Indian Journal of Geo-Marine Sciences
Vol. 42(1), February 2013, pp. 58-66

Climate changes influence the phytoplankton bloom (prymnesiophyceae: *phaeocystis* spp.) in North Andaman coastal region

V. Sachithanandam, P. M. Mohan*, R. Karthik, S. Sai Elangovan & G. Padmavathi

Department of Ocean Studies and Marine Biology, Pondicherry University, Brookshabad Campus, Post Bag No. 1, Port Blair 744 112, Andaman and Nicobar Islands, India

*[E mail: pmmtu@yahoo.com]

Received 26 October 2012 ; revised 31 January 2013

Phytoplankton bloom occurred during the period of June 2011 pre monsoon in Andaman waters. Total four classes of bloom are identified as such as; Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellate), Cyanophyceae (Cyanobacteria or Blue-green algae) and Phaeocystales. *Phaeocystis* spp. were observed with following seawater physio-chemical parameters between surface to 15 m depth. Numerous anthropogenic activities such as eutrophication caused by water discharge in this region and high nutrient enrichment in the water column, as well as effects from precipitation, upwelling and wind stress, could have favoured the outbreak of this *Phaeocystis* spp. Due to the physio-chemical parameters which are induced by climate changes may be the reasons for phytoplankton blooms in the coastal waters of north Andaman regions. As per the review of algal blooms off India[28] suggested that till date, nowhere in Indian coastal stretch noticed the bloom of *Phaeocystis*.

[**Keywords:** Phytoplankton, Algal bloom, Primary producer, Species]

Introduction

Phytoplankton taxon abundance depend upon the growth, immigration, physical concentration and other mechanism based upon the physical, chemical, biological characteristics of water and sediment fluctuation. In this regard, many species generally struggle to coexist in a water mass of seemingly similar properties. Hence, one species becomes numerically dominant than the other forms and occur as a mono specific bloom. This is a remarkable phenomenon, especially dependent upon the nature of environment.

Harmful Algal Blooms (HABs) are natural phenomena that have occurred throughout history. However, in the past two decades, these events have increased in frequency, intensity, and geographic distribution, causing greater public health and economic impact. Among the 5000 species of extant marine Phytoplankton[1], approximately 300 species can occur in such high numbers that they obviously discolour the sea surface and approximately 40 species have the capacity to produce potent toxins that can transfer through fish and shellfish to humans[2] and harmful their health. According to the Hallegraeff *et al*.[3] a worldwide increase of algal blooms occurrence near the end of 20th century. The frequent global occurrence of harmful algal blooms (HABs) has serious impacts on fishery resources and the marine environment. Andaman waters, is one of the least explored areas with reference to physiochemical and biological studies. Expansion in anthropogenic activity, urbanization, tourism and marine transportation are matters that add significant to coastal waters quality. Recently Mohan *et al*.[4] emphasised that coral bleach occurred in Andaman Islands due to the increase the temperature and climate change. However, basic information on physiochemical and biological aspects of these waters is sparse or in infant stage of data base Accumulation. Present study was an attempt to enhance the knowledge on the physiochemical parameter with references to phytoplankton population or primary produces in Diglipur, North Andaman coastal region.

Materials and Methods

Andaman and Nicobar Islands comprise over 572 Islands, situated between 06° 45’ and 13°45’ N latitude and 92° 10’ and 94° 15’ E longitude in North-South direction (Fig. 1). This Islands have a land area of 8, 293 sq. km. Climate is typically

