Potential Domoic Acid (Neurotoxin) Producing Phytoplankton *Pseudonitzschia* in Indian Coastal Water - Do We Need To Care?

Gunjan Motwani[1], Rahul Rajan[2], Mini Raman[3], Hitesh Solanki[4]

[1]Assistant Professor, Shree M. P. Shah Arts and Science College, Surendranagar, Gujarat, India
[2]Research Scholar, Department of Environment Science, Gujarat University, Ahmedabad
[3]Scientist G, Space Applications Centre, ISRO, Ahmedabad
[4]Professor, Department of Botany, Gujarat University, Ahmedabad

Abstract
Pseudonitzschia species are potential domoic acid producers, a neurotoxin, responsible for the infamous human HAB intoxication at Prince Edward Island, Canada in 1987, costing human lives. Global warming has widened the reach of these phytoplankton species and it is being reported in Indian waters. We report the occurrence of ten*Pseudonitzschia* species in the northwestern coastal waters of India, out of which, seven are potential domoic acid producers. The question arises, are we vulnerable to HAB (Domoic Acid) toxicity? In light of the observation that *Pseudonitzschia* dominates the coastal waters of Veraval and its abundance is increasing with time, the present study briefly synthesizes the available information on the ecology, metabolism, and other relevant knowledge related to the domoic acid production by *Pseudonitzschia* and assesses the risk of human intoxication through trend and forecast analysis with the possible preventive measures required.

Keywords: *Pseudonitzschia* Bloom, Risk Assessment of*Pseudonitzschia* Bloom

1. Introduction

About half of the total human population lives within 200 km of coastlines (Creel,2003). According to data on the blue economy by World Bank (Blue economy, 2022),oceanic resources contributeabout $1.5 trillion annually to the world economy, apart from providing much-needed nutritional benefits to human beings. Fish and other edible oceanic natural resources are one ofthe cheap and very good sources of proteins for a large population of coastal communities. According to the data on fish landing by Central Marine Research Institute,India produces3820207tons of fish resources annually (Annual data, 2022) which supports a large coastal community, the health of such aquatic ecosystems are of critical importance in ensuring human health as well as their economic wellbeing.

One of the emerging challenges faced by the coastal ecosystems is the outbreak of harmful blooms (HAB) of phytoplankton which sometimes causes the release of toxic secondary metabolites into the water thereby posinga serious threat to the coastal ecosystem,biodiversity and human health.

Phytoplankton are microscopic, free-floating and pigment-containingorganisms performing the ecological function of fixing non-bioavailable energy (light energy) into bioavailable chemical form (carbohydrate) much like the plants of terrestrial ecosystems. Apart from the normal function of photosynthesis, a few phytoplankton species produce harmful secondary metabolic products which may be harmful to the ecosystem and/or cause toxicity to other organisms. According to a study by D'Silva et al., 2012, out of the 5000 species of phytoplankton existing in the world's oceans, 7% are reported to form blooms that included diverse phytoplankton groups such as diatoms, dinoflagellates, raphidophytes, prymnesiophytes and silicophytes. Among the bloom-forming phytoplankton, only 2% were reported to be toxic and dinoflagellates contributed 75% to the toxic bloom-forming phytoplankton.39 phytoplankton species are documented as responsible for the formation of algal bloom in Indian waters.

In context to Indian waters, the earliest event of toxicity was reported by Hornell in 1908 when massive fish mortality occurred due to an unidentified flagellate bloom. Subsequently, many toxic and nontoxic bloom events have been reported from Indian waters. Appendix 1 summarizes the occurrence of bloom events in Indian waters, their causative phytoplankton species and their effects. Considering the western coastline of India, most bloom events have been reported from Kerala followed by Mangalore and Goa(D'Silva et al., 2012). There has been no report of *Pseudonitzschia* bloom or its toxicity from any part of Indian water to date.

This study reports the first occurrence of *Pseudonitzschia* (a diatom) bloom along thenorthwestern coastline (Veraval coast, Gujarat) of India. Also, a mini review on bloom events in Indian waters along with the biology of *Pseudonitzschia* and the eco-physiology of domoic acid production is briefly considered in this paper.*Pseudonitzschia* produces a neurotoxin called domoic acid and various species of *Pseudonitzschia*are well known for causing toxic blooms in many parts of the globe (Lelong et al., 2012). The study assesses the potential risk of toxicity through trend and forecast analysis.

