Iranian Journal of Fisheries Sciences 22(2) 261-277 2023
DOI: 10.22092/ijfs.2023.128906

Research Article

Harmful blooming of *Noctiluca scintillans* in the southeast coastal waters of Iran, Oman Sea

Asefi M.A.[1]; Attaran-Fariman G.[1*]

Received: November 2022 Accepted: February 2023

Abstract

Noctiluca is a dinoflagellate genus that causes algal bloom and is distributed in the tropical coastal waters of the Pacific and the Indian Oceans. The blooming of the species on the southeastern coast of Iran (the north part of the Oman Sea) is usually green and happens in the cold seasons. A dense harmful bloom of *Noctiluca scintillans* was reported in February and March 2020 along the coastal waters of Chabahar Bay (Iran) on a significant scale. Sampling was carried out from three stations located in the bloom areas. This study aimed to evaluate the distribution of the bloom in Chabahar Bay using field data and remote sensing, as well as examining *N. scintillans* cells and identifying the species that were present in the bloom area. The results of microscopic counting revealed a high density of *N. scintillans*. The bloom duration was about 22 days; with a density of 2.37×10^5 cells L^{-1}. Apart from *N. scintillans*, 20 species of phytoplankton including 10 species of dinoflagellates, 9 species of diatoms, and 1 other phytoplankton species were identified. The bloom caused the mortality of marine organisms including jellyfish, crabs, and green sea turtles. Although *N. scintillans* is classified as a non-toxic species, it can lead to the mortality of marine organisms such as fish and invertebrates by causing severe hypoxia and ammonia release.

Keywords: Bioluminescent dinoflagellate, HABs, Chlorophyll *a*, Gulf of Oman, Red tides

1-Department of Marine Biology, Faculty of Marine Sciences, Chabahar Maritime University, Chabahar, Iran
*Corresponding author's Email: gilan.attaran@gmail.com

Introduction

Noctiluca scintillans (Macartney) Kofoid and Swezy, 1921, which is widely distributed in temperate and tropical regions, is a heterotrophic dinoflagellate and well-known for its role in the formation of algal blooms and bioluminescence (Huang and Qi, 1997; Elbrachter and Qi, 1998; Fukuda and Endoh, 2006; Miyaguchi *et al.*, 2006). The species often causes dense red tide in coastal or offshore waters (D'Silva *et al.*, 2012). *N. scintillans* is a species of unarmored non-toxic dinoflagellates (Sriwoon *et al.*, 2008; Gomes *et al.*, 2014), with long-term blooming, which can cause severe oxygen depletion and have negative impacts on the ecosystem (Al-Azri *et al.*, 2007).

N. scintillans shows two distinct morphotypes; reddish-pink or green depending on the association with endosymbiotic algae (Hansen *et al.*, 2004; Furuya *et al.*, 2006). The presence of the species has been reported by researchers in the Oman Sea (Attaran-Fraiman and Asefi, 2022). The blooming of *N. scintillans* is common in cold seasons along the coasts of the Persian Gulf and the Oman Sea (Al-Azri *et al.*, 2007; Murugesan *et al.*, 2017). It spreads from the Indian Ocean to the western coast of Oman as water temperature drops during the colder months of the year (Harrison *et al.*, 2011). The red morphotype of *N. scintillans* has been blooming in the Oman Sea every year between January and May since 1988 (Thangaraja *et al.*, 2007). However, since the early 1990s, green *N. scintillans* has also been widely abundant in both summer and winter (Al-Azri *et al.*, 2007). Inoculation of nutrients from the subsurface to the surface due to the mixing of water from which winter monsoon originates is one of the most important environmental factors that can cause anomalous phytoplankton bloom in the Oman Sea (Attaran-Fariman, 2010). Although *N. scintillans* is a dinoflagellate, it has some differences from other dinoflagellates. For example, it is a diploid vegetative cell, while other dinoflagellates are haploid. Other differences include passive buoyancy, relatively large and producing a large number of gametes during sexual reproduction (Fukuda and Endoh, 2006). Mid-term and long-term studies of satellite data improve the investigation of various biological and non-biological parameters in the seas. Therefore, the investigation of phenomena such as algal blooms and similar changes in aquatic ecosystems is facilitated (Shen *et al*., 2012).

In recent years, numerous reports have been published about the presence of *N. scintillans* and its abundance and distribution in Chabahar Bay (Saraji *et al.*, 2014; Maghsoudlou *et al.*, 2015; Rabbaniha *et al.*, 2018; Ershadifar *et al.*, 2020), however, very limited studies have been conducted on the algal bloom dynamics in the study area (Attaran-Fariman, 2010; Jalili *et al*., 2022). This study aims to investigate the bloom of *N. scintillans* as one of the dinoflagellates causing red tides on the southern coast of Iran and the Northern part of the Oman Sea.

