

Harmful algal blooms

S R Bhat, Prabha Devi, Lisette D'Souza, X N Verlecar,
C G Naik

Phytoplankton or micro-algae play a vital role as primary producers in all aquatic habitats, but when their population overwhelms other forms of aquatic life, an environmental and economic impact is likely. Very prominent in coastal waters, this population increase or bloom formation generally discolours the surface waters to red, pink, brown, or white. It was red, when such an instance was first reported, and hence the phenomenon carried the name 'red tide' and is now also popularly called as harmful algal bloom. Bloom formation is a natural process and it enhances biological productivity, but turns worrisome when caused by toxic species, leading to massive fish mortalities and hazards to human health. Incidences of 'red tide' are increasing in the Indian seas, particularly along the west coast. Reports on discolouration of waters accompanied by fish mortalities and nauseating stench sickening the people along coastal stretches are quite common. Incidences of paralytic shellfish poisoning are also hitting newspaper headlines. We summarize here some such instances that occurred along the west coast of India, and illustrate how these tiny microscopic forms suddenly grow into a disproportionate mass to draw global concern.

Introduction

The oceans and the seas teem with microscopic organisms called 'plankton', which include both zooplankton and phytoplankton. Most of the plant forms or 'phytoplankton' contain chlorophyll, a photosynthetic pigment that enables them to manufacture their own food, like any land plant. Though tiny in size, their overwhelming numbers, widespread distribution, and photosynthetic ability make them essential components of marine food web. The quantum of food

For correspondence: bhat@darya.nio.org

or organic matter produced by these phytoplankton (by primary productivity) - ultimately determines the production of fish, prawns, mussels, or other seafood that we harvest. Despite being invisible, they play an outstanding role in scavenging atmospheric carbon dioxide and producing about 80% of the oxygen that we breathe. In short, they are essential in many ways to our existence.

What is puzzling is their sudden and explosive growth. The bloom can spread in a matter of days, and disappear just as rapidly. It is not yet clear as to what environmental make-up creates a favourable condition or triggers some of the species to such an explosive growth covering hundreds of kilometres. Several factors have been suggested to be the cause of increased bloom occurrences and their trigger, such as, an increase in anthropogenic (includes aquacultural activities) activities and natural nutrient enrichment of marine environment, transportation of exotic species and cysts, particularly of dinoflagellates via ship's ballast water, translocation of shellfish stock from one area to another, and ocean currents.

Hazards caused by harmful algal blooms

Of the 5000 species of marine phytoplankton, only about 300 have been reported to form blooms while about 80 species have the capacity to produce potent toxins (Hallegraeff 1993). Since blooms cause discernible harm in one way or the other, they have been termed HAB (harmful algal blooms). Some cause massive fish mortality while others, when eaten by marine animals such as shellfish, enter the food web as toxins, proving dangerous to the humans and other animals. Some forms emit toxic aerosols as they decompose, causing respiratory problems. Marine biotoxins and harmful algae pose a significant and extensive threat to human health and fisheries resources throughout the world.

The damages or hazards caused by HABs are given below.

- Decaying of the bloom utilizes dissolved oxygen from the waters, creating oxygen-deficient condition (anoxia), leading to the death of fishes and invertebrates.
- Polymers secreted out into the surroundings by some blooms render the water viscous and make it too difficult for fishes to pump in water through their gills.
- Some species with spiny structures cause irritation to the fish gills and release mucus that damages the gills.
- Heavy blooms cause hindrance to fishing operations and their weight at times damages the fishing net.

But the real danger comes from the toxic forms. Often their toxins enter the food chain of clams, mussels, oysters, and scallops. The four major adverse effects caused by the toxins through shellfish are PSP (paralytic shellfish poisoning), DSP (diarrhetic shellfish poisoning), NSP (neurotoxic shellfish poisoning), and ASP (amnesic shellfish poisoning). Many toxins and their