2. Mini Review-*Pseudonitzschia* and domoic acid

- **Toxin-producing*Pseudonitzschia* species**

Morphologically,*Pseudonitzschia* is a diatom with lanceolate or spindle-shaped frustule in its value view. Frustules overlap at value ends to form stepped chains (Tomas 2007). It is a marine and estuary diatom with approximately 37 species of worldwide distribution (Hubbard et al. 2008; Hasle et al., 2002; Bates 2000; Lelong et al., 2012 and references therein). 14 out of 37 species have been reported to produce domoic acid, a potential neurotoxin (Lefebvre and Robertson,2010, Bates 2000; Trainer et al. 2008; Lelong et al., 2012). Trick et al. 2010 observed toxin production from *Pseudonitzschiagranii* in a shipboard continuous culture of natural seawater thus making it the most recent addition to the list of toxin-producing*Pseudonitzschia*. It is believed that all spices of *Pseudonitzschia* are potential toxin producers, given the appropriate growth and toxin-producing conditions along with highly sensitive toxin detection methods (Parsons et al. 1999; Wells et al. 2005; Lelong et al., 2012).

- **Habitat preference by *Pseudonitzschia***

Studies by Trainer et al. 2008; Caron et al. 2010; summarized that most toxin-producing species of *Pseudonitzschia* inhabit coastal waters. Also, coastal species were observed to produce higher concentrations of domoic acid (0.15 to 136 ng ml^{-1}) (Howard et al. 2007; Trainer et al. 2007) in comparison to the few oceanic (undetectable to 0.1 pg ml^{-1}) (Marchetti et al. 2008; Trick et al. 2010) counterparts (Lelong et al., 2012).Similar to many other diatoms, *Pseudonitzschia* often blooms in the upwelling zones where light and nutrient conditions are most favourable. It was observed by Trainer et al. 2008; that *Pseudonitzschia* blooms are common along the western coast of the continents due to upwelling and water circulation produced by sea floor and coastal topographies. A distribution map documentingthe worldwide occurrence of various species of *Pseudonitzschia*was given by Lelong et al., 2012.

- **History of bloom events**

The first incidence of harmful effects produced by *Pseudonitzschia* was reported from the eastern coast of Prince Edward Island,Canada, in 1987; when many people got ill and three died due to the consumption of intoxicated mussels (*Mytilus edulis*) (Todd, 1990). Following this, the toxic blooms of *P.multiserae*were observed for three years along the eastern coast of Canada (Smith et al., 1990a; Villac et al., 1993). Since then, *Pseudonitzschia* blooms and production of domoic acid has been observed in many other parts of the world (Shumway 1989; Chang 1993; Hallegraeff 1994; Miguez et al. 1996; Beltran et al. 1997; Lelong et al., 2012).

- **Symptoms of domoic acid toxicity**

The most unusual and serious symptom of domoic acid poisoning in humans is loss of short-term memory and in some cases, it causes permanent damage to the brain. The poison is not destroyed either by cooking or freezing. Apart from *Pseudonitzschia*, domoic acid is released by a variety of other macro and microalgae The poison was first discovered from red algae called 'doumoi' (*Chondriaarmata)* in the Japanese language, in 1958 and was used as a folk medicine in Japan to treat intestinal pinworm infestations (Villac et al., 1993; Mos, 2001).

- **General properties of domoic acid**

Domoic acid is water soluble and heat-stable amino acid (Hatfield et al., 1995; Leira et al., 1998) but gets degraded by bacterial action (Windust, 1992; Stewart et al., 1998) and by exposure to UV radiation (Wright et al., 1990, Bates et al., 2003). It is also known to chelate iron and thus iron is also considered as a potential degrading agent (Rue and Bruland, 2001). Limitations of nutrients such as phosphorus, silica and metals like iron and copper have been shown to promote toxin production (Pan et al., 1996b; Bates, 1998; Wells et al., 2005). Also, increased levels of salinities, dissolved inorganic carbon and urea have been related tothe enhancement of toxin production (Howard et al., 2007; Doucette et al., 2008; Sun et al., 2011; Tatters et al., 2012). *Pseudonitzschia*is especially known for its interaction with iron and its ability to store it (Marchetti A, et al. 2009).

3. Materials and Methods

Water samples were collected to study phytoplankton diversity from the coastal waters of Veraval, Gujarat, which is a part of the northeastern Arabian Sea. The study was conducted from March 2003 to April 2017.The geographical distribution of all the sampling sites is shown in Figure 1.