*Authour for Correspondence

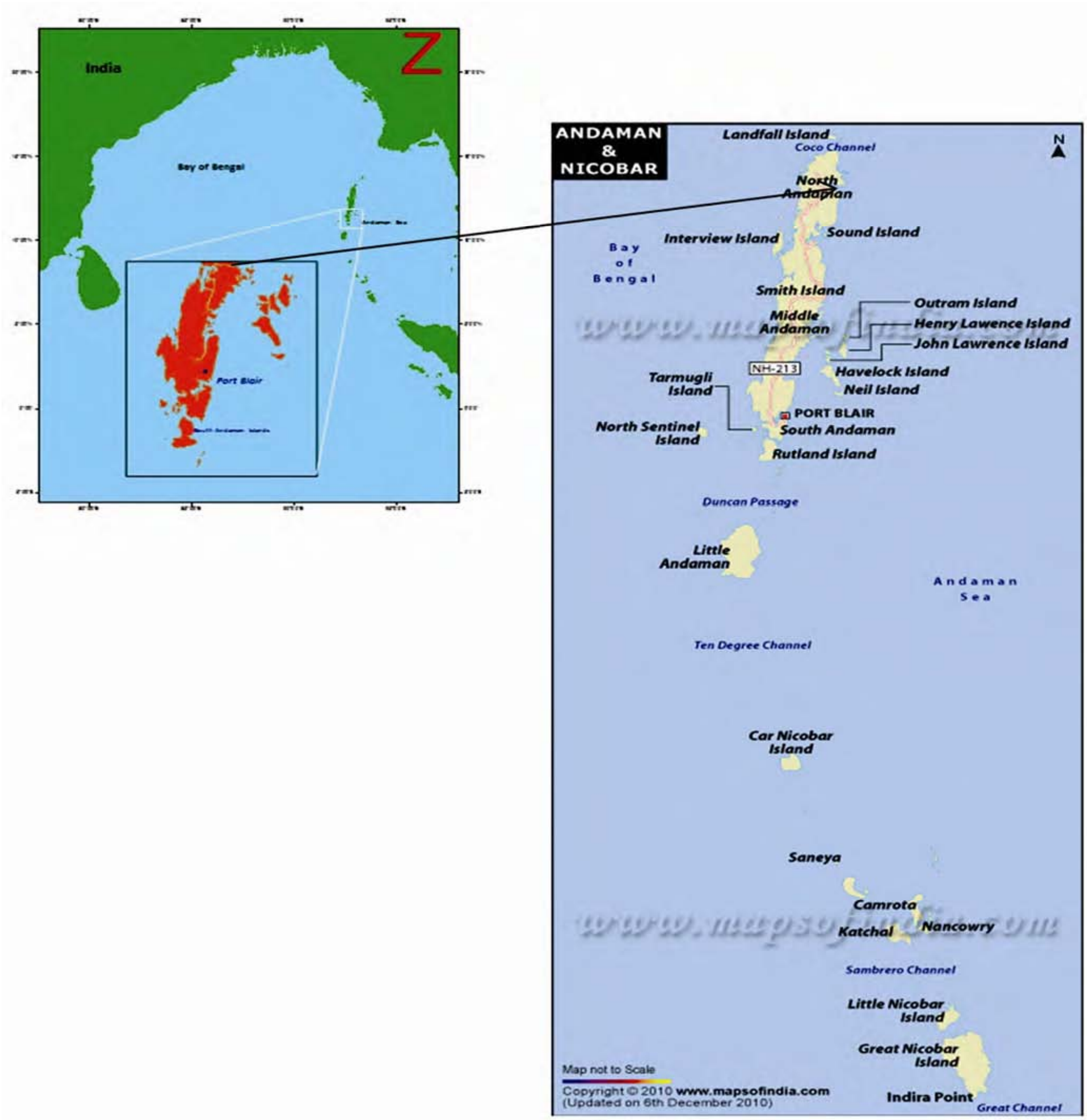

Fig. 1—Study Area

tropical with annually rainfall of about 3000 mm and experiences on active South–West monsoon from June–September and North–East monsoon from December-April. The coastal water temperature 27°C to 32°C and salinity fluctuated between 22 to 32 PSU[5]. Present study has been made extensively in the North Andaman coastal region Off Diglipur. The study was conducted to estimate temperature, salinity, pH, disolved oxygen (DO) and Eh through HYDROLAB (USA) probe (Table 1).

Plankton samples were collected using the Plankton net (20 μ). Samples were preserved in 5% diluted formalin, 5% Magnesium chloride ($MgCl_2$) and 10 ml of Lugaol solution/1000mL added then samples were stored in the polythene cane. Qualitative analysis for the settling method described[6]

Table 1—Range of physio-chemical parameters for surface to 15 m depth in Offshore of Diglipur

Sl. No.	Parameters	Values
1	Temperature	26.56 to 28. 48°C
2	*p*H	8.50 – 8.68
3	Salinity	32.23 – 32.74
4	DO%	4.1 – 5.43
5	ORP/Eh	277 – 281
6	Turbidity	55.35 – 57.9

was adopted. Phytoplankton was identified based on the standard identification keys and earlier published literature[7-9]. Planktonic sample was counted at 600 X using Nikon inverted epi- fluorescence microscope.

Results

Present study enumerated totally four classes of identified phytoplankton such as; Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellate), Cyanophyceae (Cyanobacteria or Blue-green algae) and Phaeocystales consists of 25 genus with 43 species of phytoplankton (Table 2) were recorded during June 2011, First Phase of Monsoon (May–August). Among these, 16 genera was represented by 5 species of diatoms, six genera with 15 species of Dinoflagellates, two genera and two species of Cynophaceae, one genera and one species of Prymnesiophyceae. During the study, dominated 90–95% of *Phaeocystis* spp. which was consided as a bloom occurred between (13° 17' 47.71" N - 093°03'27.80''E) in North Andaman. *Phaeocystis* spp. was more population (26,000 cell/mL) of total phytoplankton biomass in the surface water column (Fig. 2). Massive growth of phytoplankton bloom-forming was found predominantly in physiochemical parameter fluctuation or enrichment in water column Off Diglipur coastal region i.e., temperature and salinity significant changes (26.56 to 28.48°C and salinity profile of 32.23–32.74 from surface to 25 meters water column).

Discussion

The genus *Phaeocystis* is only key taxa in marine pelagic ecosystems acknowledged by scientists[10-11] for its communes in salient portion of ocean capable of sequestering carbon and nutrients in tremendous amounts. More than hundreds of study and decades of observation the fundamental question like, why these colonies form massive bloom? Is it any unusual trophic link could be provided by these genus? What factor determined diatom or *Phaeocystis* dominant? are unanswered till date.