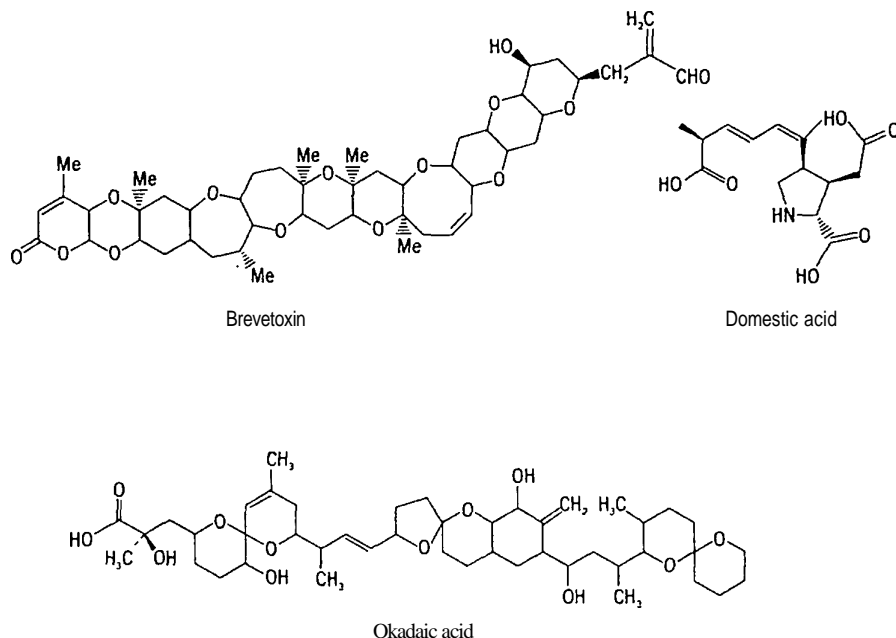


Figure 1 Structures of typical toxins of harmful algal blooms

derivatives such as saxitoxins, gonyautoxins, neosaxitoxins, and brevetoxins have been isolated from shellfish and dinoflagellates. These toxins are considered to be the most potent non-proteinaceous lethal material. Chemical structures of some typical toxins causing illnesses are shown in Figure 1 and syndromes of the affected victims are listed in Table 1.

The presence of toxic species does not necessarily lead to a deleterious impact, as it requires a threshold population above which the effects are discernible.

A variety of toxins are associated with algal bloom episodes, many of which have been identified. They are reported to contain hemolytic, cardiotoxic, and anti-cholinesterase components (Mazumdar, Bupta, Kumar, *et al.* 1997). The massive fish kills associated with Florida red tides are believed to result from the hemolytic fraction. Brevetoxin (PbTx-3) is believed to be responsible for the respiratory irritation associated with toxin inhalation (Baden, Fleming, and Bean 1995). Among all the neurotoxins, brevetoxins are considered to be an important group. The causative organism *Karenia brevis* (formerly *Gymnodinium breve*) produces a suite of 10 polyether neurotoxins that have been isolated in sea water blooms. They occur as intracellular toxins and can be released into the water (Pierce, Henry, Blum, *et al.* 2001). Brevetoxins cause massive fish kills and the filter feeders accumulate them resulting in NSP in

Table 1 Various illnesses caused by harmful algal blooms

Syndrome •	Source	Symptoms	Causative species	Toxins produced
Paralytic shellfish poisoning	Clams, scallops, mussels, oysters, some coral reef gastropods and crabs, lobster	Life-threatening, tingling, numbness, giddiness, muscular paralysis, fever, possible respiratory arrest	<i>Pyrodinium bahamense</i> <i>Alexandrium</i> spp. <i>Amphidinium</i> sp. <i>Cochlodinium</i> sp. and <i>Gymnodinium catenatum</i>	Saxitoxin and its derivatives
Diarrhetic shellfish poisoning	Scallops, mussels, short-necked clams	Nausea, vomiting, diarrhoea, abdominal cramps acute gastroenteritis	<i>Dinophysis</i> spp. <i>Prorocentrum</i> spp.	Okadaic acid, Dinophysis toxin (DTXs)
Neurotoxic shellfish poisoning	Clams, scallops, mussels, oysters	Neurological symptoms, vomiting, diarrhoea, abdominal and muscular aches, dizziness, numbness and tingling of mouth and eye irritation	<i>Amphidinium</i> sp. <i>Cochlodinium</i> sp. <i>Gymnodinium</i> sp.	Brevetoxin
Amnesic shellfish poisoning	Clams, mussels, dungeness crabs, scallops	Nausea, vomiting, abdominal cramps, diarrhoea, chronic memory loss	<i>Pseudo-nitzschia</i> spp.	Domoic acid and derivatives

human consumers. They are also released as aerosols, causing severe respiratory irritation. The neosaxitoxin is one of the main toxins that cause life-threatening PSP syndrome. There is no antidote for PSP. Each year, about 2000 cases of PSP are reported globally with 15% mortality.