The relative abundance of phytoplankton cells was calculated to study the extent of dominance of *Pseudonitzschia* cells over other phytoplankton communities.Decadal trend analysis and forecast analysis for the next 10 years was carried out to understand the pattern of rise and estimate the potential hazardposed by *Pseudonitzschia* cells.The threshold of bloom initiation and level of risk was determined according to the method proposed by Siegel et al (2002).For this, the mean value for decadal phytoplankton cell counts was calculated and rise in *Pseudonitzschia* cell counts above 30% of the meanvalue was considered as bloom initiation.

Figure 1. Sampling sites off Veraval coast, Gujarat, India

4. Result and discussion

- **Reporting**

A study on phytoplankton assemblage revealed that diatoms dominated the overall phytoplankton diversity with 77.93% in coastal waters of Gujarat, comprising the northeastern part of the Arabian Sea. *Pseudonitzschia*alone contributed to 26% of overall phytoplankton diversity in the study region.

In order to further understand the effect of seasonal changes in *Pseudonitzschia* dominance, the study period was temporally classified as fall inter-monsoon, winter monsoon and spring inter-monsoon seasons. Again, diatoms dominated in all the seasons studied, but *Pseudonitzschia* did not (table 1). Although the abundance of *Pseudonitzschia* was significantlyhigh in all the seasons, it did not dominate the overall diversity during the two inter-monsoon seasons. *Pseudonitzschia* dominated with a relative abundance value of 0.26,exclusively in the winter monsoon season.As mentioned in the mini-review above, *Pseudonitzschia* grows best in upwelling zones and coastal waters where nutrient conditions are favourable for their growth and multiplication.During winter monsoon, cooler water at the surface sinks towards the bottom causing upwelling (Motwani et al., 2014). This upwelling water brings along nutrients from the bottom, turning the nutrient conditionfavourablefor the growth of *Pseudonitzschia*. Whereas in fall and spring inter-monsoon seasons, the hydrological condition is reversed and the water is stratified. Nutrient supply in stratified water is low thus lowering the overall phytoplankton diversity and thereby abundance of *Pseudonitzschia* as well.

Table 1. Contribution (In Percentage) of Various Phytoplankton Species to the Phytoplankton Groups in Fall Inter, Winter and Spring Inter-Monsoon Seasons

Seasons	**Phytoplankton groups**	**proportion of phytoplankton groups (in percentage)**	**Dominating species in the group**	**proportion of dominating species in the group (in percentage)**
Fall inter monsoon	Diatoms	97.68	*Asterionellopsisglaciallis*	39.81
	Dinoflagellates	1.75	*Scrippsiellatrochoidea*	0.32
	Other algae	0.55	*Trichodesmiumerythrium*	0.37
Winter monsoon	Diatoms	87.07	*Pseudonitzschiadelicatissima*	28.28
	Dinoflagellates	1.67	*Prorocentrumbalticum*	0.49
	Other algae	11.24	*Trichodesmiumerythrium*	5.20

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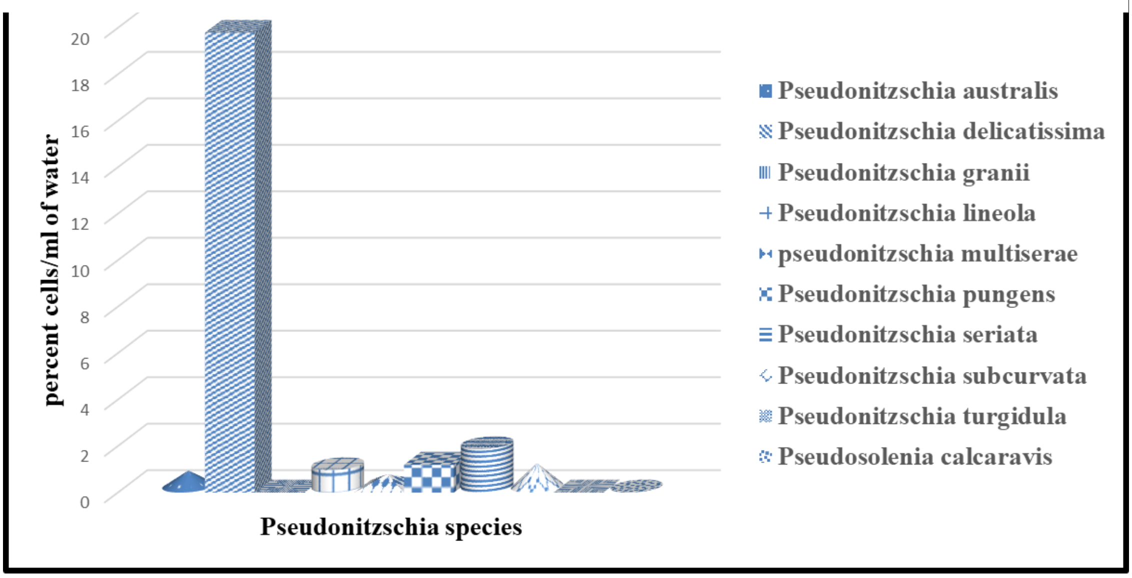
Spring inter monsoon	Diatoms	48.31	*Nitzschialongissima*	18.53
	Dinoflagellates	2.29	*Prorocentrumbalticum*	0.63
	Other algae	49.38	*Trichodesmiumerythrium*	46.36