Table 2—Lists of Phytoplankton Abundances in Study Area.

Sl. No.	Check list of Phytoplanktons	Number of individuals/mL
1.	*Bacteriastrum furcatum*	02
2.	*Bacteriastrum hyalinum*	01
3.	*Ceratium breve*	16
4.	*Ceratium furca*	03
5.	*Ceratium sp*	02
6.	*Ceratium trichoceros*	23
7.	*Ceratium uvltur*	02
8.	*Chaetoceros atlanticus*	01
9.	*Chaetoceros orientalis*	01
10.	*Chaetoceros sp*	01
11.	*Cladopyxishemi brachiata*	02
12.	*Cochlodinium potykrikoides*	09
13.	*Coscinodiscus centralis*	19
14.	*Coscinodiscus granii*	08
15.	*Coscinodiscus jonesianus*	02
16.	*Coscinodiscus marginatus*	13
17.	*Coscinodiscus oculusiridis*	02
18.	*Dinophysis caudata*	12
19.	*Dinophysis nules*	16
20.	*Guinardia blavyanus*	01
21.	*Guinardia flaccida*	01
22.	*Hemiauluss inensis*	01
23.	*Hemidiscus cuneiformis*	06
24.	*Leptocylindrus danicus*	02
25.	*Licmophora* sp	01
26.	*Navicula* sp	07
27.	*Nitzschia sigma*	02
28.	*Odontella mobiliensis*	06
29.	*Oscillatoria* sp	32
30.	*Phaeocystis* sp	26000
31.	*Proboscia alata*	02
32.	*Protoperidinium depressum*	27
33.	*Protoperidinium excentricum*	13
34.	*Protoperidinium obtusum.*	22
35.	*Protoperidinium pyriforme*	05
36.	*Pyrophacus horologicum*	02
37.	*Pyrophacus steinii*	01
38.	*Rhizosolenia imbricata*	01
39.	*Stephanopyxi spalmeriana*	01
40.	*Thalasiossira decipiens*	03
41.	*Thalasiossira hyaline*	05
42.	*Thalassionema nitzschioides*	31
43.	*Trichodesmium erythraeum*	12
44.	Unidentifying sp.	02

The *Phaeocystis* blooms normally occur in high latitude and rarely occur in low latitude except in China Sea. The rare occurrence of *Phaeocystis* blooms at low latitudes and the species identification in these environments is largely unknown[12]. Further, unusual subtropical bloom of *Phaeocystis* during summer 2003 occurs in South Atlantic Bight Continental shelf also suggested that *Phaeocystis globosa* species occurs normally in low latitude[13].

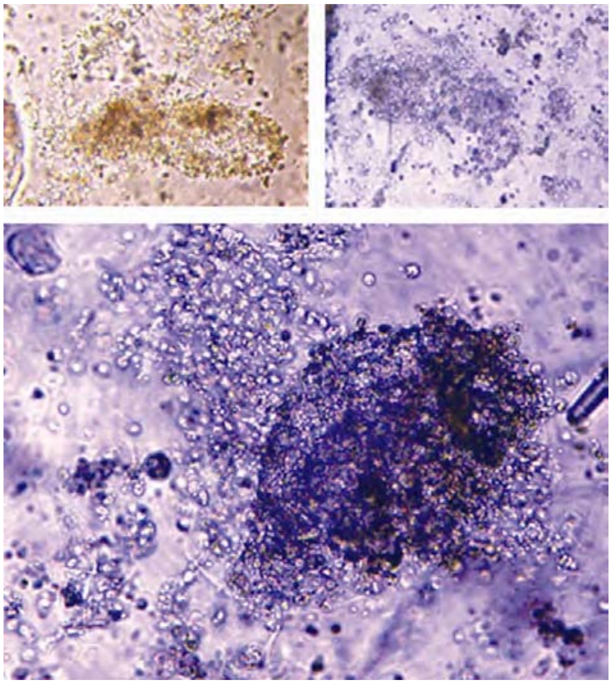

Fig. 2—Bloom-forming *Phaeocystis* spp. colony form and individual cells

Prymnesiophyte alga *Phaeocystis* sp. forms massive blooms in temperate and it is undoubtedly an important contributor both to global primary productivity and to the flux of volatile sulphur compounds from the ocean to the atmosphere[14-15]. The fate of *Phaeocystis* sp. blooms is uncertain. While some protozoa and metazoan zooplankton can graze *Phaeocystis* sp.[16-19] and others avoid feeding on it, perhaps because of its low nutritional quality[20-22]. In some areas, large quantities of *Phaeocystis* sp. may ultimately sink out of the euphotic zone[23-24].

Inhibition of bacterial activity during active growth of the alga may explain accumulations of DOC during *Phaeocystis* sp. blooms[25] and antibacterial activity properties seems with several studies in Coastal waters blooms of the North Sea[26-27].

