Revisiting the *Noctiluca scintillans* paradox in northern Arabian Sea

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In 2015, a *Noctiluca scintillans* bloom and associated water column properties were studied in the northern Arabian Sea. Our observations showed photic depth limited to 30 m with uniform oxygen concentration of ~223 μM. In general, the dissolved oxygen ranged between 180 and 223 μM within the top 80 m indicating saturated mixed layer. Chlorophyll *a* varied between 0.24 and 2.4 mg m^{-3} within the core of the bloom and <0.1 mg m^{-3} outside. We further examined Argo oxygen data from 2006 to 2013 to delineate possible surface water hypoxia associated with the initiation of *N. scintillans* bloom. Oxygen profiles from Argo data suggest oxic upper water column (~ 50 m) with strong seasonal shoaling. Our results do not indicate any mixed layer oxygen depletion associated with the *N. scintillans* bloom or any evidence of surface water hypoxia in the past. However, examination of silicate/nitrate (Si/N) climatology suggests strong longitudinal variation. The silicate in the surface waters in the northwestern Arabian Sea is depleted much earlier (Si/N < 1) compared with the eastern part, resulting in a strong spatial trend. This presumably facilitates easy community transition to a *N. scintillans* bloom. This is supported by the heterotrophic nature of the species which, under detectable and below-detectable nitrate conditions, gives it a competitive advantage over other phytoplankton communities.

Keywords: Hypoxia, monsoon, *Noctiluca scintillans*, oxygen, silicate/nitrate ratio.

THE recurrent *Noctiluca scintillans* bloom in the northern Arabian Sea remains poorly understood. Recent work[1] suggests proliferation of the species by influx of oxygen-deficient waters at the surface due to anthropogenic perturbations in neighbouring regions[1]. *N. scintillans* species are heterotrophic dinoflagellates which often form red or green tides in the coastal and open oceans[2]. The green *N. scintillans* contains a photosynthetic symbiont *Pedinomonas Noctiluca scintillans* (a prasinophyte), and can also graze on other plankton. In addition, it is restricted to the temperature range 25°–30°C (refs 2, 3) and occurs mainly in tropical waters of Southeast Asia, Red Sea, Bay of Bengal (east coast of India) and northern Arabian Sea, including coastal waters of Pakistan and Gulf of Oman[4,5].

Algal blooms documented from the Indian sector highlight the presence of *N. scintillans* sp. as early as 1900 (ref. 6). Sustained studies during the last decade have provided more information on this bloom[1,7–10]. The northern Arabian Sea experiences strong seasonal forcing from the southwest monsoon (summer) to the northeast monsoon (winter). The coastal upwelling during summer monsoon and convective mixing during winter monsoon are the dominant physical processes in the northern Arabian Sea. Both physical processes bring subsurface nutrients to the euphotic zone[11–13] providing suitable conditions for phytoplankton to bloom[14,15]. Predominance of *N. scintillans* during the late phase of the northeast monsoon and early spring inter monsoon, covarying with patchy *Trichodesmium* blooms, indicates negligible nitrate in the surface mixed layer. Though the initiation of *Noctiluca* blooms has been attributed to hydrographic and biological factors, their accumulation in the form of a bloom is governed by favourable meteorological conditions such as low rainfall and weak wind[16]. Recent biogeochemical measurements show a well-oxygenated mixed layer with warm surface temperature, rather than surface water hypoxia[17,18].

In this communication, we present the water column properties from a green *N. scintillans* bloom recently investigated in the northern Arabian Sea. We also examine the long-term Argo oxygen data to identify possible historical events of hypoxic water spreading to the surface. Finally, we study the role of convective mixing and associated biogeochemical processes that may be linked to *N. scintillans* proliferation in this region.

