Oceanologia (2018) 60, 419—425

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SHORT COMMUNICATION

Characterization of light absorption coefficient of red *Noctiluca scintillans* bloom in the South Eastern Arabian Sea

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Received 27 June 2017; accepted 20 December 2017
Available online 8 January 2018

KEYWORDS
Noctiluca scintillans;
Phytoplankton absorption coefficient;
Upwelling;
Oil sardine;
South Eastern Arabian Sea (SEAS)

Summary The red *Noctiluca scintillans* bloom was observed off Cochin in the South Eastern Arabian Sea (SEAS), affecting a very large area during July—August 2016. The surface water samples from the bloom region were collected to study the physical, biological and light absorption characteristics. The bloom affects the food chain by their voracious predation on the species of both first and second trophic levels. The *N. scintillans* cell density during the bloom was estimated at 4.73×10^5 cells l^{-1}. In the phytoplankton absorption coefficient spectra, the accessory pigments displayed peaks in the 488—558 nm regions, which represent the characteristic carotenoid pigment (red colored pigment) for the bloom of red *Noctiluca*. Signature of the coastal upwelling was found from the salinity and temperature distribution, which was measured prior to the bloom occurrence. From the sea surface temperature (SST), it is also confirmed the presence of fresh water from the Cochin estuary. Increased productivity near coastal region, along with episodic events of strengthening of the upwelling, favors the proliferation of smaller diatoms. The plankton succession from smaller diatoms to larger diatoms and dinoflagellates, favors the proliferation of the red *Noctiluca*. The occurrence of blooms of red *N. scintillans*, which feed on phytoplankton, mainly diatoms, and other dinoflagellates, could be a threat to larvae of oil sardine during the upwelling period, and may negatively impact on the commercially important fishery of oil sardine, in this region.

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Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

https://doi.org/10.1016/j.oceano.2017.12.002

Noctiluca scintillans (Macartney) Kofoid & Swezy 1921, a marine planktonic dinoflagellate, is one of the most important and abundant red tide organisms. It has a worldwide distribution and occurs in two forms. Red *Noctiluca* is heterotrophic and acts as a microzooplankton grazer in the food web. Green *Noctiluca* contains the photosynthetic symbiont *Pedinomonas noctilucae* (Subrahmanyan) Sweeney, 1976 (Prasinophyte), also feeds on other plankton. Red *Noctiluca* occurs over a wide temperature range from 10 to 25°C and at salinities higher than 28 psu. It is particularly abundant in high productivity areas such as upwelling or eutrophic areas where diatoms dominate, since they are its preferred food source. Green *Noctiluca* is restricted to a temperature range of 25—30°C and occurs mainly in tropical waters of the southeast Asia, Bay of Bengal (east coast of India), eastern, western and northern Arabian Sea and Red Sea (Baliarsingh et al., 2016; Gomes et al., 2014; Harrison et al., 2011; Turkoglu, 2013). The red *N. scintillans* lacks symbiotic association with diatoms and its red color is due to the grazing of diatoms, which contains carotenoids (Balch and Haxo, 1984). The red *N. scintillans* blooms affects the food chain by their voracious predation on the species of both first and second trophic level (Baliarsingh et al., 2016; Padmakumar et al., 2016). Blooms of *N. scintillans* have been linked to massive mortality of fish and marine invertebrates. Although this species does not produce toxin, it has been found to accumulate toxic levels of ammonia, acting as killing agent in blooms and deteriorating the water quality (Sahayak et al., 2005). Identification of phytoplankton types on the basis of absorption spectra is a challenge for the Harmful Algal Bloom (HAB) monitoring. This study is an approach to improve the knowledge of the optical characteristics of important HAB species in South Eastern Arabian Sea (SEAS) and to provide information on the possible effect on the fishery.

The coastal waters of SEAS were largely influenced by freshwater discharge and seasonally reversing monsoon. The summer (southwest) monsoon extends from June to September whereas the winter (northeast) monsoon extends from November to February. The upwelling process, supported by the southerly current observed along the coastal waters during the southwest monsoon, results in maximum primary production (Habeebrehman et al., 2008; Joshi and Rao, 2012). A seasonal hypoxia arises due to increased oxygen demand for mineralization of organic matter following high surface production (Gupta et al., 2016). The Cochin backwater is the largest estuarine system of the southwest coast of India, and receives 1.04×10^5 m^3 of industrial and 260 m^3 of domestic wastes per day without treatment (Gupta et al., 2009). During southwest monsoon, the hydrographic parameters are significantly influenced by strong freshwater influx (Srinivas and Dineshkumar, 2006).

