

Blooms of phytoplankton along the west coast of India associated with nutrient enrichment and the response of zooplankton

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ABSTRACT

Incidents of blooms of phytoplankton, discolouration of coastal and estuarine waters and swarms of zooplankton are regular features along the west coast of India. These are generally concomitant with changes in the chemical properties of coastal waters. This area is subject to episodic introduction of nutrients during the summer monsoon period (June–September) through river run-off and coastal upwelling. Responses of phyto- and zooplankton to such inputs are often predictable and have been observed to form persistent patterns in numerous investigations.

Along the west coast of India regular blooming of *Noctiluca*, during or immediately after the onset of the monsoon, occurs following increases in phytoplankton populations. Intermittent blooms of species of diatoms and dinoflagellates are also common. Spectacular bloom formations of *Trichodesmium* is a regular phenomenon during the later part of the NE monsoon season. At times, these blooms cover hundreds of kilometres. Very often successions of phyto- and zooplankton communities could be traced. During upwelling period, nutrient-rich cold subsurface waters occur in coastal areas and sometimes penetrate river mouths leading to high abundance of both phyto- and zooplankton.

Cladocerans, amphipods, pteropods, tunicates and herbivorous copepods are some of the common zooplankton organisms which swarm following phytoplankton abundance. Apex communities are usually dominated by chaetognaths, siphonophores and medusae.

INTRODUCTION

Major changes in the physical and chemical properties of coastal waters occur along the west coast of India during the summer monsoon (June–September). During this period, a large nutrient input into the coastal system takes place through river run-off and coastal upwelling. Surface salinity and water temperature come down, nutrient values shoot up, detrital load increases and consequently light penetration diminishes. These rapid changes often lead to very high productions at

primary and secondary levels (Devassy, 1983; Madhupratap et al., 1990). However, even after the event tapers off, effects still last for a good part of the ensuing season (October–January). During the early part of the winter monsoon period (October–April), surface temperature decreases in the northern Arabian Sea (monthly mean for February north of 24°N is 22°C) and blooms develop in association with wind mixing and convective overturning of the surface waters (Banse and McLain, 1986; Shetye et al., 1991). Blooms of phytoplankton and swarms of zooplankton occur during both monsoon periods. This paper reviews the situation and sequences in the neritic ecosystem along the west coast of India.

AREA AND GENERAL HYDROGRAPHY

The west coast of India (ca. 7° N–24° N) is about 3000 km long and has an exclusive economic zone of about 0.7 million km². Many rivers like Sabarmati, Narmada, Tapti, Vaitarna, Savitri, Vashishti, Karli, Mandovi, Zuari, Kali, Gurupur, Netravati, Ponnani and Pamba empty into it (Fig. 1). This area is also one of the most productive regions of the Asian subcontinent. Surface waters here drift south-easterly during March–September and north-easterly during October–February (Shetye et al., 1990). During the NE monsoon season the neritic waters are generally well mixed. Sea surface temperature shows diurnal variation (27–32°C) while salinity remains more or less uniform (35–36‰). The neritic waters have a pH of 8 to 8.3 (Shetye et al., 1990).

Moderate to intense upwelling occurs along this coast coincident with the onset of the summer monsoon and it also parallels the gradual progress of the monsoon from south to north (Madhupratap et al., 1990). This occurs up to 17° N and the signatures of upwelling, surface current (and the undercurrent) grow progressively weaker from south to north and is not noticeable beyond 20° N (Shetye et al., 1990). Upwelled waters were observed in the coastal waters off Cochin (9° 30' N, 76° 15' E) during July–September (Banse, 1968) and off Goa (15° 24' N, 73° 48' E) during August–October (Sankaranarayanan et al., 1978). Nutrient input through upwelling and river run-off during the monsoon season appear to influence the abundances of phytoplankton and, in turn, the community structure of zooplankton along the west coast of India.

