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Response of phytoplankton community and size classes to green *Noctiluca* bloom in the northern Arabian Sea

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ABSTRACT

A comprehensive analysis on the phytoplankton ecology with special reference to different phytoplankton size classes was carried out at green *Noctiluca scintillans* (hereafter *Noctiluca*) bloom and non-bloom locations in offshore waters of the northern Arabian Sea. At the bloom locations, green *Noctiluca* represented a dense mono-specific proliferation with average cell density of $10.16 \pm 5.806 \times 10^4$ cells-L^{-1} and relative abundance share of 98.63%. Active photosynthesis through prasinophytic endosymbiont was depicted from net community production magnitude reaching 85.26 mgC/m^3/Day under low prey abundance. Parallel swarming of *Porpita porpita*, a voracious copepod feeder signified the competitive advantage of *Noctiluca* to have the phytoplankton prey. Average concentration of picophytoplankton biomass was eleven times lower in surface waters of non-bloom stations in comparison to bloom. Higher N:P ratio in subsurface waters of non-bloom stations signified non-utilization of nitrogenous nutrients. Green *Noctiluca* bloom onset subsequent to diatom rich conditions was evident from spatio-temporal ocean colour satellite imageries.

1. Introduction

Arabian Sea is regarded as the most productive component of the Indian Ocean. Nutrient injection from subsurface to surface due to winter convective mixing is one of the major environmental factors that trigger phytoplankton bloom in the northern Arabian Sea. Physical forcing of winter monsoon plays an important role in this mixing (Madhupratap 1999; Dwivedi et al. 2015). Previous research on phytoplankton dynamics in this region envisaged phytoplankton bloom rank order as diatom, cyanobacteria and dinoflagellates (Sawant and Madhupratap 1996). Annual episodes of green coloured *Noctiluca scintillans* (henceforth *Noctiluca*) bloom has been reported to occur in the open waters of northern Arabian Sea especially during winter (January–March) since early 2000s (Gomes et al. 2014). However, the green *Noctiluca* bloom is believed to be eco-friendly and support fishery in this region. Unlike *Noctiluca* blooms elsewhere, there is no consequent ammonification and oxygen depletion in surface waters of the northern Arabian Sea (Dwivedi et al. 2012). However, green *Noctiluca* bloom was reported to be linked with low dissolved oxygen conditions in the northern Arabian Sea (Gomes et al. 2014). In general, green *Noctiluca* bloom intensifies depending upon the prey availability, especially diatoms. Diatoms often prevail in high density during green *Noctiluca* bloom (Madhu et al. 2012). In context of phytoplankton metabolism, molar ratios of inorganic macronutrients decipher the change in nutrient supply and depict the phytoplankton growth limitations (Redfield et al. 1963; Yin et al. 2001). Variability in ambient concentration of inorganic macronutrients favour metabolism of the endosymbiont of green *Noctiluca* as well as the growth of diatom, the preferred prey of *Noctiluca* (Sriwoon et al. 2008). Although, green *Noctiluca* is slow grower in comparison to coexisting diatoms, the relative abundance of inorganic nutrients provides advantage for green *Noctiluca* growth (Furuya et al. 2006a). In context of different size classes of phytoplankton, smaller sized phytoplankton viz. picophytoplankton and nanophytoplankton plays important role in bloom dynamics apart from microphytoplankton. The heterotrophic green *Noctiluca* also predate upon nanophytoplankton and picophytoplankton (Umani et al. 2004). Phytoplankton size class distribution alters with change in seasons in the northern Arabian Sea (Varunan and Shanmugam 2015; Sahay et al. 2017). In addition, *Noctiluca* presents a complex ecology by feeding upon and being preyed by zooplankton (Prasad 1958; Matondkar et al. 2012). The ecological complexity of the north-eastern Arabian Sea is considered as an ideal expanse to study the

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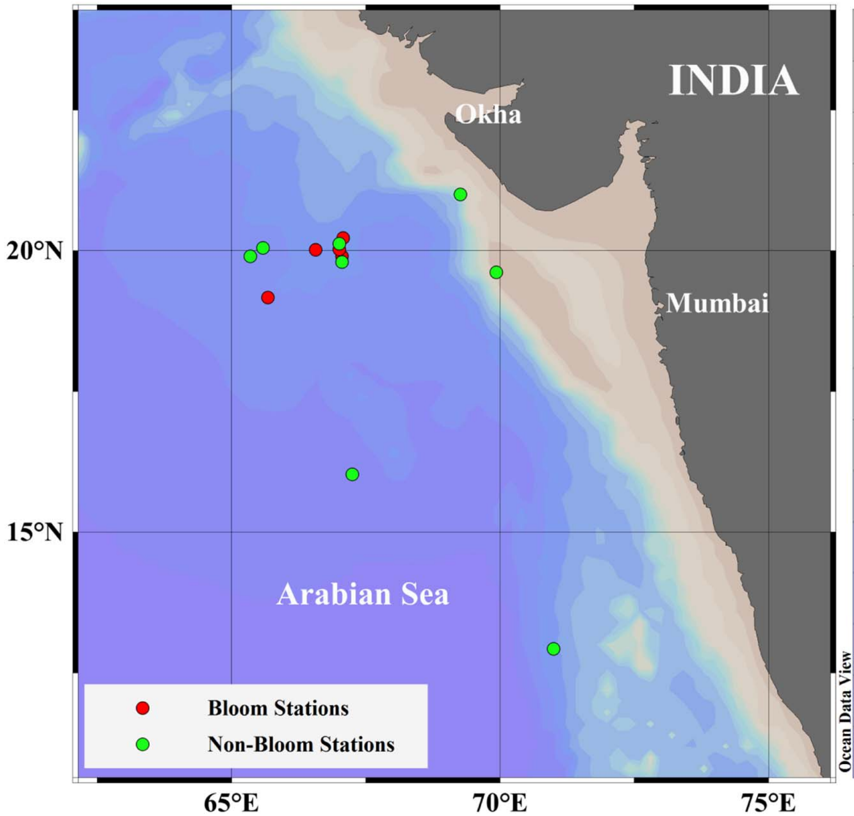