The surface water samples were collected onboard INS *Sagardhwani* on 21st July at the CTD stations and on 2nd August 2016, a representative water sample from the bloom patches were also collected to estimate the Chlorophyll *a* (Chl-*a*) concentration. For this, the collected samples were filtered through 25 mm Whatman GF/F filter under low vacuum (100—1000 ml based on the concentration visually seen from the filter paper) and extracted with 90% acetone and analysis were done by using Turner Designed 10AU Fluorometer. Also surface water samples from the bloom region were collected for the measurements absorption characteristics. The light absorption coefficient of phytoplankton [$aph(\lambda)$] was measured using a quantitative glass fiber filter technique (QFT) and standard procedures (Hoepffner and Sathyendranath, 1993; Shaju et al., 2015; Vijayan and Somayajula, 2014). In brief, surface water samples collected were filtered through 25 mm Whatman GF/F filter under low vacuum and the filtrate measured against a blank filter using a Shimadzu UV-VIS spectrophotometer attached to an integrating sphere following the protocol of Mitchell (1990). The wavelength scan was done from 300 nm to 750 nm with the resolution of 1 nm before and after rinsing the filter paper with warm methanol for one hour to determine the detrital absorption (Kishino et al., 1985). For each of the measured spectra, the optical density obtained at 750 nm was subtracted from that of all other wavelengths. Optical density of the total suspended matter was corrected for the pathlength amplification (β effect) and converted into light absorption coefficients by the total particulate matter [$ap(\lambda)$] (m^{-1}) and detritus matter [$ad(\lambda)$] (m^{-1}), i.e. before and after extraction with methanol, respectively (Cleveland and Weidemann, 1993; Kyewalyanga et al., 1998). The plankton absorption component [$aph(\lambda)$] was derived as a difference between the particulate and detritus absorptions of the total particulate matter by subtraction $ad(\lambda)$ from $ap(\lambda)$ (Bricaud et al., 2004; Kishino et al., 1985). Samples were also collected from the bloom area to identify the phytoplankton composition. Inverted microscope (Leica Generic DMIL) with phase contrast was used to estimate the phytoplankton diversity and abundance using standard identification keys (Tomas, 1997). In this study, light absorption characteristics of red tide were analyzed based on the pigments in the bloom samples by the decomposition of phytoplankton absorption coefficient spectra using the 4th derivative analysis (Shaju et al., 2015). The fourth derivative of $aph(\lambda)$ was calculated by applying the 41 point fourth degree polynomial smoothing and then by differentiation using the Savitzky—Golay method (Savitzky and Golay, 1964). The polynomial smoothing was applied because differentiation tends to amplify the effects of high frequency noise in the spectra (Aguirre-Goméz et al., 2001). The procedure was carried out using the Origin 8.0 scientific analysis software. Peaks in the fourth derivative curves were selected using the peak finder tool in the software. The physical conditions prevailing in the area were measured using the conductivity temperature depth (CTD) profiler Idronaut Ocean Seven 320 plus system on 21st July 2016. Microwave+Infra-red (IR) Optimally Interpolated (OI) Sea Surface Temperature (SST) data obtained by Remote Sensing Systems sponsored by National Oceanographic Partnership Program (NOPP) and the NASA Earth Science Physical Oceanography Program, available at www.remss.com/measurements/sea-surface-temperature were also used in this study.

Reddish discoloration of coastal waters off Cochin, at 09°48′N and 76°03′E, was observed from the vessel MV *Prashikshani* on 28th July 2016 and subsequently, on 2nd August, from INS *Sagardhwani* (Fig. 1). The species causing the bloom was identified as the *N. scintillans* (Macartney) Kofoid and Swezy, 1921 (Fig. 2a), which is a heterotrophic dinoflagellate and one of the abundant "red tide" organisms in the tropical, subtropical, temperate coastal waters (Sriwoon et al., 2008) and upwelling regions (Dela-Cruz et al., 2008). The red patches of the bloom (Fig. 2b) were observed in a vast area

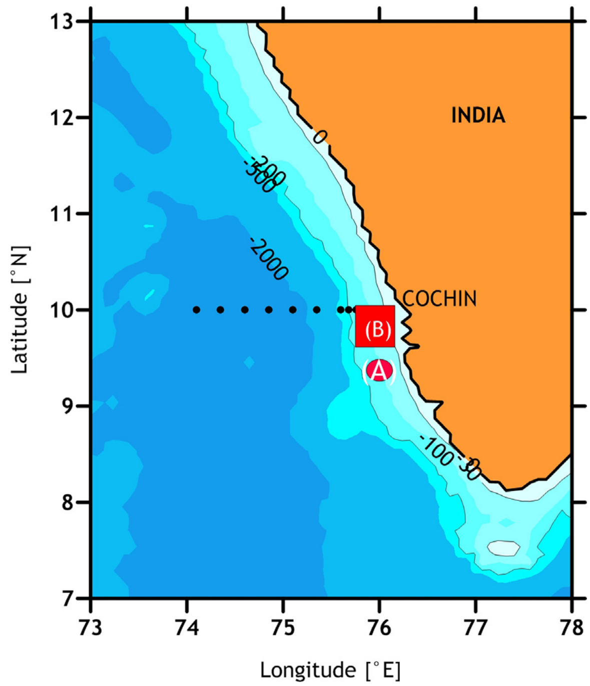

Figure 1 Map of the study area showing the hydrographic stations (dotted points) sampled one week before the first observation of the bloom (A — indicates bloom observation on 28th July 2016 onboard MV *Prashikshani*, B — indicates bloom observation on 2nd August 2016 onboard INS Sagardwani).