The phenomenon of 'phytoplankton bloom', 'red tide', or 'HAB' is episodic, spreading globally and causing enormous economic loss and human health hazards (Hallegraeff 1993; MacLean and White 1985; Smayda and White 1990). In the seas around the US alone, for example in the last two decades, the expansion of HAB has been altogether on a different scale: more toxic species have been identified and many new areas are being invaded. The adverse impact of HAB is estimated to cost 50 million dollars annually.

Transfer of toxins

The transfer of toxins takes place largely through the food web. Zooplankton grazing on phytoplankton play an important role. For a better understanding of HAB dynamics, it is important to study the preference of zooplankton for a particular phytoplankton. Besides the primary food web, toxins affect other trophic levels also; for example, birds or fish that generally do not feed directly on

phytoplankton are also affected. It is through zooplankton feeding on harmful algal species that the toxins get redistributed, firstly in their tissues, and then may be to the excreted faecal pellets that are important toxic vectors of the benthic food web. The fish feeding on benthic toxic algae transfer the toxins to the human consumers, resulting in ciguatera syndrome. Benthic cysts contain more toxins and are very potent (Anderson and Wall 1978). The responsible ciguatoxins have potency similar to PSP or NSP. Exposure to aerosolized red tide toxins also causes human health hazards. The exposure usually occurs on or near beaches with an active red tide bloom that releases toxins into the water and into the onshore aerosol (Pierce, Henry, Blum, *et al.* 2001). The well-known lone diatom genus responsible for this is *Pseudo-nitzschia*.

Blooms along the west coast of India

Compared to east coast, the west coast of India is known for its higher productivity, due to the frequent upwelling process, particularly in the southern region. A strong upwelling is regularly observed here during summer (Prasannakumar, Madhupratap, Dileep Kumar, *et al.* 2000) and the whole of southwest monsoon season, largely restricted to the shelf (Banse 1959). Upwelling is an important process in redistribution of nutrients in the oceanic regime. It causes profound increase in productivity of a region by increasing nutrient content in the euphotic zone. In the process, the cooler nutrient-rich waters from beneath are drawn upwards when strong winds push the warm surface waters away from shore. The plant life, particularly plankton, thrives here and not surprisingly such areas are associated with active fishery (Madhupratap, Nair, Gopalakrishnan, *et al.* 2001) and also regular occurrence of algal blooms.

It was, James Hornell who first recorded observations on algal bloom in the Indian waters, in 1908 (Hornell 1908). While cruising in the coastal waters of Malabar, he witnessed massive fish mortality, largely of sardines floating on the dark yellow coloured waters that contained plankton. But due to time constraints, he could not investigate in detail. However, in 1916, he found *Euglenids* and *Noctiluca* species to be responsible for such episodes (Hornell 1908, 1917). Since then, there have been several reports on various blooms, particularly from the west coast of India.

Trichodesmium and *Noctiluca* blooms

The two most reported blooms from the west coast are those of *Trichodesmium* and *Noctiluca*. Several freshwater species of cyanobacteria (to which the *Trichodesmium* belongs) are known to produce toxic substances, causing public health risk in drinking water reservoir. Some neurotoxic-like substances have been recently characterized from *Trichodesmium erythraeum* and *T. thiebautii* (Jackson, Carmichael, and Carpenter 2001) but literature on *Trichodesmium* bloom

particularly in the Indian seas still group them as non-toxic, which needs to be relooked. The aggregation of *Noctiluca* sp. is reported to produce toxic ammonium.

Trichodesmium forms extensive surface blooms and discolours vast regions of tropical and subtropical seas, with colours varying from red, brown, green, yellow, and silvery grey, depending on the age of the bloom and the concentration of the species. It occurs as a single filament or trichomes that are visible to the naked eye (1-10 millimetres in length) and is one of the conspicuous phytoplankton reported.