PHYTOPLANKTON BLOOMS

Increase of phytoplankton biomass occurs along with the onset of the monsoon in June–July at the southern part of the west coast (Subrahmanyam et al., 1975). Very soon, this extends to the central and northern regions. Often blooms of some species of dinoflagellates/dia-

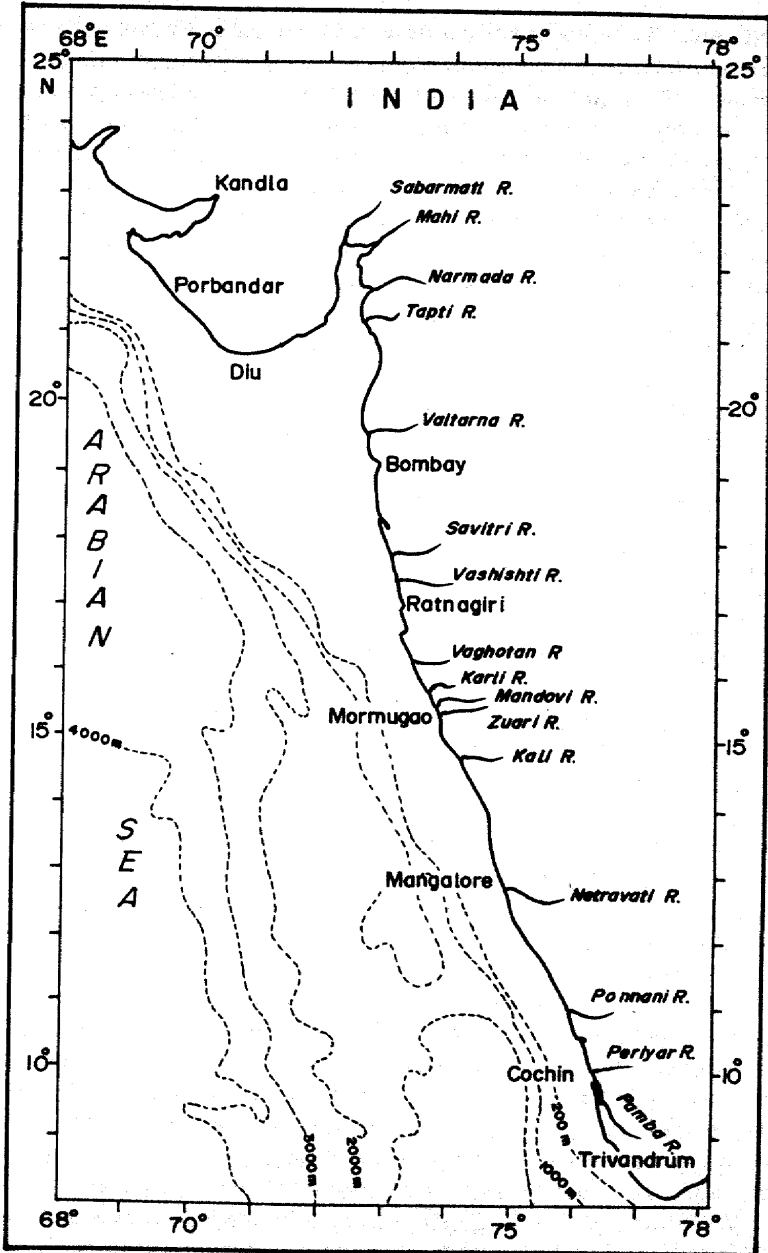


Fig. 1. Map of the west coast of India showing the principal riverine systems.

toms are noticed which are usually followed by swarms of zooplankton.