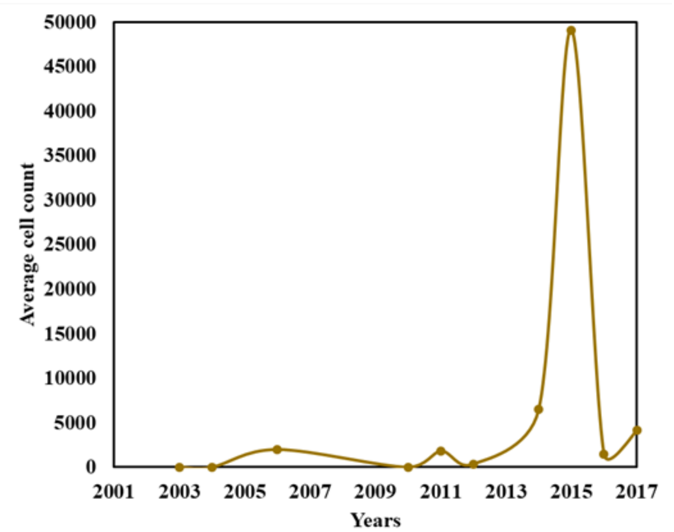
Tenspecies of *Pseudonitzschia* viz. *P. australis,P. delicatissima, P.granii, P.lineola,P. multiserae, P.pungens,P.seriata,P.subcurvata,P.turgidula*and *P. calcaravis*were present in the coastal waters of Gujarat. Based on the list of toxin producing species byLelong et al., 2012, sevenamong tenhave been reported to produce toxin indifferent parts of the world.With respect to overall phytoplankton diversity during the study seasons, *P.delicatissima*was the most abundant species with a 20% contribution to diversity. Although *P.delicatissima* is a toxin-producing species, presence of toxin was not observed in the study region. Similar observations were made by Lundholm&Skov 1993; Hallegraeff 1994; Walz et al. 1994, where blooms of *P.pseudodelicatissima*occurred in Scandinavia, Australia, and California, but there was no presence of toxin. The possibilities may be either these *Pseudonitzschia*species were not producing toxins or the produced toxin wastoo low to produce any harmful effect and that they were assimilated into the aquatic system.

Figure 2. Percent Cells of Pseudonitzschia Species Present in 1 ml of Water Sample



The decadal trend of *Pseudonitzschia* abundance showed that its abundance in the coastal waters of Gujarat was almost zero (Figure 3) till 2004. Later, after its introduction in the region, itincreased in number continuously such that it can now be considered an invasive species. In 2015, its cell countoutcompeted the overall phytoplankton diversity and formed a bloom due to the occurrence of two extremely severe cyclonesChapala and Meghone after the other in October-November.

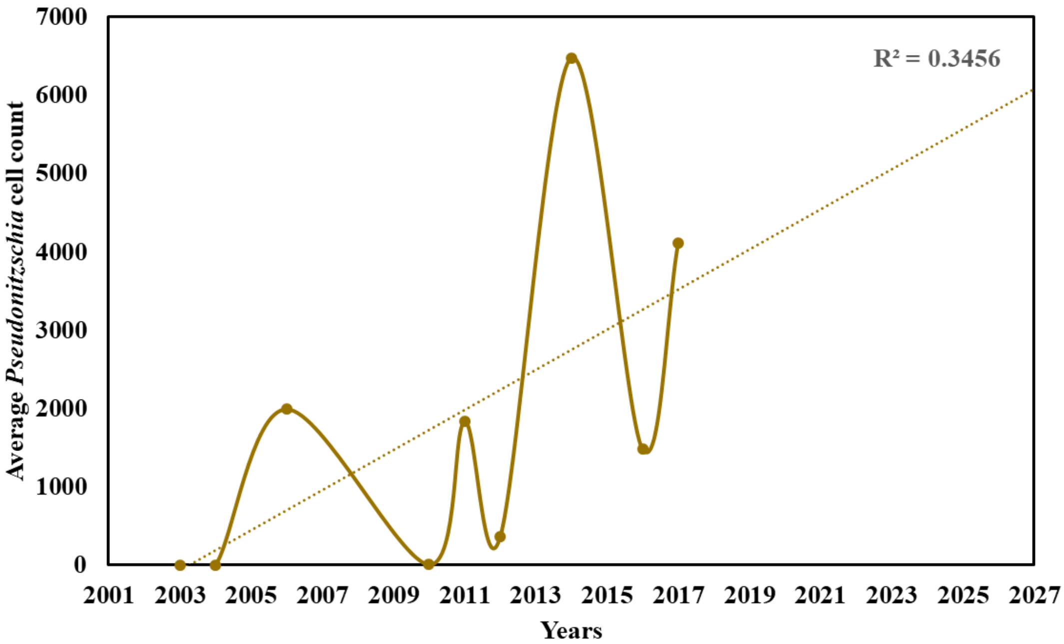
Figure 3.The trend for Pseudonitzschia cell counts