As per the review of algal blooms off India[28] suggested that till date, nowhere in Indian coastal stretch noticed the bloom of *Phaeocystis* (Table 3). So, the occurrence of *Phaeocystis* is considered one among the process of upwelling waters[29-30] might have reached coastal waters from high latitudes and proliferate its bloom in the coast off Diglipur for its favourable condition existed during the month of July because of high rainfall and influx of nutrient in to the nearshore environment from terrestrial system through rain water. This is inferred by the temperature difference of 32°C to 26.5°C which is 6.0°C colder

Table 3—Comparative table for the bloom occurrence in the off coast of India - PrM: Pre–monsoon, SWM: South–West Monsoon, PoM: Post–monsoon (D'Silva *et al*., 2012).

Sr. No.	Causative organism	Place of Occurrence	Year	Season
		Diatom		
1	a) *Ditylum* sp.	Malabar coast	1st May 1922	PrM
	b) *Thalassiosira* sp.		7th May 1922	PrM
2	*Fragilaria oceanica*	Off Kaikani, Mangalore	August 1972	SWM
3	a) *Nitzschia sigma*	Cochin backwaters,	May 1970	PrM
	b) *Skeletonema costatum*	Kerala	November 1970	PoM
4	*Skeletonema costatum*	Dharamtar Creek, Mumbai	October 1984–1985	PoM
5	*Coscinodiscus asteromphalus* var. *centralis*	Off Kodikkal – Calicut, Kerala coas	August 2006	SWM
		Dinoflagellate		
6	Unidentified flagellate (*Noctiluca* ?)	Malabar coast	November 1908	PoM
7	Unidentified Peridian (*Noctiluca* ?)	Malabar to south Kanara coasts	September–October 1916	SWM
8	a) *Glenodinium*,	Malabar coast	November 1921	PoM
	b) *Gymnodinium* sp.1, sp.2 & sp.3		December 1921	PoM
	c) *Prorocentrum micans*		January 1922	PoM
	d) *Prorocentrum* sp.		January 1922	PoM
	e) *Cochlodinium* sp.1		August 1922	SWM
	f) *Cochlodinium* sp.2		October 1922	PoM

(*Contd*.)

Table 3—Comparative table for the bloom occurrence in the off coast of India - PrM: Pre–monsoon, SWM: South–West Monsoon, PoM: Post–monsoon (D'Silva *et al*., 2012). (*Contd*.)

Sr. No.	Causative organism	Place of Occurrence	Year	Season
9	*Noctiluca miliaris*, *Gymnodinium* sp.4 & *Dinophysis* sp.	Malabar & Kanara coasts	October 1948	PoM
10	*Gonyaulax polygramma*	off Cochin, Kerala coast	November 1963	PoM
11	*Noctiluca miliaris*	a) off Quilon, Kerala	August 1976	SWM
		b) Cochin, Kerala	August 1977	SWM
12	Species not identified (toxin profile corresponded to *Alexandrium tamiyavanichi*)	Kumble estuary, Mangalore coast	4th April 1983	PrM
13	*Noctiluca miliaris*	Mandovi & Zuari estuaries; coastal waters of Goa	February–April 1987	PrM
14	Unknown causative species	Mangalore	April 1985 & March–April 1986	PrM
15	*Noctiluca miliaris*	Mangalore	January 1987	PoM
16	*Gymnodinium nagasakiense*	Brackwish water fish farm at Kodi, Karnataka	11th–15th December 1989	PoM
17	*Noctiluca miliaris*	off Mangalore	May 1993	PrM
18	Unknown causative species	Vizhinjam, Kerala coast	September 1997	SWM
19	*Noctiluca* sp.	Cochin–Calicut, off Kerala coast	8–10th August 1998	SWM
20	*Cochlodinium polykrikoides*	off Goa	October 2001	PoM
21	*Noctiluca scintillans*	Off Goa to Porbandar (Gujarat) coast	26th February–15th March 2003	PrM
22	Causative species varied, a)*Cochlodinium polykrikoides* b) *Karenia brevis*	Kerala coast	17th September 2004	SWM
23	*Noctiluca miliaris*	Off south Thiruvananthapuram, Kerala coast	29th September 2004	SWM
24	*Karenia mikimotoi*	Kerala coast	July–September 2004	SWM
25	*Noctiluca miliaris*	Off Gujarat	March 2007	PrM
26	*Protoperidinium* sp.	Mangalore coast	8th October 2008	PoM
27	*Noctiluca miliaris*	Off Goa	8th October 2008	PoM
28	*Noctiluca scintillans*	off Kochi, Kerala	19th August 2008	SWM
29	*Karenia mikimotoi*	Cochin barmouth, Kerala	21st October 2009	POM
		Cyanobacteria		
30	*Trichodesmium erythraeum* & *Trichodesmium hildebronti*	Ullal, off Mangalore coast	13th & 21st March 1964	PrM
31	*Trichodesmium erythraeum*	Minicoy Island, Lakshadweep	May–June 1965	SWM
32	*Trichodesmium erythraeum*	Laccadive island	April 1968	PrM
33	*Trichodesmium erythraeum*	near–shore waters of Goa	March 1972	PrM
34	*Trichodesmium erythraeum*	coastal waters of Goa	February–April 1975	PrM
35	*Trichodesmium erythraeum*	Ratnagiri–Mangalore & Laccadive island	March 1977	PrM
36	*Trichodesmium erythraeum*	Mangalore–Quilon	6–20th May 2005	PrM
37	*Microcystis aeruginosa*	Chalakudy River in Central Kerala	March 2008	PrM
38	*Trichodesmium erythraeum*	off Kollam, Kochi & Kannur, Kerala coast	29th May–11th June 2009	Onset of SWM
		Raphidophyte		
39	*Hornellia marina*	Calicut, North Kerala	August & November 1949, September 1952,	SWM