Bio-optical and water column properties associated with *N. scintillans* bloom were investigated on-board *FORV Sagar Sampada* (Cr. No. 335) in the northeastern Arabian Sea between 14 February and 5 March 2015 (Figure 1). The physical parameters (temperature and salinity) were measured using conductivity–temperature–depth (CTD; Make: Sea-Bird Electronics, USA; model 19 plus). The euphotic depth was estimated from the vertical profile of downwelling irradiance measured with hyperspectral radiometer (make: Satlantic, USA; model HyperPro-II). The radiometer was also equipped with ECO triplet sensor (Wetlabs™ ECO series, USA) measuring chlorophyll fluorescence, CDOM fluorescence and volume scattering function at 650 nm (β_{650}). The data from hyperspectral radiometer were recorded using SatView™ software and multi-level processing was carried out using Prosoft™ software. Chlorophyll was also estimated from water samples by filtering known volumes of sea water through GF/F filters. The filters were then extracted with 90% acetone for 24 h in dark and analysed fluorometrically based on standard protocol[19].

Data from two Argo floats (WMO ID 2900776 and WMO ID 2902093) deployed in the northern Arabian Sea were analysed to elucidate seasonal and longer-term variability in dissolved oxygen (DO) in the water column

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from 2006 to 2013 (Figure 1). The floats were equipped with optical oxygen sensors (make: Anderra, USA). Typically, the floats were programmed to take profiles at 10-day intervals. Figure 1 shows the trajectories of Argo floats. The float WMO ID 2902093 remained mostly within the core of the oxygen minimum zone during its operation, thus providing important data on variability of water column oxygen within such environments.

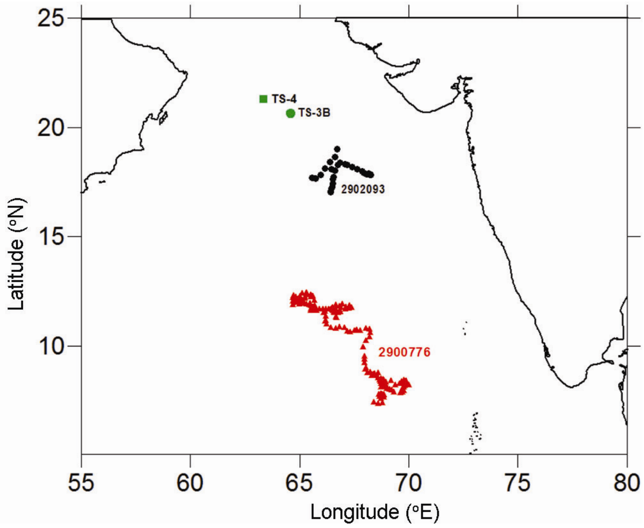

Figure 1. Sampling locations and Argo float trajectories: TS-4 and TS-3b are from *ORV Sagar Sampada* (SS335) during February 2015. Red triangles (float ID: 2900776) and black dots (float ID: 2902093) respectively, show the trajectories of Argo floats in the northern Arabian Sea.

The coastal zone colour scanner (CZCS) data, with a spatial resolution of 9 km, were acquired from NASA's Ocean Colour Web, supported by the Ocean Biology Processing Group (OBPG). The data were processed using OC3C maximum band ratio algorithm. This empirical algorithm uses the maximum ratio of remote sensing reflectance at 443 and 520 nm with 550 nm (http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a#sec_2). Monthly composite images of sea surface temperature (SST) from Moderate Resolution Imaging Spectroradiometer (MODIS) on-board Aqua satellite were prepared using on-line visualization tool from NASA GES DISC (http://daac.gsfc.nasa.gov/giovanni). Temporal variability of assimilated chlorophyll for the grid 63°–65°N and 24°–22°E was acquired from NASA Ocean Biogeochemical Model (NOBM) assimilating ESRID global monthly data with latitude resolution of 0.667° and longitudinal resolution of 1.25° from 1 January 1998 to 31 December 2012.