Noctiluca scintillans is a common bloom-forming organism along the west coast of India. Red tide caused by *Noctiluca* is a regular feature along the coastal waters and estuaries. Usually this happens from August to April (Venugopal et al., 1979; Devassy and Nair, 1987; Anon, 1988) when high abundance of diatoms and other micro-organisms create an ideal situation for these heterotrophs to multiply. Along the southwest coast, *Noctiluca* blooms are an annual feature around August (Venugopal et al., 1979). *Noctiluca* was observed to stay in subsurface (1–2 m below the surface) waters in estuaries in order to avoid low salinity. Their densities ranged from 0.3 to 0.7 million cells/m³ inside estuaries and upwelled waters entering river mouths appeared to initiate the bloom. High numbers of other phytoplankton such as *Ceratium* spp., *Nitzschia* spp., *Skeletonema costatum* were also observed. In a bloom off Goa in September 1973, initial cell counts were around 51 million/m³ and this rose to 1000 million/m³ during its peak and persisted at this level for a fortnight (Devassy, 1989). *Peridinium* spp., *Prorocentrum* spp., *Gymnodinium* spp., *Dinophysis* sp., were other dinoflagellates which occurred along with this bloom. Nutrients were generally higher than normal values when the bloom developed (0.3–3 $\mu\text{m l}^{-1}$ phosphate-phosphorus and 0.7–2.3 $\mu\text{m l}^{-1}$ nitrate-nitrogen) enhancing growth of diatoms. A more recent observation (Devassy and Nair, 1987) describes the bloom of *Noctiluca miliaris* extending about 600 km from Mangalore to Ratnagiri coast (11° 53' N, 74° 48' E to 16° 30' N, 73° 15' E) in February; the entire coastal water was transformed into a greenish soup. During this bloom the *Noctiluca* population varied between 2 and 51 million cells/m³. A flagellate, *Pedinomonas noctilucae* (Subr.) Sweeney harboured in the *Noctiluca* was responsible for imparting the greenish colour. *Noctiluca* blooms have been traced as late as May (Devassy, 1989). In a bloom coinciding with tapering off of a *Trichodesmium* bloom, (Devassy et al., 1979) *Noctiluca* attained cell densities of 64 million cells m⁻³.

Noctiluca blooms are generally followed by a succession of zooplankton organisms. Copepod swarms consisting of a few species appeared a week after the *Noctiluca* bloom (Devassy et al., 1979). This was then followed by swarms of carnivores such as siphonophores and chaetognaths.

Upwelled waters rich in nutrients and low in dissolved oxygen are regularly observed in the subsurface waters of many estuaries along the west coast of India during June–October (Ramamirtham and Jayaraman, 1963; Devassy, 1983). Phytoplankton blooms comprise mainly of diatoms and dinoflagellates and later intense zooplankton swarms occur as a result of this enrichment. Standing crops of phytoplankton reach peaks by the end of October (ca. 550 million cells/m³) with diatoms

dominating. *Coscinodiscus* spp., *Chaetoceros* spp., *Leptocylindrus* spp., *Navicula* spp., *Pleurosigma* spp., *Rhizosolenia* spp. and *Skeletonema* sp. were dominant. A few dinoflagellates like *Gonyaulax* sp., *Peridinium* sp., *Exuviella* sp. and *Prorocentrum* sp. were other components at times (Devassy, 1983).

Fragilaria oceanica dominated a mixed diatom-blue green alga bloom off Manglore in August with high densities (up to 37 million cells l^{-1}) forming about 92% of the phytoplankton population (Devassy, 1974). *Rhizosolenia* sp., *Pleurosigma* sp., *Coscinodiscus* sp. and the alga *Richelia intracellularis* were the other phytoplankters observed along with *F. oceanica*. Inorganic phosphates were high ($2-4 \mu l^{-1}$) during the onset of this bloom.

Regular blooms of *Trichodesmium erythraeum* is a dominant event along the coastal and open waters. These blooms generally start around February and perish by April. Warming of surface waters and increase in salinity are identified as preconditions for the onset of *Trichodesmium* blooms. These blooms were first recorded in the early 1970s (Qasim, 1970; Ramamurthy et al., 1972) and subsequently studied in greater detail from 1975 to 1978 (Devassy et al., 1978) and 1986-1989 (unpublished data). Temperature in the uppermost layer of the water column (0-2 m) during the bloom period varied from $27-31.8^{\circ}C$ and the salinity values ranged between 35.1 and 36.0×10^{-3} . Inorganic nutrients like phosphate-phosphorus were moderately high during the bloom period and then declined. Nitrate-nitrogen is usually low during early bloom season and increased during later phases. The significant point is that *Trichodesmium* filaments are known to fix nitrogen and release it into the environment on its decay (Devassy et al., 1978). Although *T. erythraeum* is the most important species contributing to the blooms, *T. thiebauti* also occurs in small numbers. During peak of the bloom (March-April), densities reach $> 10\ 000$ filaments/ml. These blooms are of irregular shapes and sometimes assume long bands or lanes. *Trichodesmium* blooms are confined to the surface (< 5 cm). *Trichodesmium* filaments occur only in insignificant numbers during the pre-bloom phase. In a matter of few days, a sudden proliferation of filaments occur (Devassy et al., 1978). Later this bloom is accompanied by increases in numbers of several other algal species such as *Nitzschia closterium*, *N. serata*, *Chaetoceros* spp., *Navicula* spp. and *Rhizosolenia* spp. This probably happens because of the addition of nitrogenous nutrients through decay of *Trichodesmium*.