- **Potential Hazard**

The occurrence of cyclones Chapala and Meghin 2015 resulted in abnormally high phytoplankton diversity along with exuberantly high numbers of *Pseudonitzschia*. Thus considering the values for the year 2015 as an anomaly, we recalculated the trend after removing the data for 2015. Recalculated results also showed an increasing trend for*Pseudonitzschia*cell counts. Forecast analysis for the next 10 years showed that *Pseudonitzschia* is likelyto increase(figure 4) and therefore is a potential future hazard for the region. Veraval is a known fishing centerand a busy shipping port.Apart from fishing and shippingactivities, the shipbuilding industries of Veraval also influence the water chemistry of the region. A lot of organic matter and metal wastes are disposedinto the adjacent coastal waters.The presence of Somnath temple (an old Shiva temple of historical importance)makes Veraval an important pilgrimage and tourist center of the state. Commercial activities make Veraval prone to excessive eutrophication and pollution, causing an imbalance in the proportion of essential nutrients such as nitrogen, phosphorous and potassium. Such eutrophic conditionsseemingly turnedfavourable for the growth of *Pseudonitzschia*and can act as a potential trigger for the release of domoic acid in future. According to Bhat and Matondkar, 2004, pollution and nutrient enrichment due to anthropogenic activities are the major factors that trigger and stimulate the growth of bloom-forming species.Both these triggering agents prevail in Veraval and undoubtedly are responsible for the continuously increasing abundance of *Pseudonitzschia*.

Figure 4.Trend (excluding data for the year 2015) and forecast analysis for Pseudonitzschia cell counts



- **Risk Assessment**

Results of the threshold method showed that *Pseudonitzschia*cells were higher than 50% of the mean value for overall phytoplankton diversity. It not only formed bloom but also posed a major risk tothe human health and fishing industry of the region under concern. The dominance of *Pseudonitzschia* and its increasing trend is definitely an alarming situation. To understand the potential risk due to the presence of *Pseudonitzschia* in alarmingly high numbers, the risk assessment method proposed by the government of South Australia, Department of Education and Children'sServices was followed. The outcome of the risk assessment process showed that human health, ecosystem and fisheries industries are extremely vulnerable to possible catastrophic effectsdue to*Pseudonitzschia*bloom in coastal waters off Gujarat. Further ahead, there is no awareness or management strategiesundertaken to handle the possible risk (table 2).

Although, there were no reports of any harm by toxin release in the study area. There is anextreme risk of domoic acid production in the near future and by all means it can affect the commercial activities of the region as well as the health and well-being of the human population that consumes intoxicated fishes.

Table 2. Risk assessment of toxicity by *Pseudonitzschia* in coastal waters off Gujarat

Risk (people, information, physical assets and finances, reputation)	**Consequence**	**Likelihood**	**Risk level**	**What we are doing now to manage this risk**	**Effectiveness of our strategies**	**New risk level**	**Further action needed** **Opportunities for improvement**

Human health	Major to Catastrophic	possible	extreme	No awareness and therefore nothing is being done.	Need to make strategies	same	Further research, continuous monitoring and awareness needed
ecosystem	Major	possible	extreme	No awareness and therefore nothing is being done.	Need to make strategies	same	Further research, continuous monitoring and awareness needed
Fisheries industries	Major	possible	extreme	No awareness and therefore nothing is being done.	Need to make strategies	same	Further research, continuous monitoring and awareness needed

- **Need for research**

The absence of toxication reports does not ensure that there is no production ofneurotoxins in the region. There may be neurotoxin production but in very low concentrations that it does not cause any mortality or it may be due to lack of awareness and research carried out in the region that domoic acid remains unnoticed. Detailed studies on the presence of toxic *Pseudonitzschia*in Indian waters and their toxin production activities are required. The toxin-producing stimulus to these species and highly sensitive protocols to detect the presence of toxins at very low concentrations are also subjects of research required in this region.