extending from 09°55′ to 09°57′N and 75°59′ to 76°03′E. The red *N. scintillans* blooms were last reported in the coastal waters of SEAS in 2004 and 2008 (Baliarsingh et al., 2016; Joseph et al., 2008; Padmakumar et al., 2016) whereas the green *N. scintillans* blooms were regularly reported in the coastal regions of the northern Arabian Sea (Baliarsingh et al., 2016; Gomes et al., 2014). This study attempts the bio-optical characterization of *N. scintillans* bloom in the SEAS and discusses its possible impacts on the food web and sardine fishery of the region.

The water column salinity and temperature distribution along 10°N, prior to the bloom occurrence is given in Fig. 3a and b and it has shown signature of coastal upwelling from the up sloping of salinity and temperature contours. A low saline patch was observed near the coast in the upper few meters in the salinity distribution, which would have been generated due to the freshwater influx from the estuary (Jyothibabu et al., 2006; Madhupratap, 1987). This cold less saline surface water from Cochin estuary normally carries high nutrients that help in the increased productivity during summer monsoon near the coast. Prior to the bloom initiation, Chl-*a* concentration varied from 0.28 to 0.42 mg m^{-3} with an average value of 0.34 ± 0.05 mg m^{-3} in the offshore region and from 0.55 to 4.16 mg m^{-3} with an average concentration of 1.47 ± 1.37 mg m^{-3} in the near coastal waters off Cochin. This increased productivity and episodic events of low SST visible from the time series SST (Fig. 4). The effect of intense upwelling as evidenced from data distribution along the near coastal region, favors the proliferation of smaller diatoms (Sahayak et al., 2005). The plankton succession from smaller diatoms to larger diatoms and dinoflagellates, favors the proliferation of red *Noctiluca* bloom.

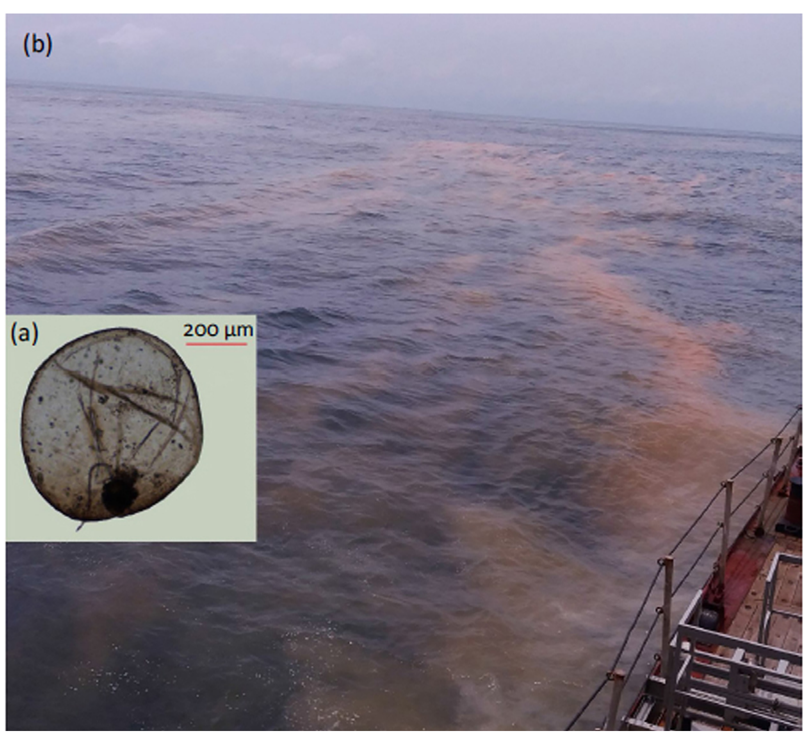

Figure 2 Bloom of red *Noctiluca scintillans* as (a) microscopic picture of the *Noctiluca scintillans*, a line indicates the 200 μm length (b) large patches extending to the vast area.

