THE IMPORTANCE OF SHORE-TYPES IN INTERTIDAL ECOLOGY OF INDIAN MARINE ALGAE

by V. KRISHNAMURTHY *and* K. SUBBARAMAIAH *CSMCRI, Marine Algal Research Station, Mandapam, Tamilnadu*

Intensive studies on the ecology of intertidal marine algae of India are very few. No account has been taken of the shore-type in describing the ecological formations and associations. In most cases, zonation patterns have been described, after the systems proposed for temperate regions. This is not valid for tropical waters such as the Indian coast and rethinking is necessary in formulating an acceptable system of zonation. In this connection a consideration of shore-types in India and the environmental factors operating on them becomes important.

Four basic types of shore can be distinguished along the Indian coasts, viz., (1) sandy shores, (2) rocky shores, (3) coral formations, and (4) estuarine regions. These can be further classified into (i) silt covered rocky areas, (ii) sand covered bedrock extending as a reef into the sea, (iii) steep rocky shores, (iv) rocky shores with overhanging cliffs, (v) coral reefs, (vi) lagoons sheltered by coral reefs, (vii) estuarine lagoons, (viii) backwaters, and (ix) mangrove swamps and salt marshes. The ecological parameters in the different types of shore are considered and their role emphasised in studies on intertidal ecology.

INTRODUCTION

Recently, one of the authors (Krishnamurthy 1967) pointed out certain general considerations on the distribution patterns of marine algae on the Indian coasts. It was shown that the dominant idea in most ecological investigations on marine algae had been to describe the so-called zonation of marine algae and their coincidence with tide levels. It is customary to apply the universal system of Stephenson and Stephenson (1949) to explain the zonation pattern on a coast. Doty (1946) recognised critical tide factors as of primary importance in bringing about zonation on rocky intertidal surfaces and these regulated the subjection of organisms on the shore to the environmental variables. Doty and Archer (1950) produced experimental evidence for the operation of critical tide factors.

In postulating his hypothesis, Doty (1946) had considered only rocky surfaces where an irregular semi-daily tide operated, a condition met with on the Indian coasts also. Most marine ecologists* have been working on rocky intertidal areas and hence little thought has been given to a consideration of different types of shores. A notable exception is the recent study by Lawson (1966) on the littoral ecology of West Africa. The tide factors are not important in all the cases in India and the shore-type determines the dominant environmental factors operating on it. For instance, tide factors do not operate in lagoons separated from the sea for most part of the year by a sand bar. Therefore, the authors attach greater importance to

*For complete bibliography, reference may be made to Doty 1957.

the geographical, geological, topographic and physical nature of the shore. Any part of the coast showing uniformity in all the above factors may be designated as one shore-type. The shore-type determines the relative importance of various other environmental factors operating on the organisms. Thus an environmental factor which plays a dominant role in the vertical distribution of marine algae in any one case is governed by the shore-type. Because of this, a variable which plays a dominant role on one shore-type may play only a minor role on another shore-type. Besides the environmental variables, another important factor to be considered is the biotic factor. The role played by the animal communities inhabiting the seashore in causing zonation of algae or in modifying it, has not been sufficiently stressed. This should always be taken into account in studying the ecology of intertidal marine algae.

The Shore Types of India

A consideration of the coastal regions of India will give us an idea as to the shore-types we meet with. A major part of the east coast of India and the coast of Bengal is sandy, while the west coast of India is predominantly rocky. However, there are patches of rocky shore on the coast, while there are stray sandy regions also on the west coast. The sandy coasts may be wholly sandy or may include outcrops of rocks which are submerged to varying degrees depending on the level at which they occur on the shore. There are also areas which are predominantly shingly, the shingle being formed either of pebbles or of coral fragments. In the latter case, it is indicative of the presence of coral formations in the subtidal regions. The rocky shores consist of igneous or sedimentary or metamorphic rock formations according to the region. The shore may be formed wholly of the silt-covered rocks or may be covered with an extensive sand belt. In the latter case, the sand cover is probably due to deposition by the tidal waters and currents, and the rock itself forms a ledge at the lower-intertidal or subtidal level. This can be seen in many parts of Gujarat, where the sand itself is largely calcareous owing to the presence of small shell fragments. Much of the west coast of peninsular India consists of fairly steep rocky-shore formed of igneous rock, with varying gradients and subject to the full range of the tides. In many places the rock surface may be almost vertical and sometimes with overhanging cliffs. The most interesting shore-type in India is constituted by coral formations. These are especially abundant on the east coast of South India and in the Gulf of Kutch in Gujarat. While the coral formations in South India occupy fairly clear waters, those in Gujarat are mostly covered with silt, thereby showing a different type of habitat. In addition to the above shore-types, one has to consider also the estuarine regions consisting of lagoons with or without connection to the open sea and mangrove swamps. These are special shore-types where many of the factors of marine environment become modified in various ways.