- **Management approaches**

Occurrence of toxin-producing*Pseudonitzschia*species in significant proportion over other phytoplankton types call upon a need for continuous monitoring of *Pseudonitzschia* abundance, water quality, nutrient levels and anthropogenic factors that can trigger the release of domoic acid. Such monitoring can help to protect the consumers and the seafood industry. Also, fishermen and people inhabiting the coastal regions of Gujarat need to be educated about the potential hazard. Eutrophication is one of the causes of *Pseudonitzschia* dominance in the region. Sustainable approaches to control industries and shipping activities need to be adopted to curb the approaching hazard.

5. Conclusion

The coastal waters of Veraval are dominated by a potential neurotoxin-producing phytoplankton '*Pseudonitzschia*'. The abundance of *Pseudonitzschia* cells showed an increasing trend over a decadal time period. Increasing abundance is not only disturbing the present diversity but also posing a potential risk of being detrimental to human health, the ecosystemand the fisheries industry of the state. Presently there is no awareness or report of the possible threat. There is indeed a need for awareness, research and management activities to handle the fore coming threat before it actually takes a toll on human health and finances.

Appendix 1. Details of Bloom Events in Chronological Order of Their Occurrence in Coastal Waters of India

Sr. No.	Causal phytoplankton species	Place of occurrence	Year of occurrence	Effect	Reference
1.	*Unidentified flagellate*	Malabar coast	November 1908	Massive fish mortality	Hornell (1908)
2.	*Unidentified Peridian*	Malabar to south Kanara coasts	September–October 1916	Massive fish mortality	Hornell (1917)
3.	*Glenodinium,*	Malabar coast	November 1921	Discoloration of water	Hornell &Nayudu (1923)
4.	*Gymnodinium sp.1, sp.2 & sp.*	Malabar coast	December 1921	Discoloration of water	Hornell &Nayudu (1923)
5.	*Prorocentrummicans& sp.*	Malabar coast	January 1922	Discoloration of water	Hornell &Nayudu (1923)
6.	*Ditylum sp. &Thalassiosira sp.*	Malabar coast	May 1922	-	Hornell &Nayudu (1923)
7.	*Cochlodinium sp.1*	Malabar coast	August 1922	Discoloration of water	Hornell &Nayudu (1923)
8.	*Cochlodinium sp.2*	Malabar coast	October 1922	Discoloration of water	Hornell &Nayudu (1923)
9.	*Noctiluca miliaris*	Madras, Tamil Nadu	June 1935	Discoloration of water. Fish mortality	Aiyar (1936)
10.	*Trichodesmiumerythraeum*	Krusadai island, Gulf of Mannar	May 1942	Mortality of marine fauna (*Holothuriaatra& fishes)*	Chacko (1942)
11.	*Trichodesmiumerythraeum*	Pamban, Gulf of Mannar	May 1942	Mortality of fishes & crabs	Chidambaram &Unny (1944)
12.	*Noctiluca miliaris, Gymnodinium sp.4 & Dinophysissp*	Malabar & Kanara coasts	October 1948	No mortality; but exclusion of fishes from	Bhimachar& George (1950)