(*Contd*.)

Table 3—Comparative table for the bloom occurrence in the off coast of India - PrM: Pre–monsoon, SWM: South–West Monsoon, PoM: Post–monsoon (D'Silva *et al*., 2012). (*Contd*.)

Sr. No.	Causative organism	Place of Occurrence	Year	Season
40	*Chattonella marina*	Calicut to Tellicherry, Kerala	a) September 2002	SWM
			b) September 2003	SWM
41	*Chattonella marina*	off Kochi, Kerala	September 2009	SWM
		Haptophyte		
42	Unidentified holococcolithophore	Kerala	September–October 2004	Withdrawal of SWM
		Table 2—Reportings of algal blooms along the east coast of India.		
		Diatom		
43	a) *Rhizosolenia alata*	inshore waters off	March 1950	PrM
	b) *Rhizosolenia imbricata*	Mandapam, Tamil Nadu	February 1951	PrM
44	*Asterionella japonica*	off Vishakhapatnam, Andra Pradesh	April 1967	PrM
45	*Asterionella glacialis*	Vellar estuary, Tamil Nadu	March & September/ October 1983	PrM SWM
46	*Asterionella glacialis*	Gopalpur, Orissa coast	26th March 1988	PrM
47	*Asterionella glacialis*	Rushikulya estuary, Orissa coast	April–May 1988	PrM
48	a) *Asterionella glacialis*	Bahuda estuary, Orissa coast	May 1991	PrM
	b) *Thalassiothrix fraunfeldii*		September 1991	SWM
	c) *Coscinodiscus centralis* & *Coscinodiscus excentricus*		June 1992	SWM
49	*Asterionella glacialis*	off Kalpakam, Tamil Nadu	May 1993	PrM
50	*Asterionella glacialis*	Gopalpur, Orissa	24th March–4th April 2004	PrM
		Dinoflagellate		
51	*Noctiluca miliaris*	Madras, Tamil Nadu	June 1935	SWM
52	*Noctiluca miliaris*	Palk Bay –Tamil Nadu	April–July 1952	PrM
53	*Noctiluca miliaris*	Vellar Estuary- TamilN adu	August 1966,	SWM
			August 1967,	SWM
			May 1968	PrM
54	Species not identified	Vayalar village, Tamil Nadu	1981	---
55	*Noctiluca scintillans*	Kalpakkam, Tamil Nadu	11–17th October 1988	PoM
56	*Noctiluca scintillans*	Port Blair Bay, Andamans	June–July 2000	SWM
57	*Noctiluca scintillans*	Minnie bay, Port Blair–Andaman's	20th December 2002	NEM
58	*Noctiluca scintillans*	Rushikulya river, South Orissa coast	5th April 2005	PrM
59	*Noctiluca scintillans*	Gulf of Mannar, Orissa	2nd –12th October 2008	PoM
		Cyanobacteria		
60	*Trichodesmium erythraeum*	Krusadai island, Gulf of Mannar	May 1942	PrM
61	*Trichodesmium erythraeum*	Southern coast of Pamban, Gulf of Mannar	May 1942	PrM
62	*Trichodesmium erythraeum*	Porto Novo, Tamil Nadu	March 1964, 1965, 1969, 1972	PrM
63	*Trichodesmium thiebautii*	Gulf of Mannar, Tamil Nadu	March–April &	PrM
			September 1973	SWM
64	*Trichodesmium erythraeum*	a) Tamil Nadu	11th April 2001	PrM
		b) off Kolkata	25th April 2001	
65	*Trichodesmium erythraeum*	Kalpakkam, Tamil Nadu	16th March 2007	PrM
66	*Trichodesmium erythraeum*	Mandapam & Keelakarai, Tamil Nadu	October 2008	PoM
67	*Microcystis aeruginosa*	Vellar estuary, Tamil Nadu	December 2009	NEM

Table 4—Results of physicochemical and nutrient analysis of waters at Station No-18 (WP-15) Off North Andaman