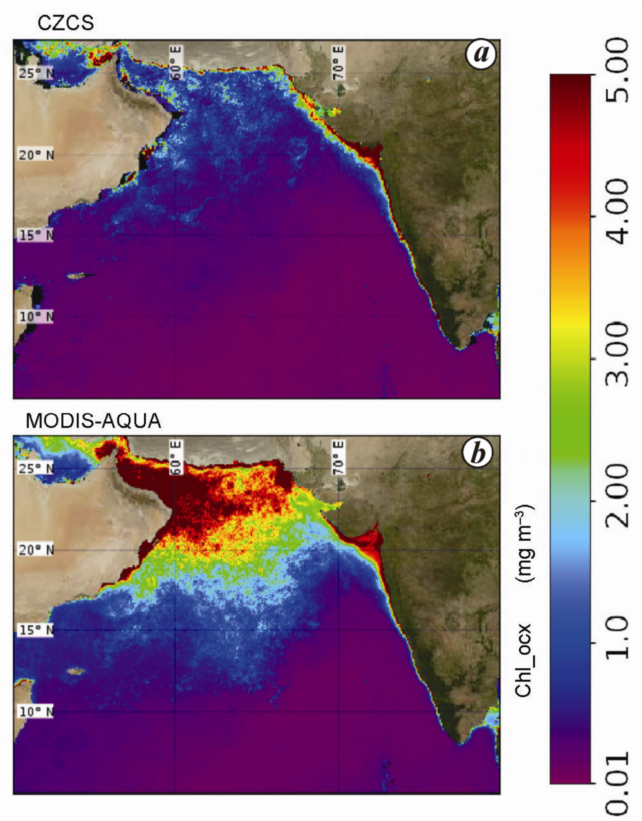

Figure 2. Composite image of chlorophyll *a* generated from (***a***) coastal zone colour scanner (CZCS) and (***b***) moderate resolution imaging spectroradiometer (MODIS) – Aqua during February for the years 1980 and 2015 respectively.

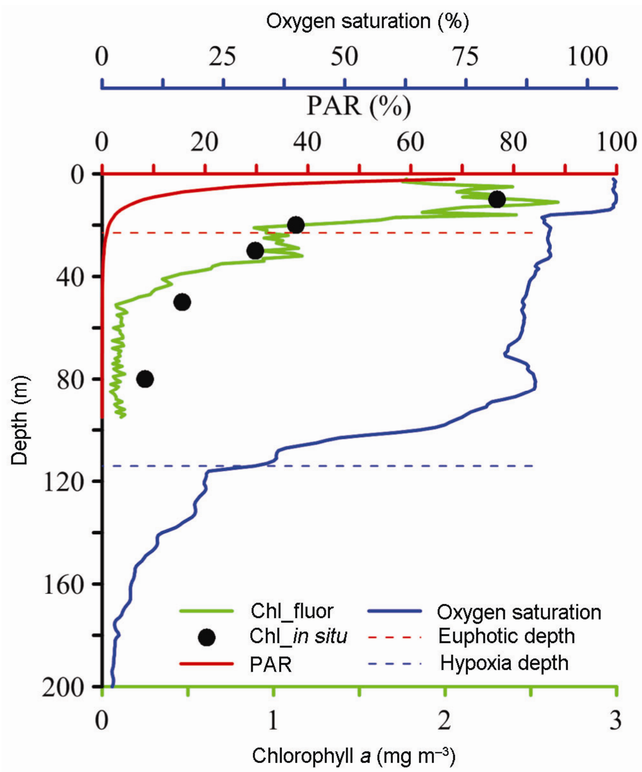

Figure 3. Vertical profiles of photosynthetically available radiation (PAR), dissolved oxygen (DO) saturation (%), chlorophyll *a* concentration as measured by fluorometer and *in situ* (mg m^{-3}) from station TS-4 on-board *ORV Sagar Sampada* (SS 335) during an intense *Noctiluca scintillans* bloom. The blue dotted line corresponds to hypoxic level and the red dotted line corresponds to euphotic depth.

Climatology data for silicate (Si) and nitrate (N) were downloaded from *World Ocean Atlas* (https://www.nodc.noaa.gov/OC5/woa13/) and the Si/N ratio was computed as an aid to study silicate limitation in the region[20].