Other phytoplankton species causing bloom situations along the west coast of India are *Asterionella japonica* (off Cannannore in June; Devassy, 1974), *Nitzschia sigma* during May and *Skeletonema costatum*

during November (in Cochin backwaters; Devassy and Bhattathiri, 1974).

ZOOPLANKTON SWARMS

Generally, zooplankton biomass attains peak values along the west coast of India during August–December. Cladocerans, ostracods, amphipods, tunicates, pteropods, mysids, polychaetes and copepods are the common swarming groups.

Cladoceran swarms occur frequently along the west coast of India (Selvakumar, 1970). Higher numbers of these filter feeders are usually found after the phytoplankton cell counts go up and swarms usually start around August and peak by September–October. Cladocerans undergo diapause during unfavourable season (Onbe, 1977) and reproduce sexually and parthenogenetically when environmental conditions become ideal. *Evadne tergestina* appears first and usually outnumber *Penilia avirostris* (Selvakumar, 1970; Nair et al., 1980) probably because the latter is a raptorially feeding herbivore (Kim et al., 1989). Selvakumar (1970) observed that *Evadne* sp. prefers a lower salinity ($16.17\text{--}30.94 \times 10^{-3}$) and seawater temperature ($26.0\text{--}27.6^\circ\text{C}$). Inside estuaries cladocerans also proliferate only during the rainy season when salinity goes down (Madhupratap, 1981). The swarming of cladocerans along the coastal waters appears to have a direct bearing on the mackerel fishery (Selvakumar, 1970).

Abundances of other filter feeders like tunicates also increase during September and attain peak densities by October. The salp *Pegea confoederata* formed swarms off Bombay in October (Lodh et al., 1988) and zooplankton biomass was as high as 7.35 ml/m^3 . This is a recurring phenomenon and their turnover rates are very high. Lodh et al. (1988) found that during this season salps form a major food item to an economically important fish viz. silver pomfrets (*Parastromateus niger*, up to 43% of gut content). Incidentally, along the east coast, tunicates formed > 98% (biomass ca. 4 ml m^{-3}) of zooplankton amidst a bloom comprising diatoms and blue-green algae (Madhupratap et al., 1980). Additionally, carcasses of Thaliacea and abandoned houses of Appendicularia are major constituents of marine snow. These harbour high bacterial biomass and have an important bearing on vertical fluxes.

Swarms of zooplankton are often associated with *Trichodesmium* blooms. A pteropod, *Creseis acicula*, was observed to swarm along with the cladocerans *Penilia avirostris* and *Evadne tergestina* off Cochin in March (Sakthivel and Haridas, 1977). This swarm was associated with a *Trichodesmium* bloom. Zooplankton biomass appears to be directly

