Nair (1970, *Bull. cent. mar. Fish. Res. Inst.*, 22 : 1-56[18]).

Phytoplankton biomoss show, on the south-east coast, peaks in March, May and October or February, August and November depending on the setting and the intensity of the monsoons. At Madras there are two distinct peaks one in April-June and a minor one in November-December, while in Waltair phytoplankton blooms once in April-May and in the west coast during June-August period. According to Subramanyam and Sarma (1960, *Indian J. Fish.*, 7 : 307-336[19]), 37 phytoplankters, of which 1 blue green alga, 7 dinoflagellates and the rest diatoms, are known as mass forms, which contribute 70-80% of the total biological process in west coast. Standing crop of phytoplankton of east coast is said to be not even 1/4 of the west coast (Jones and Banerji, 1979, In. *Proc. Symp. Living Resources of the Seas around India,'CMFRI*: 1-17[20]). In the inshore waters of west coast during South-West Monsoon phytoplankton standing crop average for a period of five years for net hauls in terms of number has been estimated to be 29×10^6 cells/l. Minimum is to be found during November when it is about 2×10^5 cells/l. The nanoplankton which are 2.20 μ in size vital for mussels as larval feed and so also for the adults have been estimated to range from 30-85% while at times may even be of the order of 96%. In terms of pigment units 248000 Harvey Units/m^3 has been recorded during South-West Monsoon.