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Environmental dynamics of red *Noctiluca scintillans* bloom in tropical coastal waters

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ABSTRACT

An intense bloom of red *Noctiluca scintillans* (NS) occurred off the Rushikulya estuarine region along the east coast of India, an important site for mass nesting events of the vulnerable Olive Ridley sea turtle. At its peak, densities of NS were 3.3×10^5 cells-l^{-1}, with low relative abundance of other phytoplankton. The peak bloom coincided with high abundance of gelatinous planktivores which may have facilitated bloom development by their grazing on other zooplankton, particularly copepods. Ammonium concentrations increased by approximately 4-fold in the later stages of bloom, coincident with stable NS abundance and chlorophyll concentrations in the nano- and microplankton. This increase likely was attributable to release of intracellular ammonium accumulated through NS grazing. Dissolved oxygen concentrations decreased in sub-surface waters to near hypoxia. Microphytoplankton increasingly dominated chlorophyll-*a* biomass as the bloom declined, with diminishing picoplankton abundance likely the result of high predation by the ciliate *Mesodinium rubrum*. Together, these data illustrate factors that can disrupt ecosystem balance in this critically important Indian coastal region.

1. Introduction

Noctiluca scintillans ((Macartney) Kofoid & Swezy) [hereafter NS], a mainly heterotrophic dinoflagellate, often causes intensely colored red or green tides in coastal and offshore waters (D'Silva et al. 2012). Green strains of NS contain *Pedinomonas noctilucae* (a green alga) as an endosymbiont (Elbrachter and Qi 1998; Sriwoon et al. 2008), which provides an added source of nutrition. In contrast, red NS strains are entirely heterotrophic. Blooms of red (non-chlorophyll containing) NS are observed globally in subtropical and temperate seas, whereas, the green NS blooms are generally restricted to western Pacific and Indian waters (Elbrachter and Qi 1998; Saito and Furuya 2006). In general both red and green NS feed voraciously on phytoplankton (especially diatoms) by phagotrophy, thereby shaping the size distribution and species composition of phytoplankton assemblages, some zooplankton, particularly copepods, and fish eggs (Elbrachter and Qi 1998; Nakamura 1998; Saito and Furuya, 2006). Phytoplankton assemblages often are rich in diatoms at the onset of both red and green species of NS proliferation (Mohanty et al. 2007; Madhu et al. 2012) suggesting that they are a preferred prey, although NS also feed upon nanoplankton and picoplankton (Umani et al. 2004). When grazing on toxic phytoplankton, NS can transfer these toxins to higher trophic levels (Escalera et al. 2007). While zooplankton can graze on NS (Erkan et al. 2000), the collapse of NS blooms are more often the result of prey depletion (Kiorboe and Titelman, 1998; Nakamura 1998). Ammonia excretion by NS species during grazing, and particularly the release of high intracellular ammonia pools upon cell death, can result in fish mortality and toxicity to other organisms (Aiyar 1936; Okaichi and Nishio 1976). The sudden collapse of these blooms also can generate hypoxic conditions in coastal regions (Naqvi et al. 1998). This broad range of negative environmental impacts is the reason why the ecophysiology of NS and their blooms are topics of active research.

Both red and green NS blooms are common in Indian coastal waters along both the eastern (Bay of Bengal) and western (Arabian Sea) shores, although they appear to be more frequent in the Arabian Sea than in the Bay of Bengal (Table 1 and references therein). Green NS blooms are most common in the Arabian Sea, except along Kerala coast where red NS recurrences are reported. Red and green NS blooms occur in the Bay of Bengal region, particularly off the Chennai coast and Rushikulya estuarine region (Table 1). The Rushikulya estuarine region, midway along the east coast of India, is recognized internationally as an

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Table 1
Records of *Noctiluca scintillans* (also known as *Noctiluca miliaris*) blooms and their impacts in Indian waters [updated from D'Silva *et al.* (2012)].