Bottle No	Depth (m)	Seawater Temperature (°C)	*p*H	Silicate (µmol/L)	Nitrite (µmol/L)	Phosphate (µmol/L)	Nitrate (µmol/L)
1	Surface	29.2	8.31	0.00	0.30	0.13	0.14
2	5	29.1	8.35	0.00	0.00	0.13	0.32
3	25	29	8.4	0.00	0.00	0.31	0.23
4	50	28.7	8.41	0.00	0.14	0.31	0.28
5	100	21.5	8.12	0.00	0.10	1.57	18.64
6	250	15	8.1	0.00	0.00	2.11	30.36
7	550	13.7	8.14	0.00	0.16	2.33	34.79
8	800	11.2	8.21	0.05	0.06	2.55	37.23

than the normal temperature. This factor also support the South Atlantic Bight Continental shelf bloom occurrence that was noticed 8°C difference in this environment than the normal[13]. Further, the unpublished data from the ORV Sagar Manjusha (Table 4) also support that near 800 m depth off Diglipur the temperature is 11.2°C and nutrients also rich in these waters i.e. phosphate (2.55 µmol/L) and nitrate (37.23 µmol/L). However, it is essential to understand the factors which influences the bloom development in the tropical condition that also similar to the laboratory condition suggested[30-31,12-13], who reported that high temperature and low nutrients support the colony formations in the laboratory condition. Further, the grazers of micro-zooplankton also migrated from the place of occurrence of *Phaeocystis* spp. bloom due to temperature difference leads to reduction of consumption of this species and help the blooming process as reported by Jahnke and Baumann[32] and Tang[33].

The outbreaks of blooms threat to the coastal fish and shellfish and aquaculture affected throughout world[34]. *Phaeocystis* sp. communities more dominated reflect the outcome of a host of physical, chemical and biological properties changes or climatic changes. *Phaeocystis* spp. high concentration of species colony blooms negative effects on fisheries and fish farming Lancelot *et al.*[15] such a blooms of *Phaeocystis* spp. colonies considered as harmful algal blooms (HABs). HAB species blooms are very unpredictable, HAB species responses, which increases the difficulty in distinguishing between anthropogenic stimulation of harmful blooms and natural behaviour. Maddock *et al.*[35] concluded that phytoplankton respond only to certain features of weather properties, or to those accompanying long-term changes *Phaeocystis* spp. blooms constrain water column and physical properties have significant play in the formation of bloom.

The earlier work bloom *Phaeocystis* spp. observed in different regions suggested that high nutrient and low temperature in high latitude and low nutrient and high temperature in subtropical conditions[36-43,30] and[15]. A variety of filtering or suspension-feeding organisms decrease or stop their feeding when *Phaeocystis* colonies are present, including zooplankton and various bivalves[44] may be due to the physico chemical condition it may drive environment sensitive zooplankton from the bloom locations instead of negative effect of HAB by the way of harming the organisms[13]. *Phaeocystis* has also been shown to release of Dimethyl Sulphonio Propionate (DMSP) and as well as herbivorous zooplankton growth control and dynamic negative impact[45].

Present work summarises that the Andaman Coastal regions as a whole and in particular North Andaman coastal region exhibited very limited work on marine science related activities. *Phaeocystis* spp., bloom had first time documentation for this study area as well as whole country's coastline. So, it is essential to have a continuous monitoring of water column and planktonic compositions for this bloom and its impact on tropical coastline. P.M.M thanks the Captain of ORV sagar Manjusha and the Director NIOT, Channai for the facility extended during the cruise on September 2008.

Acknowledgements

Authours are grateful to the Vice Chancellor and other higher authorities of Pondicherry University, Puducherry, India for their support and Ministry of Earth Sciences (MoES), New Delhi, India for financial support under Geotracer programme. The Central Instrumentation Facility (CIF), Pondicherry University also gratefully acknowledged for the sample analysis.

References

1 Sournia, A., Chretiennot-Dinet, M.J. & Ricard, M., (1991). Marine phytoplankton: how many species in the world ocean? *J. Plankton Res.,* 13, 1093–1099.

2 Hallegraeff, G.M., Anderson, D.M., Cembella, A.D., (1995). Manual on Harmful Marine Microalgae. *UNESCO.*, pp. 1–22.

3 Hallegraeff, G.A. 1993. A review of harmful algal blooms and their apparent global increase. *Phycologia.,* 32, pp. 79-99.

4 Mohan, P.M., Dhivya, P., Sachithanandam, V. & Baskaran, R. (2010). Coral Bleaching in and Around Port Blair, Andaman and Nicobar Islands, India. *Seshaiyana*, 18, pp. 1-3.

5 Rao, D.V., Devi, K. & Rajan, P.T., *An Account of Ichthyofauna of Andaman and Nicobar Islands*, *bay of Bengal.Record.* [Zoological Survey of India, ZSI, Calcutta. Occ. Paper No. 178 2000, pp. 434.]

6 Sucknova, Z. N. (1978). Settling without the inverted microscope. In phytoplankton manual, UNESCO (ed .A. Sourine) page Brothers (Nourisch) Ltd, PP 97.