The monthly composites of chlorophyll, during February from 1980 and 2015, estimated from CZCS and MODIS respectively were examined for the presence of *N. scintillans* bloom in the northern Arabian Sea (Figure 2). Both the satellite images suggest presence of high chlorophyll with more proliferation during 2015. Figure 3 shows the *in situ* measured oxygen, photosynthetically available radiation (PAR) and chlorophyll concentration from station TS-3B (taken at 12 : 00 h; Cruise. no. 335, 2015) where we encountered *N. scintillans* bloom (>40,000 cells/litre). PAR data indicate photic depth limited to ~30 m with uniform oxygen concentration of ~223 μM at a saturation level of 92–105%. Chlorophyll *a* ranged between 0.24 and 2.4 mg m^{-3} within the core of the bloom (Figure 3). In general, the oxygen concentration varied between 180 and 223 μM within the top 80 m of the water column indicating saturation values from 89% to 105%, and was constant within the photic zone (~223 μM). Figure 4 shows time-series data from station TS4. Here, the photic depth varied between 25 and 30 m from 09 : 00 to 17 : 00 h in tandem with chlorophyll *a* and oxygen. The ~63 μM oxygen contour corresponding to the upper limit of hypoxic boundary shoaled between 110 m and 125 m. The mixed layer was well oxygenated, suggesting no intrusion of hypoxic water. Chlorophyll *a* had similar ranges as at TS-3B. Chlorophyll *a* measured from fluorescence sensor and estimated from water samples showed good match (Figure 3).

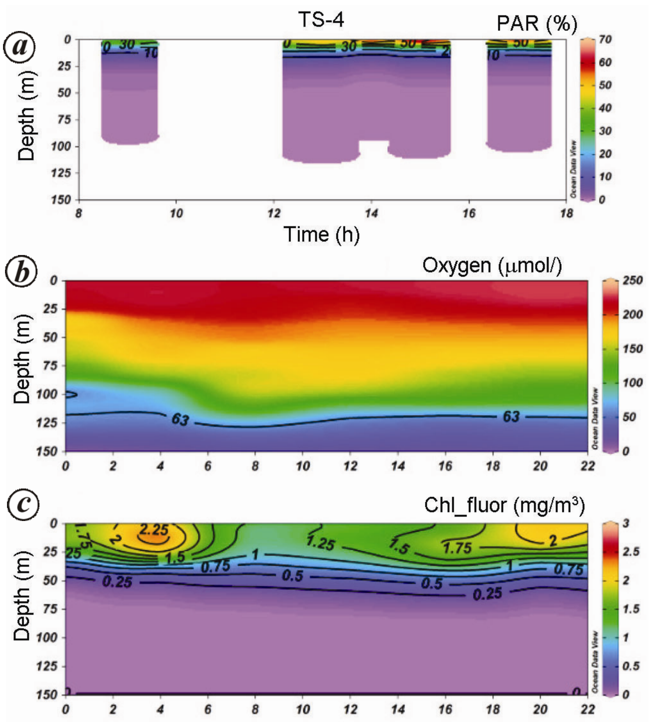

Figure 4. Time-series data collected every 4 h for PAR, DO (μM) and chlorophyll fluorescence (mg m^{-3}) from station TS-4. Note the hypoxic layer shoaling between 110 and 125 m much below the photic depth. Blank space represents lack of data.

The observed community shift from diatoms (in winter monsoon) to *N. scintillans* during inter-monsoon in the northern Arabian Sea remains poorly understood. In 2015, we investigated the biogeochemical properties associated with *N. scintillans* bloom to understand its manifestation in the surrounding environment. The photic depth (~limited to 30 m) was well oxygenated (up to ~223 μM) and oversaturated (105%) with no indication of oxygen depletion. Time-series data collected within the bloom region also show saturated upper layer. Therefore, our data do not show the presence of hypoxic waters within the euphotic zone. High surface DO, 3.06 ml l^{-1} (~134 μM) and 2.71 ml l^{-1} (~121 μM) during active and declining bloom phases respectively, has also been reported during a *Noctiluca* bloom in 2009 in the Northern Arabian Sea[21]. The reported DO concentrations also show well-oxygenated surface layer during the bloom period. A comparison between CZCS and MODIS time series (Figure 2) suggests increase in surface chlorophyll during 2015; however, basin-scale changes in surface chlorophyll from this region exhibit no significant trend[22]. Also, some bias due to sensor differences cannot be ignored.