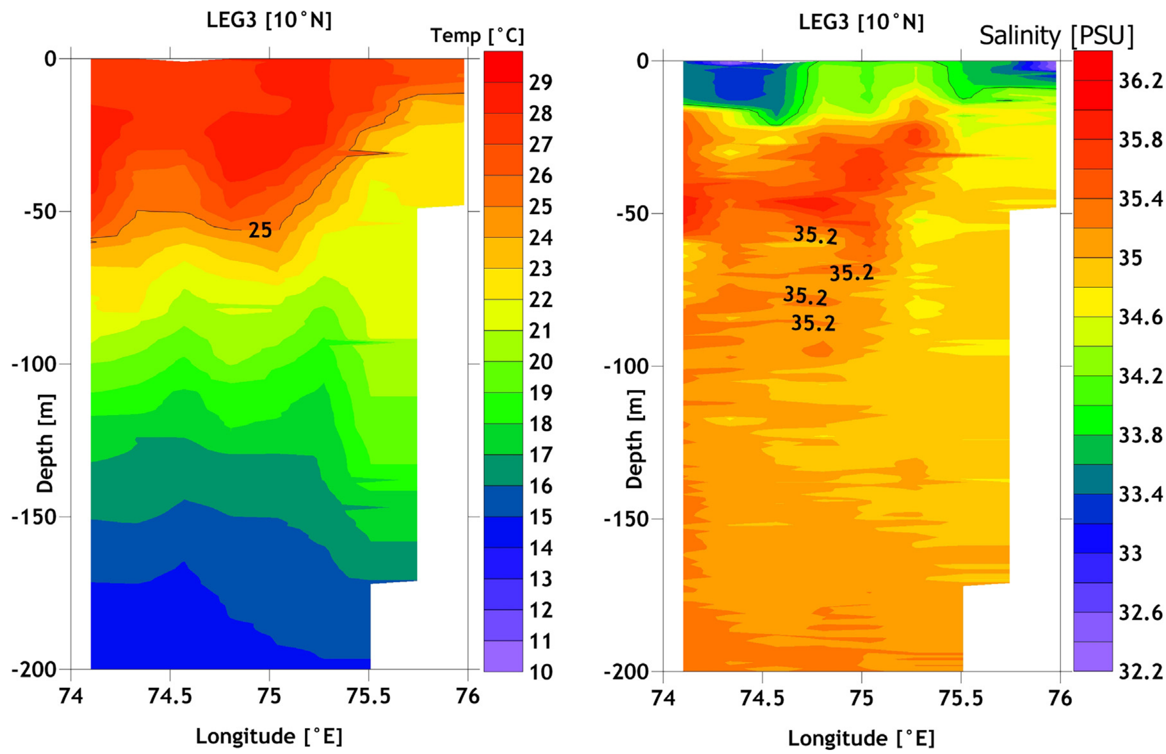

Figure 3 Longitude depth section of (a) temperature (°C) and (b) salinity (psu) along 10°N in the off Cochin region measured onboard INS Sagardwani on 21st July 2016.

The density of *N. scintillans* was found to be 4.73×10^5 cells l^{-1} and the measured Chl-*a* concentration varied from 0.73 to 1.47 mg m^{-3} in the bloom region. This is comparable to the bloom event of the southeastern Black Sea on April 2011 with cell number ranges between 1.1×10^3 to 6.81×10^6 cell l^{-1} (Kopuz et al., 2014) and Sea of Maramara with cell density of 2.20×10^6 cell l^{-1} (Turkoglu, 2013). Other phytoplankton species in the bloom area were *Ceratium* sp., *Rhizosolenia* sp., *Porocentrum* sp., *Thalassiosira* sp., *Nitzchia* sp. and *Dinophysis* sp. The percentage composition of *N. scintillans*, diatoms and other dinoflagellates in the bloom waters were 72.67%, 10.92% and 16.32% respectively. A very low species diversity and abundance of other dinoflagellates and diatoms were observed. The diatom, *Thalassiosira* sp. was notable, since it is considered to be the most preferred prey species of the red *N. scintillans* (Baliarsingh et al., 2016; Sahayak et al., 2005).

A representation of the measured phytoplankton absorption coefficient spectra [$aph(\lambda)$] from the water samples collected from the bloom and its fourth derivative are given in Fig. 5. Absorption maxima for the pigment Chl-*a* in the phytoplankton absorption spectrum were found around wavelengths of 444 and 676 nm, while accessory pigments displayed their absorption peaks in the 488—558 nm regions, which represents characteristic carotenoid (red pigment) for the red *Noctiluca* bloom. The optical measurements from the Belgian coastal waters during a red *Noctiluca* bloom event on 2015 also showed the same results with a maximum absorption at 488 nm which corresponds to the carotenoids (Astoreca et al., 2005). Karabashev and Evdoshenko (2016) identified that the high content of accessory pigments makes inequalities in remote sensing reflectance (R_{rs}). It was also found that $R_{rs}(488) < R_{rs}(531)$ and $R_{rs}(488) < R_{rs}(469)$. Absorption and reflectance values and effect of R_{rs} deficit due to accessory pigments and their relations give indication of the bloom for the ocean color application and products.