Impact of bloom on fisheries

To illustrate a few examples, Panikkar (1959) furnished details on the mass mortality of fish in the Arabian Sea during 1955-58. He attributed this to the rapid increase in the population of *Noctiluca* and *Trichodesmium* during the months of June, January, and October. However, he could not establish whether the mass mortality observed in the region, particularly in longitudes 60°-64° E and latitudes 9°-22° N, was due to the planktonic bloom or the direct influence of upwelled oxygen-depleted waters. Nagabhushanam (1967), while reporting on the bloom in the waters of Minicoy Islands in the Arabian Sea, described the aggregation of *Trichodesmium erythraeum* filaments as unusually dense and extensive covering at least 35 square miles (90.6 square kilometres) around the Island. The sudden fall in the tuna catch in the month of May was attributed to the long duration of the bloom. Similar observations were made by Prabhu, Ramamurthy, Dhulkhed, *et al.* (1971) while carrying out experimental fishing operations along the Mangalore coast, at depths of 12-25 metres. They observed extensive greenish yellow patches of bloom formed by *T. erythraeum*. They did not find any discernible changes in the hydrological features of the surface waters but there was a complete absence of other planktonic species and the bloom had adverse effect on the oil sardines and mackerel fishery in general.

Several reports (Bhimachar and George 1950; Devassy 1983; Devassy and Sreekumaran 1987; Devassy, Bhattathiri, and Qasim 1979; Qasim 1970; Ramamurthy, Selvakumar, and Bhargava 1972; Thajuddin and Subramanian 2002; Verlecar 1978) also suggest an adverse effect on fisheries and other fauna. One obvious cause for this effect was high demand for oxygen by the bloom biomass, particularly during its decay phase. It exhausts dissolved oxygen from the surrounding waters, thus depriving it to the fish and other associated fauna. The *Trichodesmium* filaments have also been found to create a physical barrier to the fish and damaging their gills when they pump in filament-laden water.

Noctiluca blooms are known to occur along the southwest coast of India during the monsoon and post-monsoon periods but less frequently than the *Trichodesmium* blooms. *N. scintillans*, commonly called 'sea sparkle', is a single-celled heterotrophic dinoflagellate. When it forms bloom, the water is

discoloured pink or green. The reason for this variation in colour is not very clear. The green colour is said to be due to the flagellate endosymbiont *Pedinomonas noctilucae* harboured in the *Noctiluca* cell. The *Noctiluca* blooms are generally regarded as harmless, but there are occasional reports on fish mortality and reduced fish yields (Dharani, Nazar, Kanagu, *et al.* 2004; Eashwar, Nallathambi, Kuberaraj, *et al.* 2001; Katti, Gupta, and Shetty 1988; Matondkar, Bhat, Dwivedi, *et al.* 2004; Nayak, Karunasagar, and Karunasagar 2000; Nayar, Gupta, and Prabhu 2001; Naqvi, George, Narvekar, *et al.* 1998; Prasad 1953; Subramanian 1986). Though exact reasons are not known for this adverse effect, it is surmised that the ammonium build-up takes place when bloom biomass is very large, which gradually reaches a toxic level. Naqvi, George, Narvekar, *et al.* (1998) observed *Noctiluca* bloom off Kerala (from Cochin to Calicut) and also saw severe mortality of fish *Nemipterus japonicus*, but could not ascertain the actual cause. Nayak, Karunasagar, and Karunasagar (2000) observed mono-specific bloom of *N. millions*, off Mangalore during summer, which persisted for a week. However, bacteriological studies could not establish any relationship between the bacterial population and *Noctiluca* bloom. Matondkar, Bhat, Dwivedi, *et al.* (2004), while cruising on board FORV *Sagar Sampada* during satellite pass of the Indian satellite IRS-P4 during 2003 and 2004, observed an extensive *Noctiluca* bloom in the North-East Arabian Sea, that gradually extended westward towards Oman. This was confirmed from the time series generated from the OCM (ocean colour monitor) data on board the satellite for chlorophyll studies.

Toxic blooms

India is lucky that its waters are not frequently infested with HAB species as is the case in the Pacific coast or elsewhere, which leads to a huge economic loss and human health hazards. The dinoflagellate bloom of *Gonyaulax polygrama* observed in the vicinity of Cochin harbour during the International Indian Ocean Expedition (Prakash and Sarma 1964) was in fact the first case of toxic bloom in the Indian waters. The bloom was very extensive with cell density of 11 000 000/litre, but neither fish mortality nor destruction of other fauna was noticed.