Discussion of the Shore Types

1. *Sandy shores*

More than a half of the total coastline of India is sandy. In most of this region, the shore is wholly sandy and apparently bereft of any algal vegetation.

The reason for this almost barren appearance is the absence of any hard and firm substratum suitable for the attachment of marine algae. However, one should not get the impression that this type of shore is totally lifeless. An examination of the sand especially from that part of the coast which is constantly wetted by the tidal waters, waves and by spray shows the presence of a number of unicellular or filamentous algae. The chief factor controlling their presence appears to be the moisture content of the sand. Other factors such as aeration, air temperature, insolation and wind act as secondary factors modifying the moisture content of the sand. The organisms include, among the algae, soil-inhabiting diatoms, a number of flagellates and a few blue-green algae. Many of these are ephemeral and show seasonal faulty seperation. Another important feature of these algae is their vertical migration through the sand layer.

All sandy coasts, however, are not without some solid substrate. There are shores (Srinivasan 1946; Umamaheswara Rao and Sreeramulu 1964) where an outcrop of boulders protrude from the sand at various levels on the shore with varying amounts of submergence (Fig 1 *A*). Such boulders form an excellent substrate for marine algae and depending on the level of occurrence, exhibit various phenomena of zonation. The boulders are usually scattered and then each boulder has to be considered as a distinct unit inhabiting a particular level and harbouring an algal flora which is adapted to that level. It is, however, possible to visualise the boulders occurring in one vertical row extending from the higher high-water level to the subtidal (Fig. 1 *B*). In such a case the boulders would together present all the characteristics of a rocky intertidal surface and the tide factors would operate as the primary factors governing the zonation of the marine algae on these. In actual fact, the boulders are scattered and very little zonation is recognisable on any one boulder. However, it is often possible to find single well-defined communities or a single species occurring on rocks at a particular level (Umamaheswara Rao and Sriramulu 1963) generally conditioned by a critical tide factor. One important feature of such a shore-type is the periodical sand cover which is caused by deposition by the action of waves and currents (Umamaheswara Rao and Sreeramulu 1964). Such periodical sand cover may have the result of smothering any algal growth at levels at which this occurs. Alternately, the algae at these levels may be able to survive such cover by sand layers. This factor may sometimes be responsible for the seasonal phenomena in the algae of such shores. As one moves from the Northern to the Southern latitudes the tidal range becomes shorter, while the amplitude of waves may be greater, particularly during the monsoon. This may result in the obliteration of any tendency towards zonation.

Another factor to be taken into consideration is the surface of the boulder presented to the onslaught of the waves. While one face of the boulder may be constantly exposed to the force of waves, the opposite face is usually sheltered from it, although it may be bathed by the sea-water. There will always be a corresponding delimitation of the type of algae occurring on the two faces. For instance, on boulders occurring at the higher low-water level at Covelong and Mahabalipuram, *Bangiopsis subsimplex* always occupies the sheltered face of the boulder, while the exposed face is occupied by algae like *Bryocladia thwaitesii*.

2. *Shingle*

Shingles are shores with a layer of stones and pebbles or fragments of coral. In the latter case the presence of coral formations in the vicinity is indicated. The shingle offers suitable substrates for small algae which may be filamentous or leafy or crust forming. These may occur either throughout the intertidal or may be confined to the low water level. Sand cover is frequently met with and this may modify the algal growth. Any current or tidal lift may also cause movements of the shingle which may inhibit algal growth. However, in sheltered lagoons with a shingly beach, the shingle may form a favourable substrate. But there is very little evidence of zonation on these shores. No single factor can be regarded as dominant in such shore-types, and the vegetation is more or less characteristic, consisting of crust forms like *Hildenbrandtia* and *Peyssonelia,* filamentous reds like *Polysiphonia,* filamentous browns like members of the Ectocarpales, green algae like *Cladophora, Enteromorpha* and *Ulva*, and various blue-green algae. The ecology of such shores should be an interesting study.