Region	Date	Maximum Abundance (cells l^{-1})	Chl-*a* (mg m^{-3})	Observation	Reference
East coast of India (red *Noctiluca scintillans*)					
Off Rushikulya estuary, South Odisha coast	Apr 2014	32.87×10^4	12.3	Brown to dull-red discolouration of seawater. Lack of fish in the area	Present study
Rushikulya river, South Odisha coast	5 Apr 2005	2.38×10^5		Red discolouration of seawater, O_2 depletion	Mohanty et al. (2007)
Madras, Tamil Nadu	June 1935			Pink colouration of seawater; fish mortality	Aiyar (1936)
East coast of India (green *Noctiluca scintillans*)					
Gulf of Mannar	2 –12 Oct 2008	13.5×10^5	116	Deep-green colouration of seawater; coral bleaching due to O_2 depletion; death of fish & other sea animals	Gopakumar et al. (2009)
Minnie bay, Port Blair, Andamans	20 Dec. 2002	0.2×10^5	32.7	Green colouration of seawater	Dharani et al. (2004)
Port Blair Bay, Andamans	June–July 2000	2.3×10^4	17.6	Green colouration of seawater	Eashwar et al. (2001)
Palk Bay, Mandapam, Tamil Nadu	Apr–July 1952			Green *Noctiluca*	Raghu Prasad (1953, 1958)
Kalpakkam, Tamil Nadu	11–17 Oct. 1988	0.4×10^5	28	Green *Noctiluca*	Sargunam and Rao (1989)
East coast of India (no color reported)					
Mandapam and Keelakarai, South east coast of India	July to Dec. 2008				Anantharaman et al. (2010)
Vellar Estuary, Tamil Nadu	Aug 1966, Aug. 1967, May 1968	2.9×10^6			Santha Joseph (1975)
West coast of India (red *Noctiluca scintillans*)					
Kerala coast	Sept 2004		0.7	Red discolouration of seawater	Joseph et al. (2008)
Offshore of Kochi, Kerala	19 Aug2008	5×10^8		Brick red discolouration of seawater; no fish mortality observed	Padmakumar et al. (2010)
Offshore south of Thiruvananthapuram, Kerala coast	29 Sept. 2004	9×10^5	0.6	Red discolouration of seawater	Sahayak et al. (2005)
Cochin–Calicut, off Kerala coast	8–10 Aug. 1998			Red discolouration of seawater. O_2 depletion resulted in fish mortality	Naqvi et al. (1998)
Cochin, Kerala	Aug 1977	7.7×10^2		Red coloration of seawater	Devassy et al. (1979)
Off Quilon, Kerala	Aug 1976	4.1×10^2		Red colouration of seawater	Venugopal et al. (1979)
West coast of India (green *Noctiluca scintillans*)					
Arabian Sea	Feb 2009	9.6×10^3	25	Green *Noctiluca*	Gomes et al. (2014)
Off Gujarat	17 Feb. 2009		27.7	Green colouration of seawater	Tholkapiyan et al. (2014)
Off Mangalore	12 May 2011	10.5×10^5	9.1	Green colouration of seawater	Sulochanan et al. (2014)
Northern Arabian Sea	Mar 2011			Green colouration of seawater	Matondkar et al. (2012)
Northern Arabian sea	Mar 2000	3×10^6	2.5	Yellowish-green mat over the surface water	Madhu et al. (2012)
Northern Arabian Sea	9–29 Feb. 2009	9600		Green colouration of seawater	Matondkar et al. (2012)
Eastern Arabian sea	20 Feb. - 11 Mar. 2004		2.7	Green *Noctiluca*	Prakash et al. (2008)
Offshore near Gujarat	Mar 2007	4×10^3	21.9	Deep green colouration of seawater	Padmakumar et al. (2008)
Offshore near Goa to Porbandar (Gujarat) coast	26 Feb.–15 - Mar. 2003	2542		Green colouration to seawater	Matondkar et al. (2004)
Mangalore	Jan 1987	7.6×10^6		Intense green coloration of seawater	Katti et al. (1988)
Mandovi & Zuari estuaries; coastal waters of Goa	Feb –Apr. 1987	5.1×10^4	16.7	Green coloration of seawater; reduced fish yields	Devassy and Nair (1987)
Malbar and Kanara Coast	Oct 1948	0.5×10^5		Pink and red discolouration of seawater. No mortality but fish avoided the area; abrupt reduction in fish yield was observed	Bhimachar and George (1950)
West coast of India (no color reported)					
Offshore near Goa	8 Oct. 2008	2×10^4		No fish kills observed	Sanilkumar et al. (2009)
Offshore near Mangalore	May 1993	1.6×10^3		Increased number of *Moraxella*-like bacteria associated with bloom	Nayak and Karunasagar (2000)

eco-sensitive zone hosting mass nesting events of Olive Ridley sea turtles. The long-term data from time-series stations revealed significant variability in water quality parameters showing two local water types (Baliarsingh et al. 2015) along with a bi-modal distribution of chlorophyll-*a* (chl-*a*) at annual scales (Lotliker et al. 2015). Further, long-term satellite data analysis and previous reports on chl-*a* trends