During one of our recent cruises on board CRV *Sagar Shukti* during October and November 2004, while monitoring the coastal waters between Goa and Mangalore for HABs, we found a wide distribution of both dinoflagellates and diatom genera, prominently *Chaetoceros*, *Coscinodiscus*, *Navicula*, *Rizosolenia*, *Ceratium*, *Gonylaux*, etc., with higher densities in the waters between Coodapur and Mangalore. The waters here appeared more productive as evidenced by the frequent shoals of sardines and squids. Similar was the case with the Karwar waters (Figure 2).

The 1980s started witnessing the cases of PSPs, largely from the west

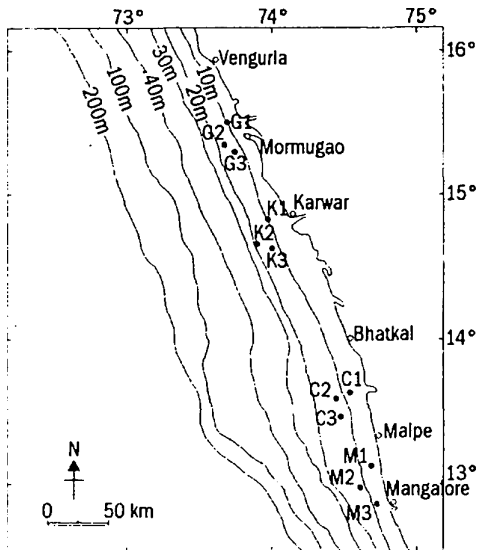


Figure 2 Bloom monitoring stations during cruise on Sagar Shukti-74

coast of India (Table 2). The report on the bloom of *Gymnodinium catenatum* was interesting as the authors for the first time made observations on cysts from the sediments, besides the routine observations of planktonic cells from the waters of Mangalore (Godhe, Indrani, and Karunasagar 1996). However, there was no toxic effect due to poor cell density. This incidence was followed by another PSP episode in 1997 that affected three coastal villages along the Kerala

Table 2 Some cases of toxic/harmful blooms along the west coast of India

Year	Bloom site	Causative species	Consequences	Reference
1983	Mangalore, Karnataka	Species not identified	Several hospitalized due to the consumption of bloom-affected shellfish	Karunasagar, Gowda, Subburaj, <i>et al.</i> (1984)
1996	Mangalore, Karnataka	<i>Gymnodinium catenatum</i>	No toxic effect	Godhe, Indrani, and Karunasagar (1996)
1997	Kerala	Paralytic shellfish poisoning	Seven deaths, over 500 hospitalized following consumption of mussel, <i>Perma indica</i>	Karunasagar, Joseph, Philipose, <i>et al.</i> (1998)
2001	Goa	<i>Cochlodinium polykrikoides</i> ,	Fish mortality observed	Bhat and Matondkar (2004)
200-4	Kerala	<i>Cochlodinium polykrikoides</i> / <i>Karenia brevis</i>	About 200 hospitalized, and large number offish kills reported	<i>The Hindu</i> (2004)

coast (Karunasagar, Joseph, Philipose, *et al.* 1998). A case of seven deaths and hospitalization of over 500 people, who had consumed bloom-affected mussel *Perna indica*, was reported. The surprising incidence was the bloom occurrence of a dinoflagellate, *Cochlodinium polykrikoides* in the Goa waters (Bhat and Matondkar 2004). This species hitherto unreported from the Indian waters is a known fish killer in Korean waters. In addition, during September 2004, a fresh case of bloom was reported from Kerala. A large-scale fish mortality in different coastal villages and hospitalization of over 200 school children due to illness caused by the nauseating stench from the bloom and putrefying fish was reported. The reports on the causative species varied as some suggested it to be *Cochlodinium polykrikoides* and others *Karenia brevis* (*The Hindu* 2004). One thing is sure that the incidences of HABs are on the rise and it is time to monitor our waters regularly for HABs.

Area needing attention

HAB has now become a global phenomenon, spreading across over 30 countries, India being one of them. Extensive surveillance programmes have been implemented in many countries to monitor HABs. The organizations involved in monitoring or marine research and industry are now well informed and have better facilities for research. Some are closely monitoring maritime activities as HABs may pollute the coastal waters. India, with 7000 kilometre coastline and fishing as one of the largest industries, has now realized the damaging effects of HABs. What is required now is networking of the existing institutions along the coast for research, monitoring, and outreach to ensure the safety of the life and the livelihood of the coastal population.