3. *Rocky shores*

These may be varied in origin, but three principal types can be distinguished with reference to their geology and physical characteristics :

Silt covered rocky flats—occur in various places along the Indian coast, particularly in the vicinity of the Gulf of Cambay and in the Gulf of Kutch. Gopnath, a short distance south of Bhavnagar and located in the Gulf of Cambay is a typical example of such a shore type. The rocky flats here are of recent calcareous sandstone, eroded to various extents and showing a number of gullies and tide-pools. The substrate does not offer a firm hold for the algae. Hence the algal growth is confined to the tide-pools and gullies. The flora is limited to *Ulva* and a few dwarfish filament types which attain their maximum development in tide-pools, e.g., *Polysiphonia* sp., *Gracilaria verrucosa, Enteromorpha* sp. and *Cladophora* sp.

One feature of these flats is the great area exposed during the lowest lower low-water, when there is a vertical emersion of about 12 meters and the shore is emersed to an extent of about 152 meters (Fig. 1 *C*). Therefore, the effect of temperature, insolation and consequent desiccation may be more marked, a possible cause for the delimitation of the algal growth to tide-pools. Salinity and temperature fluctuation of the tide-pools are probably the dominant factors governing the algal growth here.

In Gulf of Cambay locations, the monsoon may bring about distinct changes in the environmental variables, particularly salinity of the sea-water and often turbidity. These may govern the seasonal phenomena in the algal vegetation.

A more common type of rocky shore on the Gujarat coast consists of a bed rock of limestone which becomes covered with a thick sand deposit in the upper intertidal region. The rock itself is often flat or gently sloping into the sea and occupies the lower intertidal region. In some places such a sand cover does not exist and the rock extends beyond the highest higher high-water level. A feature of these rocks is their great expanse, 98–137 meters, and the presence of well-defined shallow tide pools (Fig. 1 *D*). In places where the rock is not covered with sand a zone of littorinids is discernible above the highest high-water level. Between this and the intertidal region marked by the upper limit of the barnacles, limpets (*Cellana* sp.) are well