7 Cupp, E.E., (1943). Marine plankton diatoms of the west coast of North America. *Bulletin Scripps of Indian Oceanography*, 5, 1-237 p.

8 Tomas, C.R. (1997) *Identifying Marine Phytoplankton.* [*Academic Press*, Harcourt Brace and Company], 1997, 857pp.

9 Taylor, F.J.R., (1976). Dinoflagellates from the international Indian Ocean Expedition A report on material collected by the "*R.V. Anton Brunn*,132: 1-226 p.

10 Baumann, M.E.M., Lancelot, C., Brandini, F.P., Sakshaug, E. & John, D.M., (1994). The taxonomic identity of the cosmopolitan prymnesiophyte*Phaeocystis*: a morphological and ecophysiologicalapproach. *J. Mar. Sys.*, 5, pp. 5–22.

11 Lange, M., Chen, Y.Q. & Medlin, L.K. (2002). Molecular genetic delineation of *Phaeocystis* species (Prymnesiophyceae) using coding and non-coding regions of nuclear and plastid genomes. *Eur. J. Phycol*., 37, 77–92.

12 Chen, Y.Q., Wang, N. & Zhang, P. (2002) Molecular evidence identifies bloom-forming Phaeocystis (Prymnesiophyta) from coastal waters of southeast China as Phaeocystisglobosa. *Biochem. Syst. Ecol*., 30, pp. 15–22.

13 Long, J.D., Frischer, M.E. & Robertson, C.Y. (2007). A *Phaeocystsisglobosa* bloom associated with upwelling in the subtropical South Atlantic Bight. *Journal of Plankton Research*, 29, pp. 769-774.

14 Bates, T.S., Charlson, R.J. & Gammon, R.H. (1987). Evidence for the climatic role of marine biogenic sulphur. *Nature,* 329, pp. 319-321.

15 Lancelot, C., Billen, G., Sournia. A., Weisse, T., Colijn, F., Veldhuis, M.J.W., Davies, A. & Wassmann, P. (1987). *Phaeocystis* blooms and nutrient enrichment in the continental coastal zones of the North Sea. *Ambio.,* 16: 38-46.

16 Admiraal, W. & Venekamp, L.A.H., (1986). Significance of tintinnid grazing during blooms of *Phaeocystispouchetii* (Haptophyceae) in Dutch coastal waters. Neth. *J. Sea Res*., 20, pp. 61–66.

17 Huntley, M., Tande, K.S. & E~lertsen, H.C. (1987). On the trophic fate of Phaeocystjspouchetii. Grazing rates of *Calanushyperboreus* feeding on diatoms and different size categories of*P.pouchetii*. *J. Exp. Mar. Biol. Ecol*., 110: 197-212.

18 Tande, K.S. & Ban-stedt, U. (1987). On the trophic fate of *Phaeocystispouchetii* I. Copepod feeding rates on solitary cells and colonies of *P.pouchetii*. *Sarsia,* 72, pp.313-320.

19 Weisse, T. & Scheffel-Moser, U. (1990). Growth and grazing loss rates in single-celled *Phyaeocystis*sp. (Prymnesiophyceae). *Mar. Biol*., 106, pp. 153-158.

20 Smith, S. L. (1988). Copepods in Frarn Strait in summer, distribution, feeding and metabolism. *J. mar. Res*., 46, pp. 145-81.

21 Verity, P.G. & Smayda, T.J. (1989). Nutritional value of *Phaeocystispouchetii* (Prymnesiophyceae) and other phyto-plankton for *Acartia* spp. (Copepoda): ingestion, egg productlon, and growth of nauplii. *Mar. Biol*., 100, pp. 161-171.

22 Claustre, H., Poulet, S.A., Waams, R., Marty, J.C., Coombs, S., Ben-Mlih, F., Hapette, A. M. & Martin-Jezequel, V. (1990). A biochemical investigation of a Phaeocystis sp. bloom in the Irish Sea. *J. Mar. Biol. Ass.,* U.K. 70, pp. 197-207.

23 Savage, R.E. & Hardy, A.C. (1934). Phytoplankton and the herring. Part I, 1921 to 1932. *Fishery Invest*., 2, 1-73p.

24 Wassmann, P., Vernet, M., Mitchell, B.G. & Rey, F. (1990). Mass sedimentation of *Phaeocystispouchetii* in the Barents Sea. *Mar. Ecol. Prog. Ser*., 66, pp. 183- 195.

25 Eberlein, K.M., Leal, T., Hammer, K.D. & Hickel, W. (1985). Dissolved organic substances during a *Phaeocystispouchetii* bloom in the German Bight (North Sea). *Mar. Biol*., 89, pp. 311-316.

26 Lancelot, C. & Billen, G. (1984). Activity of heterotrophic bacteria and its coupling to primary production during the spring phytoplankton bloom in the southern bight of the North Sea. *Limnol. Oceanogr*. 29,pp. 721-730.