Acknowledgement

Our thanks to Dr P Vethamony, Project Leader, Coastal Impact Studies, for the encouragement, the Publication Committee for scrutiny of the manuscript and Director, National Institute of Oceanography for the support.

References

- Anderson D M and Wall D. 1978
Potential importance of benthic cysts of *Gonyaulax tamarensis* and *G. excavata* in initiating dinoflagellate blooms
Journal of Phycology 14: 224-234
- Baden D G, Fleming L A, and Bean J A. 1995
Marine toxins
In *Handbook of Clinical Neurology*, 21:1-34,
edited by F A DeWolf
New York, USA: Elsevier

Banse K. 1959

On upwelling and bottom-trawling off the southwest coast of India

Marine Biological Association of India 1 (1): 33-49

Bhat S R and Matondkar S G P. 2004

Algal blooms in the seas around India—networking for research and outreach

Current Science 87 (8): 1079-1083

Bhimachar B S and George P C. 1950

Abrupt setbacks in the fisheries of the Malabar and Kanara coasts and 'red water' phenomenon as their probable cause

Proceedings of the Indian Academy of Sciences (B: Biological Science) 31 (6): 339-335

Devassy V P. 1983

Plankton ecology of some estuarine and marine regions of the west coast of India

Kerala: University of Kerala. 275 pp. [Doctoral thesis]

Devassy V P and Sreekumaran Nair S R. 1987

Discolouration of water and its effect on fisheries along the Goa coast

Mahasagar 20 (2): 121-128

Devassy V P, Bhattathiri P M A, and Qasim S Z. 1979

Succession of organisms following *Trichodesmium* phenomenon

Indian journal of Marine Science 8 (2): 89-93

Dharani G, Nazar A K A, Kanagu L, Venkateshwaran P, Kumar T S, Ratnam K, Venkatesan R, Ravindran M. 2004

On the recurrence of *Noctiluca scintillans* bloom in Minnie Bay, Port Blair: impact on water quality and bioactivity of extracts

Current Science 87 (7): 990-994

Eashwar M, Nallathambi T, Kuberaraj K, Govindarajan G. 2001

***Noctiluca* blooms in Port Blair Bay, Andamans**

Current Science 81 (2): 203-206

Godhe A, Indrani, and Karunasagar I. 1996

***Gymnodinium catenatum* on west coast of India**

Harmful Algae News 15:1

Hallegraeff G M. 1993

A review of algal blooms and their apparent global increase

Phycologia 32 (2): 79-99

Hornell J. 1908

Report of the results of a fishery cruise along the Malabar coast to the Laccadive Islands in 1908

Madras Fisheries Bulletin 4: 71-126

Hornell J. 1917

A new protozoan cause of widespread mortality among marine fishes

Madras Fisheries Bulletin 11:53-66

Jackson W C T Jr, Carmichael W W, and Carpenter E J. 2001.

The paralytic shellfish toxins. N-sulfocarbamoyl and gonyautoxin are the major neurotoxic factors associated with the bloom-forming *Trichodesmium* spp.
[Abstracts]

[*Fifth International Conference on Toxic Cyanobacteria*, Noosa Lakes, Australia.]

Karunasagar I, Joseph B, Philipose K K, Karunasagar I. 1998

Another outbreak of PSP in India

Harmful Algae News 17:1

Karunasagar I, Gowda H S V, Subburaj M, Venugopal M N, Karunasagar I. 1984

Outbreak of paralytic shellfish poisoning in Mangalore west coast of India

Current Science 53 (5) 247-249

Katti R J, Chandrashekhara Gupta T R, and Shetty H P C. 1988

On the occurrence of 'green tide' in the Arabian Sea off Mangalore

Current Science 57 (7): 380-381

MacLean J L and White A W. 1985

Toxic dinoflagellate blooms in Asia: a growing concern

In *Toxic dinoflagellates*, pp. 517-520, edited by D M Anderson, A W White, and D G Boden

New York, USA: Elsevier

Madhupratap M, Nair K N V, Gopalakrishnan T C, Haridas P, Nair K K C,

Venugopal P, Gauns M. 2001

Arabian Sea oceanography and fisheries off the west coast of India

Current Science 81 (4): 355-361

Matondkar S G P, Bhat S R, Dwivedi R M, Nayak S R. 2004

Indian Satellite IRS-P4 (OCEANSAT) monitoring algal blooms in the Arabian Sea waters