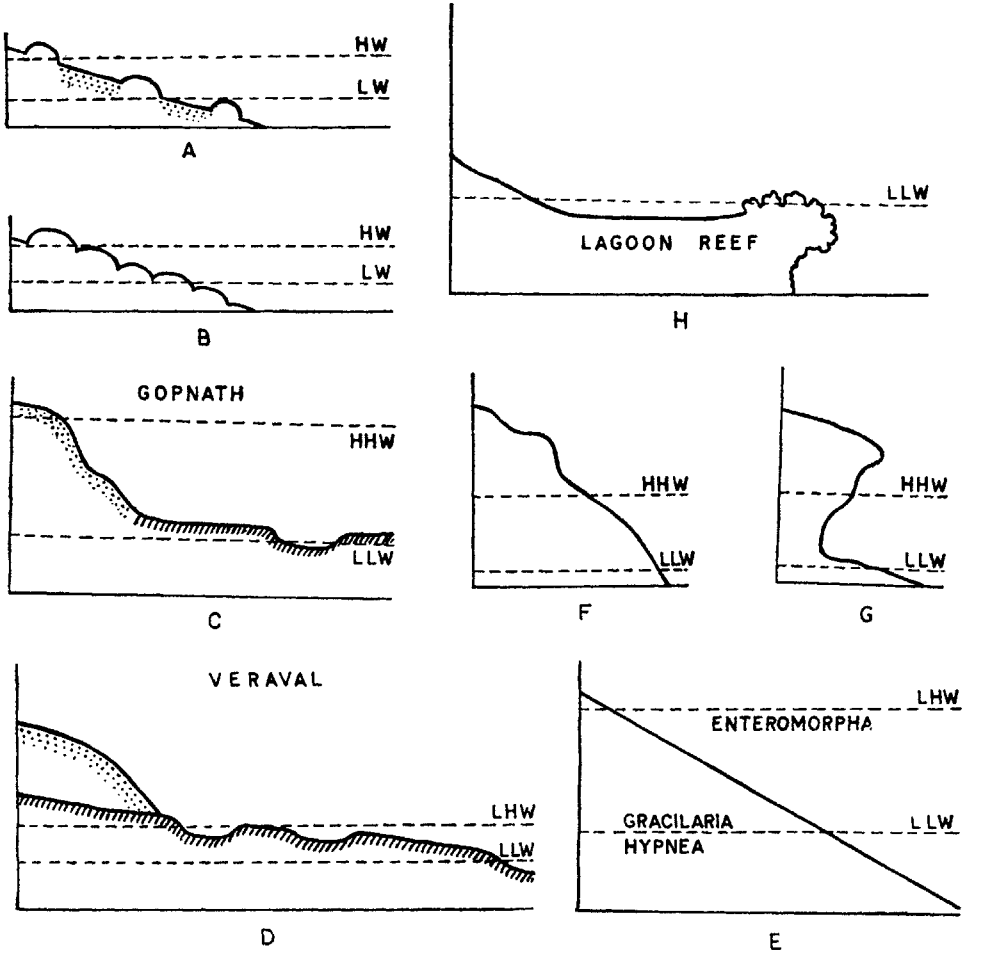

FIG. 1. Diagrams showing the profiles of different shore-types. *A*, sandy coast with outcrops of rocks ; *B*, hypothetical structure of *A* with the scattered rocks placed in a continous vertical line ; *C*, rocky flat as at Gopnath ; *D*, rocky shore as at Veraval, Gujarat coast ; *E*, diagram to show the 'breaks' of *Enteromorpha* and *Gracilaria-Hypnea* zones at Veraval ; *F*, steep rocky shore ; *G*. steep rocky shore with overhanging cliff ; *H*, coral-reef and associated lagoon.

represented. However, algal growth is very poor in this region except for some blue-green algae and a sparce growth of *Enteromorpha.* In regions where sand cover exists, the entire reef is covered with abundant algal growth and the upper limit of the algal zone is delimited by the sand cover. The reef itself extends from the subtidal level up to the lower high-water level. Clear breaks in the algal vegetation occur at the lower low-water level where a zone of *Gracilaria* and *Hypnea* is present and at the lower high-water level where a zone of *Enteromorpha* and *Ulva lactuca* is present (Fig. 1 *E*). Between these two zones is a region where there is no evident

zonation and the algae occur widely scattered and intermingled, although attempts have been made to recognise clearly marked subzones (Misra 1960). The delimitation of the *Enteromorpha* zone and the *Gracilaria* zone is probably caused by the critical tide factors operating at the lower low-water and the lower high-water levels.

Seasonal fluctuation in temperature is from 20 to 35°C, but during summer-insolation the reef is protected by the occurrence of the lower low-water during the nights while there is a comparatively small emersion during higher low-water. This ensures a rich algal growth at the lower intertidal region throughout the year. From the point of view of seasonal phenomena, one can discern two associations, one occupying the upper part of the reef and the other, the lower part. The upper association is subject to climatic effects, strong summer insolation with high temperatures, a short monsoon with an intense and widespread rainfall and strong shoreward winds, which have the effect of increasing the turbidity of the sea-water and bring about greater sand cover on the upper part of the reef. The lower association marking the break at the lower low-water level shows seasonal vertical migration along with the fluctuation in the low-water level.

The algal flora is mainly composed of green and red seaweeds, the browns being few and mostly confined to the subtidal. Tide-pools are small and shallow and show a distinctive flora in which *Cystoseira* or *Gelidiella* is dominant. Fluctuations in temperature of the tide pools may be an important factor in the survival of species in the pools.

Steep rocky shores characterise much of the west coast of India from Bombay down to Kanyakumari and are interrupted at frequent intervals by sandy areas associated with creeks, rivers, backwaters, etc. The more northern coasts (from Bombay down to South of Ratnagiri) form part of the Deccan Trap and the rocks on the shore consist of green to black basalt. The southern coast consists of Archaean gneiss and schists as well as laterites. There is no flat reef anywhere on these coasts, the rocky shore being steep and sloping sharply into the sea. The inclination of the shore determines the breadth of the algal cover (Fig. 1 *F*). These rocky shores do exhibit a zonation pattern which may be prominent as in northern latitudes or insignificant as in southern latitudes because of the differences in the tidal range. The northern latitudes have a higher tidal range while in the southern latitudes the amplitude of the waves is greater than the tidal range. This is one reason why zonation is obscure in the southern latitudes.