The accessory pigment carotenoid showed an absorption peak at 488 nm and sharper decrease from 528 nm to 580 nm which matches with the earlier reports (Van Mol et al., 2007). The small peaks in the 560—619 nm regions could be accounted for the degradation products and Chl-*c*. Carotenoids, particularly fucoxanthin peaks, could be identified in the 528 nm region in the derivative spectra. The diadinoxanthin and carotene peaks were identified at 488, 528 nm. Phycoerythrobilin peak was observed at 558 nm. Smaller peaks were observed in the 590 nm and also at 615, 619, 635 and 647 nm. The shape and magnitude of the phytoplankton absorption spectrum reflect the pigment composition and its concentrations related to the phytoplankton class. The phytoplankton absorption spectrum modifies the remote sensing reflectance and contributes to the satellite detection of the bloom. Green *N. scintillans* bloom has been identified through remote sensing reflectance spectra, in the northern Arabian Sea (Dwivedi et al., 2016) and in coastal waters of the northeast coast of India (Baliarsingh et al., 2016). But no studies have been reported on the red *N. scintillans* bloom absorption spectral characteristics in the SEAS. Karabashev and Evdoshenko (2016) also identified that a better spectral resolution made it possible to distinguish the second shortwave remote sensing reflectance (R_{rs}) minimum at 488 nm for the cyanobacterial bloom of 2005 in the Baltic Sea and this can be applied to the *Noctiluca* bloom. The absorption peak identified from the phytoplankton absorption coefficient spectra between 488 and 558 nm regions

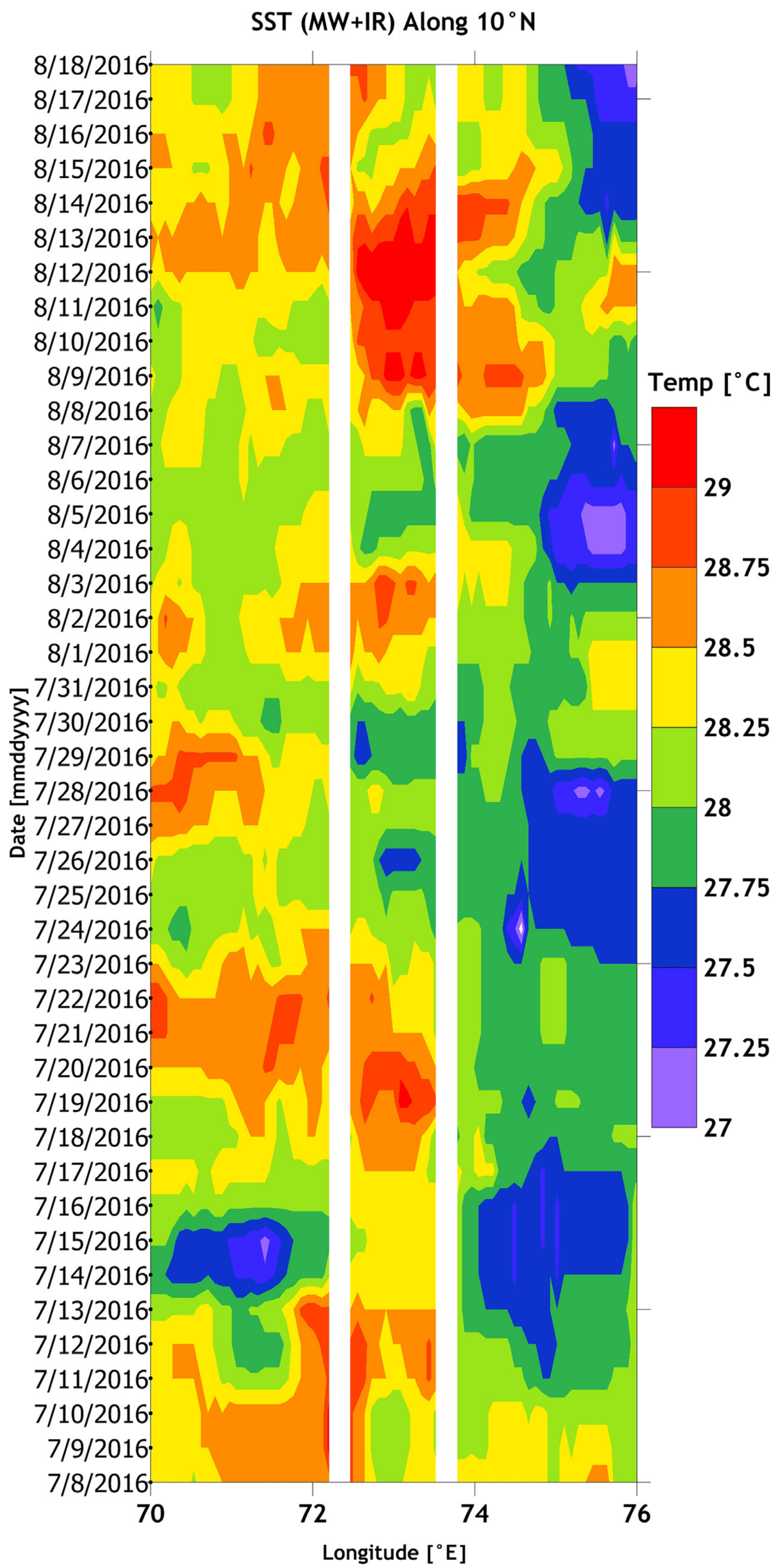

Figure 4 Hovmoller diagram of Sea Surface Temperature (SST) Microwave+Infrared (MW+IR) (°C) from 8th July to 18th August 2016 during the month of bloom period over 10°N latitude.