Harmful Algae News 26:4-5

Mazumdar P K, Bupta A K, Kumar D, Kaushik M D, Dupe S N. 1997

Mechanism of cardiotoxicity induced by marine toxin isolated from *Ptychodiscus brevis*

Indian journal of Experimental Biology 35 (6): 650-660

Nagabhushanam A K. 1967

On an unusually dense phytoplankton bloom around Minicoy Island (Arabian Sea), and its effect on the local tuna fisheries

Current Science 36 (22): 611-612

Naqvi S W A, George M D, Narvekar P V, Jayakumar D A, Shailaja M S, Sardesai S, Sarma V V S S, Shenoy D M, Naik H, Maheswaran P A, Krishna Kumari K, Rajesh G, Sudhir A K, Binu M S. 1998

Severe fish mortality associated with 'red tide' observed in the sea off Cochin
Current Science 75 (6): 543-544

Nayak B B, Karunasagar I, and Karunasagar I. 2000

Bacteriological and physico-chemical factors associated with *Noctiluca milliaris* bloom, along Mangalore, southwest coast of India
Indian Journal of Marine Science 29 (2): 139-143

Nayar S, Gupta T R C, and Prabhu H V. 2001

Bloom of *Noctiluca scintillans* McCartney in the Arabian Sea off Mangalore, southwest India
Asian Fisheries Science 14 (1): 77-82

Panikkar N K. 1959

Indian fisheries
Current Science 28 (12): 53-54

Pierce R H, Henry M S, Blum P, Payne S. 2001

***Gymnodinium breve* toxins without cells: intra-cellular and extra-cellular toxins**
In *Harmful Algal Blooms* 2000, pp. 421-424, edited by G M Hallegraeff, C J Bolch, S I Blackburn, and R J Lewis
[*Proceedings of the Ninth International Conference on Harmful Algal Blooms*, IOC of UNESCO, Paris]

Prabhu M S, Ramamurthy S, Dhulkhed M H, Radhakrishnan N S. 1971

***Trichodesmium* bloom and the failure of oil sardine fishery**
Mahasagar 4 (2): 62-64

Prakash A and Sarma A H V. 1964

On the occurrence of 'red water' phenomenon on the west coast of India
Current Science 33 (6): 168-170

Prasad R R. 1953

Swarming of *Noctiluca* in the Palk Bay and its effect on the 'Choodai' fishery, with a note on the possible use of *Noctiluca* as an indicator species
Proceedings of the Indian Academy of Sciences (B: Biological Science) 38 (1): 40-47

Prasannakumar S, Madhupratap M, Dileep Kumar M, Gauns M, Muraleedharan P M, Sarma V V, DeSouza S N. 2000

Physical control of primary productivity on a seasonal scale in central and eastern Arabian Sea
Proceedings of the Indian Academy of Sciences (Earth and Planetary Sciences) 109 (4): 433-441

Qasim S Z. 1970

Some characteristics of a *Trichodesmium* bloom in the Laccadives

Deep Sea Research 17: 655-660

Ramamurthy VD, Selvakumar RA, and Bhargava R M S. 1972

Studies on the blooms of *Trichodesmium erythraeum* in the waters of the central west coast of India

Current Science 41:803-805

Smayda T J and White A W. 1990

Has there been a global expansion of algal blooms? If so is there a connection with human activities?

In *Toxic Marine Phytoplankton*, pp. 516-557, edited by E Granelli

New York, USA: Elsevier

Subramanian A. 1986

Noxious dinoflagellates in Indian waters

In *Toxic Dinoflagellates*, pp. 525-528, edited by D M Anderson, A W White, and D G Baden

New York, USA: Elsevier

[*Proceedings of the Third International Conference*, St. Andrews, New Brunswick, Canada, 8-12 June 1985]

Thajuddin N and Subramanian G. 2002

The enigmatic bloom forming marine cyanobacterium *Trichodesmium*. Advances in marine and Antarctic science

In *Advances in Marine and Antarctic Science*, pp. 57-89, edited by D Sahoo and

P C Pandey

New Delhi, India: A P H Publishing Corporation

The Hindu. 2004

Fresh case of algal bloom at Thumba

The Hindu, 3 October 2004

Verlencar X N. 1978

Some observations on the *Trichodesmium* bloom along the south-west coast of India

Mahasagar 11 (3 and 4): 221-224