Very frequently on the steep shores, there are places with overhanging cliffs (Fig. 1 *G*). These cause a microclimate of low temperature, high humidity, low intensity of light and shelter from the elements such as rain, wind, etc. which may govern the distribution of marine algae on these shores.

Although steep rocky coasts of the types described above do exist along the west coast of India, very little is known regarding the ecology of the marine algae on these shores. The only regions where collections of algae have been made and described are Bombay (Boergesen 1930, 1932, 1933, 1935) and Malwan (Dixit 1933, 1940), but little has been studied on the ecology of these places.

4. *Coral formations*

Coral formations are prevalent in the Gulf of Mannar in South India, in the Gulf of Kutch in Gujarat and around the islands of the Arabian Sea and Bay of

Bengal. These are mostly subtidal with occasional emergence from the sea surface constituting a low intertidal reef. Frequently, coral-reefs enclose sheltered lagoons with a shingly bottom (Fig. 1 *H*). The highly calcareous 'coral stones' form very good substrates for the growth of marine algae. The coral-reef, although primarily built by the activity of anthozoans is developed as a result of association of the coralline algae with the non-living calcareous portion of the coral itself. These coralline algae are mostly members of the Rhodophyta, but may also include a few members of the Chlorophyta. The skeletons left behind by the anthozoans and the calcareous crust of the coralline algae together build the coral-reef.

Very little is known regarding the ecology of the coral-reef algae in India, although extensive collections have been described by earlier workers (Boergesen 1937, 1938; Iyengar 1927). However, a few factors of environment can be pointed out here. The reef has an exposed as well as a sheltered face and the algal vegetation on the two faces are distinctive. The sheltered face often consists of a number of variously sized 'coral stones' of irregular shape covered with a large number of algal species. Although a zonation pattern is not visible on the reef as a whole, each stone shows in miniature a zonation of the few species occurring on it. Such a 'microzonation' is a characteristic feature in coral-reefs. The sheltered lagoons formed by coral-reefs have a shingly bottom of coral fragments and the features of such lagoons have already been described in an earlier section.

5. *Easturine lagoons*

These may be open lagoons with connection to the sea or closed lagoons on the sea front but separated from the sea by a more or less permanent sand bar. These are formed usually from creeks cutting back into the land from the sea when open lagoons are likely to be formed, or in association with river mouths. A sand bar may be formed in either case leading to a closed lagoon condition.

In closed estuarine lagoons there is no tidal effect and critical tide factors do not at all operate. In open lagoons also there is no direct tidal effect. The more dominant factors are temperature and salinity of the water, which again fluctuate with climatic conditions (Krishnamurthy 1954). The algal flora is mostly composed of either floating or mud-inhabiting forms which have the capacity to withstand a wide range of salinity. *Enteromorpha prolifera, Cladophora* sp. among the green algae; forms like *Rosenvingea intricata* among the brown algae; *Gracilaria verrucosa, Hypnea nigrescens, Spyridia filamentosa* and *Polysiphonia* spp among the red algae are typical members of the community (Krishnamurthy 1954).

6. *Mangrove swamps*

In India these are also formed in connection with creeks and river mouths and are characterised by marshy tracts with typical mangrove vegetation with members of *Rhizophoraceae* and species of *Avicennia* being predominant. Certain algae are frequently associated with mangroves and these are considered very characteristic. In India these include *Catenella repens, Caloglossa* spp, *Bostrychia tenella, Herposiphonia insidiosa, Murrayella periclados* and *Polysiphonia* sp. among the red algae, and some filamentous blue-greens mostly belonging to the Oscillatoriaceae. The

algae are found attached to the lower parts of the plants, frequently to the roots (pneumatophores). The factors governing the occurrence of these algae are mainly those of a microclimate prevailing in the swamp. Most of these algae are small filament forms and are fairly resistant to desiccation as well as high salinity. They are, moreover, in a vegetative condition throughout and often get detached from their substrates and become free-living. However, no intensive work appears to have been carried out on the ecology of these interesting algae in India.

The above review reveals the very scanty nature of our knowledge of the ecology of marine algae on our coasts. The recognition of the shore-types discussed above should lead to ecological studies on our shores in the directions indicated, yielding fruitful results.

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