27 Laanbroek, H.J., Verplanke, J.C., De Visscher, P.R.M. & DeVuyst, R. (1985). Distribution of phyto- and bacterioplankton growth and biomass parameters, dissolved inorganic nutrients and free amino acids during a spring bloom in the Oosterschelde basin, The Netherlands. *Mar. Ecol. Prog. Ser*., 25, pp. 1-11.

28 D'Silva, M.S., Anil, A. C., Naik, R.K. & D'Costa, P.M. (2012). Algal blooms: a perspective from the coasta of India. *Nat. Hazards.*, 63, pp. 1225-1253.

29 Garrison, D.L., Gowing, M.M. & Hughes, M.P., (1998). Nano- and microplankton in the northern Arabian Sea during the Southwest Monsoon, August–September 1995: a US-JGOFS study. *Deep- Sea Res*- II. 45, pp. 2269– 2299.

30 Verity, P.G., Villareal, T.A. & Smayda, T.J. (1988) Ecological investigations of blooms of colonial *Phaeocystispouchetii.* I. Abundance, biochemical composition, and metabolic rates. *J Plankton Res.,* 10, pp. 219-248.

31 Verity, P.G., Smayda, T.J. & Sakshaug, E. (1991). Photosynthesis, excretion, and growth rates of Phaeocystis colonies and solitary cells. *Polar Res*., 10, pp.117– 128.

32 Jahnke, J. & Baumann, M.E.M., 1987. Differentiation between *Phaeocystispouchetii* (Har.) Lagerheim and *Phaeocystisglobosa*Scherffel. I. Colony shapes and temperature tolerances. *Hydrobiol. Bull*., 21, pp. 141– 147.

33 Tang, D., Kester, D.R., Ni, I.-H., Qi, Y. & Kawamura, H., 2003. In situ and satellite observations of a harmful algal

bloom and water condition at the Pearl River estuary in late autumn 1998. *Harmful Algae,* 2, pp. 89– 99.

34 Anderson, D.M., (1998). Study of red tide monitoring andmanagement in Hong Kong: literature review and background information. Technical Report No. 1, Hong Kong Agriculture and Fisheries Department, p. 120.

35 Maddock, L., Harbour, D.S. & Boalch,G.T. (1989). Seasonal and year-to-year changes in the phytoplankton from the Plymouth area, 1963-1986. *J. Mar. Biol. Ass.* U.K. 69: 229-244.

36 Alderkamp, A.C., Buma A.G.J. & Van Rijssel, M. (2005). The carbohydrates of *Phaeocystis*and their degradation in the microbial food web. Biogeochemistry. doi:10.10071.10533-007-9078-2

37 Brussaard, C.P.D.,Mari, X., Van Bleijswijk, J.D.L. & Veldhuis, M.J.W. (2005) Amesocosm study of *Phaeocystisglobosa* population dynamics Significance for the microbial community. *Harmful Algae*,pp. 4875-4893.

38 Ruardij, P, Veldhuis, M.J.W. & Brussaard, C.P.D. (2005).Modeling the bloom dynamics of the polymorphic phytoplankton *Phaeocystisglobosa*:impact of grazers and viruses. *Harmful Algae,* 4, pp. 941-963

39 Nichols, P.D., Skerrat, J., Davidson, A., Burton, H. & McMeekin, T.A. (1991). Lipidsof cultured *Phaeocystispouchetii*: signatures for food web, biogeochemical and environmental studies in Antarctica and the Southern Ocean. *Phytochem,* 30, pp. 3209-3214.

40 Raven, J.A. (1990). Predictions of Mn and Fe use efficiencies of phototrophic growth as a function of light availability for growth and of C assimilation pathway. *New Phytol,* 116, pp. l-18.

41 Veldhuis, M.J.W., Colijn, F. & Admiraal, W. (1991). Phosphate utilization in *Phaeocystispouchetii* (Haptophyceae). *Mar. Biol*.,12, pp. 53-62.

42 Schoemann, V., Becquevort, S., Stefels, J., Rousseau,V. & Lancelot, C. (2005) *Phaeocystis*blooms in the global ocean and their controlling mechanisms: a review. *J Sea Res* 53. pp. 43-66.

43 Peperzak, L., Colijn, F., Gieskes, W.W.C & Peeters, J.C.H. (1998). Development of the diatom-*Phaeocystis* spring bloom in the Dutch coastal zone of the North Sea: the silicon versus the daily irradiance threshold hypothesis. *J Plankton Res*., 20, pp. 517-537.

44 Weisse, T., Tande, K., Verity, P., Hansen, F. & Gieskes, W. (1994). The trophic significance of *Phaeocystis*blooms. *Journal of Mar. Syst*. 5, pp. 67-79.

45 Lancelot, C., Rousseau, V., Schoemann, V.S & Becquevort, S. (2002). On the ecologicalrole of the different life forms of *Phaeocystis*. In: Garcés E, Zingone A, Montresor M.,Reguera B and Dale B (eds.). Proceedings of the workshop LIFEHAB: Life historiesofmicroalgal species causing harmful blooms. Calvia, Majorca, Spain, octobre 2001. *Research in Enclosed Seas series* 12, pp. 71-75.