				the site.	
13.	*Rhizosoleniaalata*	Mandapam, Tamil Nadu	March 1950	-	Raghu Prasad (1956)
14.	*Rhizosolenia imbricata*	Mandapam, Tamil Nadu	March 1951	-	Raghu Prasad (1956)
15.	*Noctiluca miliaris*	Mandapam– Tamil Nadu	April–July 1952		Raghu Prasad (1953, 1958)
16.	*Hornellia marina*	Calicut, North Kerala	August & November 1949, September 1952	Green discoloration, Fish & Faunal mortality	Subrahmanyan (1954)
17.	*Gonyaulaxpolygramma*	Cochin, Kerala coast	November 1963	Non–toxic but exclusion of zooplankton	Prakash &Viswanatha Sarma (1964)
18.	*Trichodesmiumerythraeum& Trichodesmiumhildebrontii*	Ullal, Mangalore	March 1964		Prabhu et al. (1965)
19.	*Trichodesmiumerythraeum*	Minicoy Island, Lakshadweep	May–June 1965	Adverse effects on Tuna fisheries	Nagabhushanam (1967)
20.	*Asterionella japonica*	Vishakhapatnam, Andra Pradesh	April 1967	discolouration of waters	Subba Rao (1969)
21.	*Noctiluca miliaris*	Vellar Estuary, Tamil Nadu	August 1966-1967 & May 1968		Santha Joseph (1975)
22.	*Trichodesmiumerythraeum*	Laccadive island	April 1968		Qasim (1970)
23.	*Nitzschia sigma*	Cochin backwaters, Kerala	May 1970		Devassy&Bhattathiri (1974)
24.	*Skeletonemacostatum*	Cochin backwaters, Kerala	November 1970		Devassy&Bhattathiri (1974)
25.	*Trichodesmiumerythraeum*	Off Goa	March 1972		Ramamurthy et al. (1972)
26.	*Fragilaria oceanica*	Kaikani, Mangalore	August 1972		Devassy (1974)
27.	*Trichodesmiumerythraeum*	Porto Novo, Tamil Nadu	March 1964, 1965, 1969, 1972		Ramamurthy (1968), Ramamurthy

					(1970a, 1970b, 1973)
28.	*Trichodesmiumthiebautii*	Gulf of Mannar, Tamil Nadu	March–April & September 1973	Fish mortality	Chellam & Alagarswami (1978)
29.	*Trichodesmiumerythraeum*	Off Goa	February–April 1975		Devassy et al. (1978)
30.	*Noctiluca miliaris*	Quilon, Kerala	August 1976	Red coloration of water	Venugopal et al. (1979)
31.	*Trichodesmiumerythraeum*	Ratnagiri–Mangalore &Laccadive island	March 1977		Verlencar (1978)
32.	*Noctiluca miliaris*	Cochin, Kerala	August 1977	-	Devassy et al. (1979)
33.	*Unidentified sp.*	Vayalar, Tamil Nadu	1981	PSP, 85 people hospitalized & 3 deaths	Silas et al. (1982)
34.	*Unidentified sp.* (toxin profile corresponded to *Alexandriumtamiyavanichi)*	Kumble estuary, Mangalore	April 1983	Reports of PSP, one death & 85 hospitalized	Karunasagar et al. (1984)
35.	*Asterionella glacialis*	Vellar estuary, Tamil Nadu	March & September/October 1983	-	Mani et al. (1986)
36.	*Skeletonemacostatum*	Dharamtar Creek, Mumbai	October 1984-1985		Tiwari & Nair (1998)
37.	*Unknown causative sp.*	Mangalore	April 1985 & March–April 1986	low levels of PSP recorded	Segar et al. (1989)
38.	*Noctiluca miliaris*	Mangalore	January 1987	Intense green coloration of water	Katti et al. (1988)
39.	*Noctiluca miliaris*	Mandovi&Zuari estuaries; Goa	February–April 1987	Green coloration of water, fish catch decreased	Devassy& Nair (1987)
40.	*Asterionella glacialis*	Gopalpur, Orissa	March 1988	discoloration of waters	Choudhury & Panigrahy (1989)
41	*Asterionella glacialis*	Rushikulya	April–May		Panigrahy&

.		estuary, Orissa	1988		Gouda (1990)
42.	*Noctiluca scintillans*	Kalpakkam, Tamil Nadu	October 1988		Sargunam&Rao (1989)
43.	*Gymnodiniumnagasakiense*	Brackwish water Kodi, Karnataka	December 1989	Red coloration of water & fish mortality	Karunasagar (1993)
44.	*Asterionella glacialis*	Bahuda estuary, Orissa	May 1991	-	Mishra &Panigrahy (1995)
45.	*Thalassiothrixfraunfeldii*	Bahuda estuary, Orissa;	September 1991	-	Mishra &Panigrahy (1995)
46.	*Coscinodiscus centralis &Coscinodiscus excentricus*	Bahuda estuary, Orissa;	June 1992	-	Mishra &Panigrahy (1995)
47.	*Noctiluca miliaris*	Mangalore	May 1993	Increased in *Moraxella* like bacteria with bloom	Nayak et al. (2000)
48.	*Asterionella glacialis*	Kalpakam, Tamil Nadu;	May 1993	-	Satpathy& Nair (1996)
49.	*unidentified sp.*	Vizhinjam, Kerala	September 1997	Outbreak of PSP; 7 deaths, over 500 hospitalized after consuming bloom affected mussel *Perna indica*	Karunasagar et al. (1998)
50.	*Noctiluca* sp.	Cochin–Calicut, Kerala	August 1998	Oxygen depletion resulted in severe fish mortality	Naqvi et al. (1998)
51.	*Noctiluca scintillans*	Port Blair Bay, Andamans	June–July 2000	Green coloration of water	Eashwar et al. (2001)
52.	*Trichodesmiumerythraeum*	Tamil Nadu and kolkata	April 2001	Brownish–yellow coloration of	Jyothibabu et al. (2003)