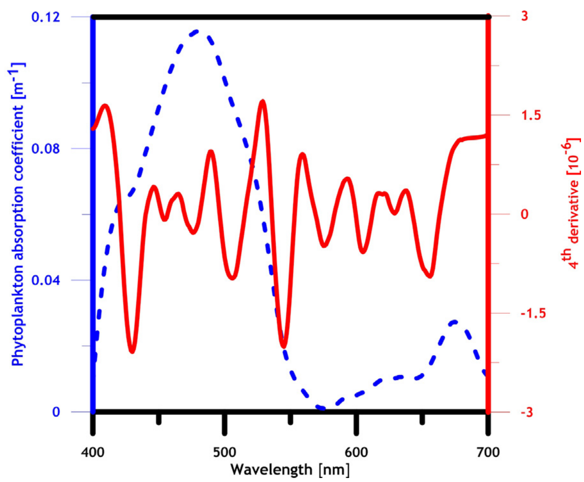

Figure 5 Phytoplankton absorption coefficient spectrum in the visible wavelength of the *Noctiluca scintillans* bloom sample (blue dotted line) and the spectra showing the 4th derivative of the phytoplankton absorption coefficient (red smooth line) against wavelength (nm).

along with the red region can be used for the specific identification of red *N. scintillans* bloom.

Frequent occurrence of dianoflagellate blooms affects the fishery resources (Boalch, 1984; Sanseverino et al., 2016). Central Marine Fisheries Research Institute (CMFRI), India, reported a drastic decline in the catch of oil sardine along southwest coast (CMFRI Newsletter, 2015; CMFRI News, 2016), ascribed to the impact of climatic change and related ecosystem changes. The occurrence of blooms of red *N. scintillans*, which graze on phytoplankton, mainly diatoms, and other dinoflagellates, becomes a threat to the food availability of larvae, juveniles and adults of the oil sardine as they also prefer the smaller phytoplanktons during the upwelling period (Padmakumar et al., 2016; Umani et al., 2004) thus would be making it as one of the major reasons for the decline in the oil sardine catch. According to CMFRI (CMFRI Newsletter, 2015; CMFRI News, 2016), the fall in oil sardine catch cause revenue loss to the tune of USD 30 million. The monitoring of Harmful Algal Blooms (HABs) using satellite observations and their early detection still have constraints due to difficulties in identifying phytoplankton functional types. This paper identifies the characteristic pigment of red *N. scintillans* in an upwelling region by optical measurements, which allows the synoptic monitoring of the bloom through satellite platform. Considering the high economic and ecological impacts in the coastal region, more studies on the plankton community structure, physical processes and monitoring of algal bloom using remote sensing would be needed.

Acknowledgements

We thank the Director of the Naval Physical and Oceanographic Laboratory for providing the necessary facilities and the officers and men of INS *Sagardhwani* for the help rendered for onboard sampling. First author thanks DRDO, Ministry of Defence, Government of India for providing Research Associate Fellowship. Authors express special thanks to Dr. Sanilkumar K.V., Group Director, Ocean Sciences Division, Naval Physical and Oceanographic Laboratory, Kochi for the encouragement of the work, help-rendered and critical evaluation of the manuscript. We also thank Dr. Vipin P.M. for the bloom observation from MV *Prashikshani*.

References

Aguirre-Goméz, R., Weeks, A.R., Boxall, S.R., 2001. The identification of phytoplankton pigments from absorption spectra. Int. J. Remote Sens. 22 (2—3), 315—338, http://dx.doi.org/10.1080/014311601449952.

Astoreca, R., Rousseau, V., Ruddick, K., Mol, B.V., Parent, J., Lancelot, C., 2005. Optical properties of algal blooms in an eutrophicated coastal area and its relevance to remote sensing. In: Proc. SPIE 5885, Optics and Photonics: Remote Sensing of the Coastal Oceanic Environment, San Diego, CA, USA, http://dx.doi.org/10.1117/12.615160.

Balch, W.M., Haxo, F.T., 1984. Spectral properties of *Noctiluca miliaris* Suriray, a heterotrophic dinoflagellate. J. Plankton Res. 6 (3), 515—525, http://dx.doi.org/10.1093/plankt/6.3.515.

Baliarsingh, S.K., Lotliker, A.A., Trainer, V.L., Wells, M.L., Parida, C., Sahu, B.K., Srichandan, S., Sahoo, S., Sahu, K.C., Kumar, T.S., 2016. Environmental dynamics of red *Noctiluca scintillans* bloom in tropical coastal waters. Mar. Pollut. Bull. 111 (1—2), 277—286, http://dx.doi.org/10.1016/j.marpolbul.2016.06.103.

Boalch, G.T., 1984. Algal blooms and their effects on fishing in the English Channel. In: Bird, C.J., Ragan, M.A. (Eds.), Eleventh International Seaweed Symposium. Developments in Hydrobiology, Vol 22. Springer, Dordrecht, 449—452, http://dx.doi.org/10.1007/978-94-009-6560-7_89.