Further, to delineate any such hypoxic events in the past, we examined the available Argo oxygen data from 2006 to 2013 (Figure 5). The variability in ~63 μM contour, corresponding to the upper limit of hypoxic boundary in the Arabian Sea, is demarcated for further discussion[23]. The data exhibit well-oxygenated upper water column (~50 m) with strong seasonal shoaling. An inter-annual trend in deepening of the hypoxic boundary is noted, which varies within ~80–120 m during early to peak summer monsoon (April–August) with gradual shift towards the upper layer (~80–50 m) with the onset of winter monsoon (November–December). However, the top 50 m (note photic depth observed <30 m during the bloom) remains well above the hypoxic boundary and exhibits >90% oxygen, not consistent with a hypoxic event.

For better understanding this community transition we plotted SST and surface chlorophyll between 63°–65°N and 24°–22°E (Figure 6). Satellite images show this region has high chlorophyll on inter-annual basis during northeast monsoon and spring inter-monsoon. Our analysis of NOBM data suggests that increase in December chlorophyll is strongly associated with decrease in SST with large interannual variability. Similar trend is also reflected in February chlorophyll (presumably due to *N. scintillans*; Figure 6). This suggests *N. scintillans* bloom is tightly coupled with the strength of the convective mixing and winter bloom (dominated by diatoms), presumably due to the following mechanism. A strong winter mixing leads to mixed layer deepening and enrichment of silicate, as silicocline is much deeper than