				water	
53.	*Cochlodiniumpolykrikoides*	off Goa	October 2001	Fish mortality coincided with bloom	O'Herald (2001)
54.	*Noctiluca scintillans*	Minnie bay, Port Blair–Andamans	December 2002	Green coloration of water	Dharani et al. (2004)
55.	*Noctiluca scintillans*	Goa to Porbandar (Gujarat)	February–March 2003	Green coloration of water	Prabhu Matondkar et al. (2004)
56.	*Chattonella marina*	Calicut to Tellicherry, Kerala	September 2002 & 2003	Fishery was affected	Jugnu& Kripa (2009)
57.	*Asterionella glacialis*	Gopalpur, Orissa;	March- April 2004	discoloration of waters	Sasamal et al. (2005)
58.	*Kareniamikimotoi*	Kerala coast	July–September 2004	Massive fish mortality	Iyer et al. (2008)
59.	*Noctiluca miliaris*	Thiruvananthapuram, Kerala	September 2004	discoloration of water	Sahayak et al. (2005)
60.	*Unidentified holococcolithophore*	Kerala	September–October 2004		Ramaiah et al. (2005)
61.	*Noctiluca scintillans*	Rushikulya river, South Orissa coast	April 2005	discoloration of water, oxygen depletion	Mohanty et al. (2007)
62.	*Trichodesmiumerythraeum*	Mangalore–Quilon	May 2005	Discoloration of water, no mortality	Anoop et al. (2007)
63.	*Coscinodiscus asteromphalus var. centralis*	Kodikkal–Calicut, Kerala;	August 2006	discoloration of waters	Padmakumar et al. (2007)
64.	*Trichodesmiumerythraeum*	Kalpakkam, Tamil Nadu	March 2007	Yellowish–green colouration of water. No fish mortality	Satpathy et al. (2007)
65.	*Noctiluca miliaris*	off Gujarat	March 2007	Deep green colouration of water	Padmakumar et al. (2008b)
66.	*Microcystis aeruginosa*	Chalakudy River in	March 2008	Discolouration of water.	Padmakumar et al. (2008a)

		Central Kerala		Itching, irritation of skin	
67.	*Noctiluca scintillans*	Kochi, Kerala	August 2008	Brick red discolouration of water, no fish mortality	Padamakumar et al. (2010a)
68.	*Protoperidinium*sp.	Mangalore coast	October 2008		Sanilkumar et al. (2009)
69.	*Noctiluca miliaris*	off Goa	October 2008		Sanilkumar et al. (2009)
70.	*Noctiluca scintillans*	Gulf of Mannar, Orissa	October 2008	Discoloration of water. Corals got bleached, due to lack of oxygen. Fishes & sea animals died	Gopakumar et al. (2009)
71.	*Trichodesmiumerythraeum*	Mandapam & Keelakarai, Tamil Nadu	October 2008	Mortality of several fishes and shellfishes	Anantharaman et al. (2010)
72.	*Trichodesmiumerythraeum*	off Kollam, Kochi & Kannur, Kerala coast	May–June 2009	Brown discolouration of water	Padmakumar et al. (2010b)
73.	*Kareniamikimotoi*	Cochin Barmouth, Kerala	October 2009	Intense brownish colouration to water	Madhu et al. (2011)
74.	*Chattonella marina*	Off Kochi, Kerala	September 2009	Rusty brownish-reddiscolouration of water	Padmakumar et al. (2011)
75.	*Microcystis aeruginosa*	VellarEstuary, Tamil Nadu	December 2009		Santhosh Kumar et al. (2010)

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7. Conflict of Interest Statement

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8. Authors' Biography

Gunjan Motwani- Assistant professor and Head, biology Department, Shree M. P. Shah Arts and Science College, Surendranagar, Gujarat.

Rahul Rajan- PhD from Gujarat University also worked as a research fellow at Space Applications Centre-ISRO.

Mini Raman- Scientist-G and head at Marine Ecosystems division, EPSA, Space Applications Centre-ISRO.

Hitesh Solanki- Professor at the Department of Botany, Gujarat University.

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