Bricaud, A., Claustre, H., Ras, J., Oubelkheir, K., 2004. Natural variability of phytoplanktonic absorption in oceanic waters: influence of the size structure of algal populations. J. Geophys. Res. 109, C11010, http://dx.doi.org/10.1029/2004JC002419.

Cleveland, J.B.S., Weidemann, A.D., 1993. Quantifying absorption by aquatic particles: a multiple scattering correction for glass-fiber filters. Limnol. Oceanogr. 38 (6), 1321—1327, http://dx.doi.org/10.4319/lo.1993.38.6.1321.

CMFRI News, 2016. The News Minute, Kochi, India, http://eprints.cmfri.org.in/id/eprint/10917.

CMFRI Newsletter, 2015. Kadalamin, No.145, Kochi, India, 28 pp., http://eprints.cmfri.org.in/id/eprint/10766.

Dela-Cruz, J., Middleton, J.H., Suthers, I.M., 2008. The influence of upwelling, coastal currents and water temperature on the distribution of the red tide dinoflagellate, *Noctiluca scintillans*, along the east coast of Australia. Hydrobiologia 598 (1), 59—75, http://dx.doi.org/10.1007/s10750-007-9140-z.

Dwivedi, R., Baliarsingh, S.K., Lotliker, A.A., Kumar, T.S., Shenoi, S.S. C., 2016. An optical approach for synoptic monitoring of red *Noctiluca scintillans* bloom and its associates from space. Environ. Monit. Assess. 188 (1), 50, http://dx.doi.org/10.1007/s10661-015-5041-1.

Gomes, H.do.R., Goes, J.I., Matondkar, S.G.P., Buskey, E.J., Basu, S., Parab, S., Thoppil, P., 2014. Massive outbreaks of *Noctiluca scintillans* blooms in the Arabian Sea due to spread of hypoxia. Nat. Commun. 5, 4862, http://dx.doi.org/10.1038/ncomms5862.

Gupta, G.V.M., Sudheesh, V., Sudharma, K.V., Saravanane, N., Dhanya, V., Dhanya, K.R., Lakshmi, G., Sudhakar, M., Naqvi, S.W.A., 2016. Evolution to decay of upwelling and associated biogeochemistry over the southeastern Arabian Sea shelf. J. Geophys. Res. Biogeosci. 121 (1), 159—175, http://dx.doi.org/10.1002/2015JG003163.

Gupta, G.V.M., Thottathil, S.D., Balachandran, K.K., Madhu, N.V., Madeswaran, P., Nair, S., 2009. CO_2 supersaturation and net heterotrophy in a tropical estuary (Cochin, India): influence of anthropogenic effect. Ecosystems 12 (7), 1145—1157, http://dx.doi.org/10.1007/s10021-009-9280-2.

Habeebrehman, H., Prabhakaran, M.P., Jacob, J., Sabu, P., Jayalakshmi, K.J., Achuthankutty, C.T., Revichandran, C., 2008. Variability in biological responses influenced by upwelling events in the eastern Arabian Sea. J. Mar. Syst. 74 (1), 545—560, http://dx.doi.org/10.1016/j.jmarsys.2008.04.002.

Harrison, P.J., Furuya, K., Glibert, P.M., Xu, J., et al., 2011. Geographical distribution of red and green *Noctiluca scintillans*. Chin. J. Oceanol. Limnol. 29 (4), 807—831, http://dx.doi.org/10.1007/s00343-011-0510-z.

Hoepffner, N., Sathyendranath, S., 1993. Determination of the major groups of phytoplankton pigments from the absorption spectra of total particulate matter. J. Geophys. Res. Ocean. 98 (C12), 22789—22803, http://dx.doi.org/10.1029/93JC01273.

Joseph, T., Shaiju, P., Laluraj, C.M., Balachandran, K.K., Nair, M., George, R., Nair, K.K.C., Sahayak, S., Prabhakaran, M.P., 2008. Nutrient environment of red tide-infested waters off south-west coast of India. Environ. Monit. Assess. 143 (1—3), 355—361, http://dx.doi.org/10.1007/s10661-007-9938-1.

Joshi, M., Rao, A.D., 2012. Response of southwest monsoon winds on shelf circulation off Kerala coast, India. Cont. Shelf Res. 32, 62—70, http://dx.doi.org/10.1016/j.csr.2011.10.015.

Jyothibabu, R., Madhu, N.V., Jayalakshmi, K.V., Balachandran, K.K., Shiyas, C.A., Martin, G.D., Nair, K.K.C., 2006. Impact of freshwater influx on microzooplankton mediated food web in a tropical estuary (Cochin backwaters — India). Estuar. Coast. Shelf Sci. 69 (3—4), 505—518, http://dx.doi.org/10.1016/j.ecss.2006.05.013.