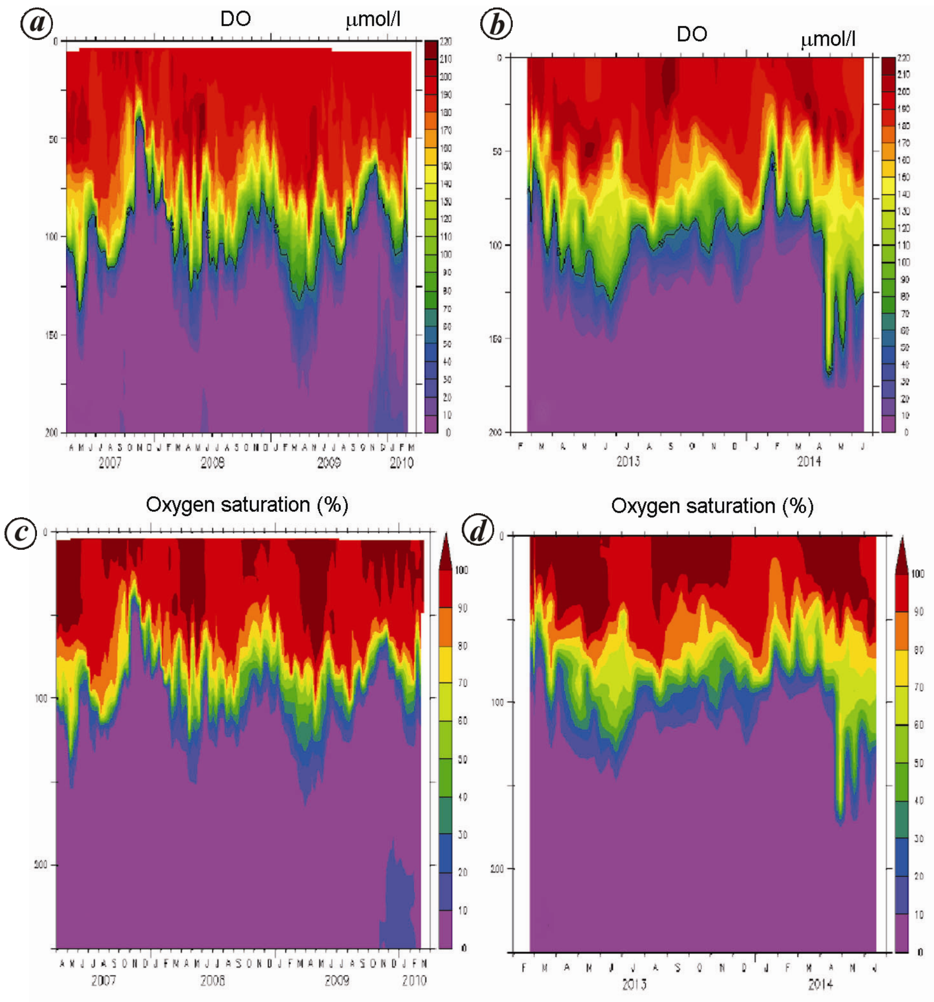

Figure 5. Time-series plot of DO (μmol/kg) and % oxygen saturation from Argo floats. (***a***) and (***c***) show DO and % oxygen saturation from the float (ID: 2900776) in the central Arabian Sea respectively. (***b***) and (***d***) show DO and % oxygen saturation from the float (ID: 2902093) in the northern Arabian Sea respectively.

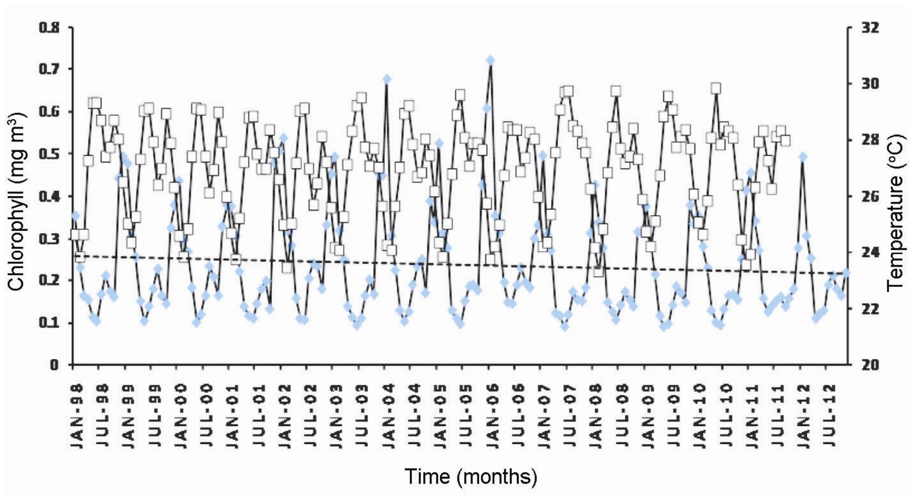

Figure 6. Temporal variability of monthly composite of assimilated chlorophyll (blue diamonds) from 63° to 65°N and 24° to 22°E based on NASA ocean biogeochemical model assimilating ESRID data global monthly with latitude resolution of 0.667° and longitudinal resolution of 1.25° from 1 January 1998 to 31 December 2012. Temporal variability of monthly data of sea surface temperature for the same region (black squares).

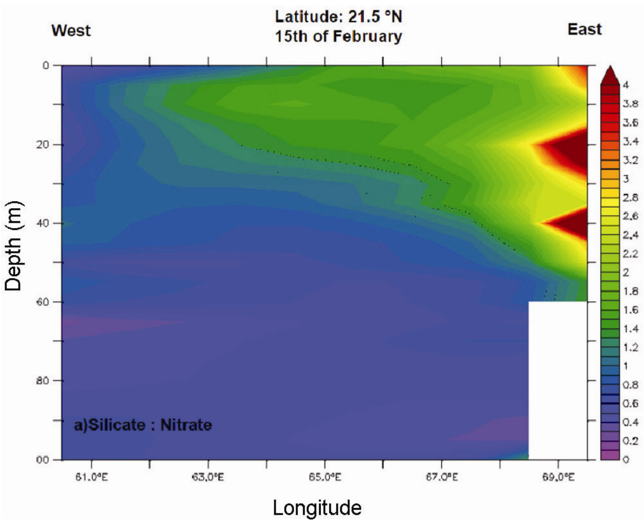

Figure 7. Longitudinal variability of silicate and nitrate ratios. Climatology derived based on https://www.nodc.noaa.gov/OC5/woa13/data as detailed in Garcia *et al.*[20].