Fig. 1. Green *Noctiluca* bloom and non-bloom stations in the northern Arabian Sea.

primary and secondary responses towards mesoscale environment changes (Padmakumar et al. 2016).

Based on the ecological complexity and wide spatial coverage, the green *Noctiluca* bloom in the northern Arabian Sea need regular monitoring. Against this backdrop, the present study was carried out with aims to (i) discern the distribution of phytoplankton size classes during green *Noctiluca* bloom (ii) understand the variation of inorganic macronutrient molar ratios at bloom and non bloom locations, (iii) decipher bloom conducive factor(s) in the northern Arabian Sea.

2. Materials and methods

2.1. Study region

The present work was carried out in offshore waters of the northern Arabian Sea (Fig. 1). In situ observations were carried out onboard Indian Ministry of Earth Sciences (MoES) research vessel "Fishery Oceanographic Research Vessel (FORV) *Sagar Sampada*" (cruise no. 348) during winter of 2016 (29th February to 19th March). The aforementioned cruise was planned based on satellite retrieved trend of green *Noctiluca* bloom in the northern Arabian Sea (Dwivedi et al. 2015). Sporadic dense patches of green and yellowish-green discolouration of surface seawater were observed at latitude 19–21°N and longitude 65–68°E during 7 to 12 March 2016 (Fig. 1, Fig. 2a–e).

2.2. In situ water sample collection and analysis

During the present survey, seawater samples were collected from 0, 10, 20, 30 m of the water column with aid of a Niskin-Rosette from bloom and non-bloom locations for onboard analysis of chlorophyll-*a* (chl-*a*), phytoplankton taxonomy and inorganic macronutrients.

Different inorganic macronutrients viz. nitrate (NO_3), phosphate (PO_4) and silicate (SiO_4) were estimated by adopting spectrophotometric method using a UV–Visible Double Beam Spectrophotometer (Thermo Scientific, Evolution 201) (Grasshoff et al. 1999). A known volume of seawater (1 to 2 l) was sequentially filtered through different pore size (20 > 2 > 0.2 μ) filter papers in order to estimate biomass of different phytoplankton size classes in terms of chl-*a* concentration (Brewin et al. 2014). Chl-*a* was analyzed flurometrically following 90% acetone extraction method with aid of a Flurometer (make: Turner Designs). The concentration of chl-*a* was expressed as mg-m^{-3}. The flurometer was calibrated onboard by using chl-*a* standard (Sigma-Aldrich) with different concentrations. The retention of green *Noctiluca* cells on to the filter is illustrated in Fig. 2c–d. Qualitative and quantitative analysis of phytoplankton was carried out in shore laboratory with aid of a trinocular compound microscope (Labomed LX-400) by referring standard identifications keys (Tomas 1997). Green *Noctiluca* was enumerated onboard soon after collection using an epi-fluorescence microscope (Nikon Eclipse, E600) (Fig. 2 e).

Net Community Production (NCP) and Respiration (R) were measured following the Dissolved Oxygen (DO) method using in situ light (transparent), dark (opaque) and initial bottle (LB, DB and IB, respectively) incubation at the surface, 10, 20, 30 and 50 m depth. Water samples were collected as IB, LB and DB in three BOD (Biological Oxygen Demand) glass bottles (300 ml). Initial concentration of DO was analyzed for each depth (IB). Subsequently each set of bottles (LB and DB) were fixed to a rope and incubated in situ for 24 h at different depths. DO concentration of seawater was analyzed onboard immediately after retrieval of the incubated bottles. The NCP and R were calculated from the differences in DO concentration by following the relation, R = IB–DB and NCP = LB–IB (Gupta et al. 2016). The metabolic rates measured as oxygen were converted to carbon equivalents assuming a photosynthetic quotient of 1.2 and respiratory quotient of 1 (Laws 1991).

2.3. Satellite data processing

In the present study, phytoplankton group/species images were