Karabashev, G.S., Evdoshenko, M.A., 2016. Narrowband shortwave minima in spectra of backscattered light from the sea obtained from ocean color scanners as a remote indication of algal blooms. Oceanologia 58 (4), 279—291, http://dx.doi.org/10.1016/j.oceano.2016.05.001.

Kishino, M., Takahashi, M., Okami, N., Ichimura, S., 1985. Estimation of the spectral absorption coefficients of phytoplankton in the sea. Bull. Mar. Sci. 37 (1), 634—642.

Kopuz, U., Feyzioglu, A.M., Valente, A., 2014. An unusual red-tide event of *Noctiluca scintillans* (Macartney) in the Southeastern Black Sea. Turk. J. Fish. Aquat. Sci. 14, 261—268, http://dx.doi.org/10.4194/1303-2712-v14_1_28.

Kyewalyanga, M.N., Platt, T., Sathyendranath, S., Lutz, V.A., Stuart, V., 1998. Seasonal variations in physiological parameters of phytoplankton across the North Atlantic. J. Plankton Res. 20 (1), 17—42.

Madhupratap, M., 1987. Status and strategy of zooplankton of tropical Indian estuaries: a review. Bull. Plankton Soc. Japan 34, 65—81.

Mitchell, B.G., 1990. Algorithms for determining the absorption coefficient of aquatic particulates using the quantitative filter technique (QFT). In: Procedings volume — Ocean Optics X, Orlando, FL, USA, 137—148.

Padmakumar, K.B., Thomas, L.C., Vijayan, A., Sudhakar, M., 2016. "Crab Jubilee" subsequent to red tide of *Noctiluca scintillans* along the central Kerala coast (SW coast of India). Indian J. Geomarine Sci. 45 (11), 1549—1551.

Sahayak, S., Jyothibabu, R., Jayalakshmi, K.J., Habeebrehman, H., Sabu, P., Prabhakaran, M.P., Jasmine, P., Shaiju, P., Rejomon, G., Threslamma, J., et al., 2005. Red tide of *Noctiluca miliaris* off south of Thiruvananthapuram subsequent to the "stench event" at the southern Kerala coast. Curr. Sci. 89 (9), 1472—1473.

Sanseverino, I., Conduto, D., Pozzoli, L., Dobricic, S., Lettieri, T., 2016. Algal Bloom and its Economic Impact. Publ. Office EU, Italy, 26—30, http://dx.doi.org/10.2788/660478.

Savitzky, A., Golay, M.J.E., 1964. Smoothing and differentiation of data by simplified least-squares procedures. Anal. Chem. 36 (8), 1627—1639, http://dx.doi.org/10.1021/ac60214a047.

Shaju, S.S., Minu, P., Srikanth, A.S., Ashraf, P.M., Vijayan, A.K., Meenakumari, B., 2015. Decomposition study of in vivo phytoplankton absorption spectra aimed at identifying the pigments and the phytoplankton group in complex case 2 coastal waters of the Arabian Sea. Oceanol. Hydrobiol. Stud. 44 (3), 282—293, http://dx.doi.org/10.1515/ohs-2015-0027.

Srinivas, K., Dineshkumar, P.K., 2006. Atmospheric forcing on the seasonal variability of sea level at Cochin, Southwest Coast of India. Cont. Shelf Res. 26 (10), 1113—1133, http://dx.doi.org/10.1016/j.csr.2006.03.010.

Sriwoon, R., Pholpunthin, P., Lirdwitayaprasit, T., Kishino, M., Furuya, K., 2008. Population dynamics of green *Noctiluca scintillans* (Dinophyceae) associated with the monsoon cycle in the upper Gulf of Thailand. J. Phycol. 44 (3), 605—615, http://dx.doi.org/10.1111/j.1529-8817.2008.00516.x.

Tomas, C.R., 1997. Identifying Marine Phytoplankton. Acad. Press, San Diego, 858 pp.

Turkoglu, M., 2013. Red tides of the dinoflagellate *Noctiluca scintillans* associated with eutrophication in the Sea of Marmara (the Dardanelles, Turkey). Oceanologia 55 (3), 709—732, http://dx.doi.org/10.5697/oc.55-3.709.

Umani, S.F., Beran, A., Parlato, S., Virgilio, D., Zollet, T., De Olazabal, A., Lazzarini, B., Cabrini, M., 2004. *Noctiluca scintillans* Macartney in the Northern Adriatic Sea: long-term dynamics, relationships with temperature and eutrophication, and role in the food web. J. Plankton Res. 26 (5), 545—561.

Van Mol, B., Ruddick, K., Astoreca, R., Park, Y., Nechad, B., 2007. Optical detection of a *Noctiluca scintillans* bloom. EARSeL eProc. 6, 130—137.

Vijayan, A.K., Somayajula, S.A., 2014. Effect of accessory pigment composition on the absorption characteristics of dinoflagellate bloom in a coastal embayment. Oceanologia 56 (1), 107—124, http://dx.doi.org/10.5697/oc.56-1.107.