related to the state of *Trichodesmium* bloom (Nair et al., 1980). For example, off Goa, the average values of zooplankton biomass (mg dry wt/100 m³) for the bloom period were: January, 165; February, 470; March, 448; April, 504; May, 269. Copepods, decapod larvae, chaetognaths, cladocerans, fish eggs, etc. were the important groups of zooplankters. Nitrogen released into the environment on decay of *Trichodesmium* filaments enrich the waters promoting phytoplankton growth and, in turn, triggers formation of zooplankton swarms. Cladocerans appear first, followed by copepods and later by the gelatinous carnivores. Thus a successional sequence is observed. *Evadne tergestina* is the most common cladoceran. *Temora turbinata*, *Acrocalanus*, *Acartia erythraea* and *Centropages furcatus* are the abundant copepods. Ctenophores, hydromedusae, scyphomedusae, and siphonophores form the tertiary community. Larvae of fishes belonging to the family Atherinidae, Engraulidae, Clupeidae and Perciformes are common in *Trichodesmium* bloom areas. It is interesting that these fish larvae assemble amidst blooms but do not directly feed upon the trichomes. This could be an adaptation to provide maximum food to young fish larvae in the form of associated algae and smaller zooplankters (Nair et al., 1980).

Other species of pteropods, reported to form swarms are *Desmopterus papilio* and *Cavolinia uncinata pulsata* (Sakthivel, 1972). The latter, although an oceanic species, was collected in swarming condition in November off Cochin. Swarms of the pteropod *Creseis acicula* regularly appeared off Goa in October, from 1976 to 1980, and formed 96% of the zooplankton population (Goswami, 1983; biomass 4.94 ml/m³). Swarms of ostracods, salps, medusae and pelagic amphipods were observed off Kutchh (22° 30' N, 69° 30' E) during the period December–May resulting in high biomass (2.8 ml/m³; Paulinose and Aravindakshan, 1977).

Amphipods are also known to swarm along the west coast of India (Nair, 1972). The hyperiid amphipod *Hyperia sibaginis* swarmed off Cochin in April with densities up to 79/m³. In another swarm, gammarid amphipods *Atylus* sp., *Concholestes* sp., and *Corophium* sp. reached very high densities off Cochin along with a swarm of the sergestid shrimp, *Acetes cochiniensis* (Achuthankutty et al., 1973). In this instance the amphipods were found actively feeding on the decaying weeds originating from the freshwater systems associated with the Cochin backwaters.

In a recent study on the response of zooplankton to coastal upwelling (Madhupratap et al., 1990), it was observed that zooplankton standing stock reach very high values in the coastal zone coincident with upwelling. Biomass values up to 12 ml/m³ were encountered. Sequential changes occur in the community structure. As a result of nutrient input, phytoplankton counts increased followed by swarms of herbivorous

copepods. Towards the end of upwelling period, carnivores such as chaetognaths, siphonophores and medusae were also observed in large numbers in the area. Herbivores like *Centropages tenuiremis*, *Temora turbinata*, *Clausocalanus arcuicornis*, *Subeucalanus* spp., *Paracalanus* spp., *Acrocalanus* spp., *Oithona* spp., and carnivores such as *Oncaea* spp. and *Corycaeus* spp. were typical copepod species abundant in the area. However, the high biomass community stayed inshore hugging the upwelling band.

CONCLUSIONS

It is evident from the foregoing account that episodic blooms of phytoplankton and swarms of zooplankton are common in coastal waters of the west coast of India. Changes in the wind field and the onset of the summer monsoon in the northern Indian Ocean set the stage for these. On the other hand, extensive *Trichodesmium* blooms occur during the later part of the NE monsoon providing nutrient enrichment through nitrogen fixation. Phytoplankton blooms in this region, however, appear to be harmless and no large-scale fish mortality has been reported in contrast to certain red tides in some eutrophicated waters (e.g. Taylor and Seliger, 1979; Okaichi et al., 1989; Graneli et al., 1990). Toxic red tide forming dinoflagellate blooms are, by and large, scarce in the Indian waters, but there has been an instance of shell fish poisoning leading to human death (Karunasagar et al., 1984).

On the other hand, such events appear to be of considerable economic importance to the local fishery. Fish catches from the coastal waters of the west coast contribute to about 80% of the total marine fisheries of India (Bal and Rao, 1984). A substantial amount of the catch occurs during or immediately after monsoon (CMFRI, 1987a,b).

Shoaling fishes like sardines, mackerel and anchovies which are plankton feeders are the main stay of this coastal fishery and on many occasions they have been observed to follow the blooms/swarms.

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