nitracline, resulting in sustained diatom bloom[24]. A longer presence of diatom in the water column during the northeast monsoon influences the proliferation and/or initiation of *N. scintillans* (some negative feedback), thereby limiting its spatio-temporal coverage. This mechanism modulates the intensity of the *N. scintillans* bloom on interannual basis. Furthermore, examination of Si/N climatology suggests strong longitudinal variation during February (Figure 7). The silicate in the surface waters in the northwestern Arabian Sea is depleted much earlier (Si/N is <1) compared to the eastern part, resulting in a strong spatial trend. This presumably triggers *N. scintillans* bloom in the west which then propagates eastward, the former region acting as a seeding source. Published nutrient data from the northeastern Arabian Sea show below-detectable nitrate and silicate within the mixed layer with dominance of pico and nanoplankton communities[17,18].

These environmental conditions, in conjunction with gradual heating of the surface ocean during intermonsoon, are conducive to the proliferation of *N. scintillans*, which leads to an observable community shift in the northern Arabian Sea. Furthermore, the heterotrophic behaviour of *N. scintillans* sp. aided by conspicuous ammonium secretion in the vicinity, probably helps the species to outcompete the previous community, leading to large phytoplankton bloom[8]. More recently, inhibition of mixed-layer deepening during winter monsoon due to Western Indian Coastal Current has also been observed which may further restricts silicate availability[25], leading to longer presence of *N. scintillans* in the water column.

We did not find oxygen depletion in the euphotic zone and mixed layer during green *N. scintillans* bloom in the northern Arabian Sea in 2015. Further, our analysis of data from two Argo-oxygen floats from the region also did not reveal any such event during the study period. We speculate that proliferation of *N. scintillans* bloom in this region is strongly associated with the strength of convective mixing, which modulates silicate availability in the mixed layer. Thus, strong winter mixing supports a diatom bloom for longer periods through silicate recharge, and therefore a short *N. scintillans* bloom. On the other hand, a weak winter mixing leads to less silicate enrichment making the water column conducive to early community transition leading to inter-annual variability as observed in the NOBM data. This is supported by the heterotrophic nature of the species, and below-detectable nitrate gives *N. scintillans* a competitive edge over other phytoplankton communities to proliferate. However, elucidation of its role in food-web dynamics will certainly require further work.

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Phytochemical and biochemical study of four legume plants with detergent and anti-lice properties from the Eastern Himalayan region of India

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This study is aimed at the qualitative and quantitative investigation of the phytochemical content, macro- and micronutrients, proximate analysis and determination of antioxidant activities of four plants belonging to the family Leguminosae namely *Acacia pennata*, *Albizia lucidior*, *Albizia chinensis* and *Gymnocladus assamicus* widely used by the Adi tribe of Arunachal Pradesh for their surfactant and insect-repellent properties. The methanol extract of the seed pod of *G. assamicus*, the most popular soap-plant among the Adi people, showed maximum 1,1-diphenyl-2-picrylhydrazyl scavenging activity with EC_{50} of 13.50 μg/ml and presence of hitherto reported insecticidal metabolites like 2-hydroxy-gamma-butyrolactone and heptadecene-(8)-carbonic acid.

Keywords: Anti-lice, *Gymnocladus assamicus*, legumes, natural soap.

PLANT-based healthcare and cosmetic products are increasingly becoming popular because of the growing concern about the probable hidden adverse effects of synthetic products. For several thousand years plants have been used to treat human disorders, for relieving pain, as beautification products, as detergents as well as bathing soap and shampoo[1]. In Southeast Asia, herbal healthcare products are highly popular and the plant-based Indian *Ayurvedic* products have a considerable and continuously increasing market share around the world[2].

Arunachal Pradesh is the easternmost part of the Eastern Himalaya inhabited by 26 major and 110 sub-tribes. Due to geographical constraints and lack of modern amenities, majority of these ethnic population still largely depend on plant-based products in their daily lives. These people are a storehouse of oral traditional knowledge inherited from their forefathers about the medicinal and other useful plant resources native to this region. However, perusal of the literature has revealed that these endemic plant resources with traditional knowledge base

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