Materials and methods

Sampling area

The southeast coast of Iran with a tropical climate is located on the north of the Oman Sea and is known as one of the permanent bloom areas of *N. scintillans*. This area is affected by the summer monsoon South West Monsoon (SWM; June-September) and winter monsoon known as North East Monsoon (NEM; January-March) (Al-Hashmi *et al*., 2019). The location and geographical position of the stations are shown in Figure 1 and Table 1.

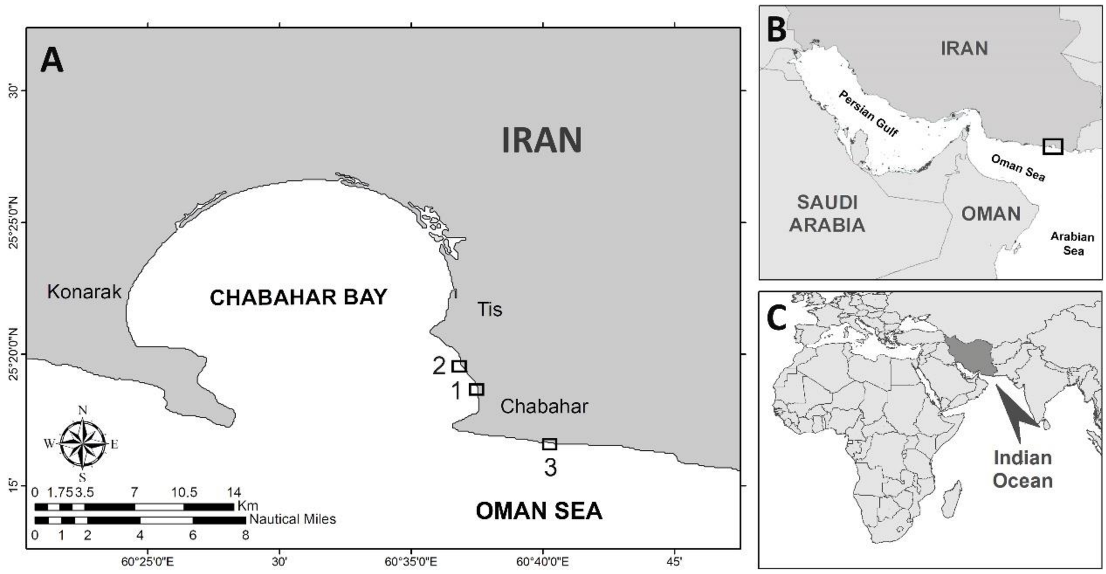

Figure 1: Chabahar Bay and sampling areas. 1) Coast of Chabahar Maritime University (CMU), 2) Coast of Lipar, 3) The rocky shore of the Great Sea. (A) The location of Chabahar Bay in the Oman Sea (B), and the location of the Oman Sea on the global map (C).

Table 1: Geographical location of the sampling stations.

No	Station	(E)	(N)
1	Coast of CMU*	60˚ 27' 39"	25˚ 18' 31"
2	Coast of Lipar	60˚ 40' 14"	25˚ 16' 24"
3	The rocky shore of the Great Sea	60˚ 67' 11"	25˚ 27' 60"

*CMU: Chabahar Maritime University

Satellite data

In order to use the satellite data, the processed data of the Modis sensor of the Aqua satellite were used. Modis sensor data were obtained from the US Space Agency (NASA) website and Ocean Color. The quantities used by the satellite include the concentration of chlorophyll-*a* (Chl-*a*) and the surface temperature of the Oman Sea. Daily and weekly data to investigate changes in Chl-*a* and surface temperature (for the blooming period from February 25 to March 14, 2020) were obtained from the NASA satellite archive. The data were cut for the Oman Sea region and the required analyzes were performed to obtain a suitable spectral output to identify the red tide and its concentration and spread in the study area using SeaDAS software version 5.7 and ArcGIS version 10.7. Eight-day mean data were used for general studies of Chl-*a* density in the region.

Field survey

Water samples were collected from the surface to a depth of 3 m with three replicates using 1-liter bottles on February 25, 2020, from the bloom area. The samples were fixed with Lugol's iodine and transferred to the laboratory for further investigation. *N. scintillans* cell density was observed and counted using Sedgewick-Rafter counting chamber (Woelkerling *et al*., 1976) under an inverted microscope (Nikon-TS100). Green *N. scintillans* cells were randomly selected to measure cell dimensions using ocular micrometers.

In the field surveys, dead marine organisms were also recorded and photographed using Nikon D5600 Digital SLR Camera. Environmental parameters samples were analyzed and recorded using Lutron WA-2017SD chemical multifunction device.

Results

Satellite studies

As shown in Figure 2 Modis sensor data from 26 February to 11 March 2020 revealed a significant increase in Chl-*a* covering almost all coastal areas of Chabahar Bay. The highest density and Chl-*a* content (~ 14 μg/L^{-1}) were observed on February 26, 2020, in the north of the Oman Sea (Chabahar Bay). Then, it declined to a minimum on March 6, but after March 11, 2020, the Chl-*a* density diminished (<4.5 μg/L^{-1}) and the region returned to normal.

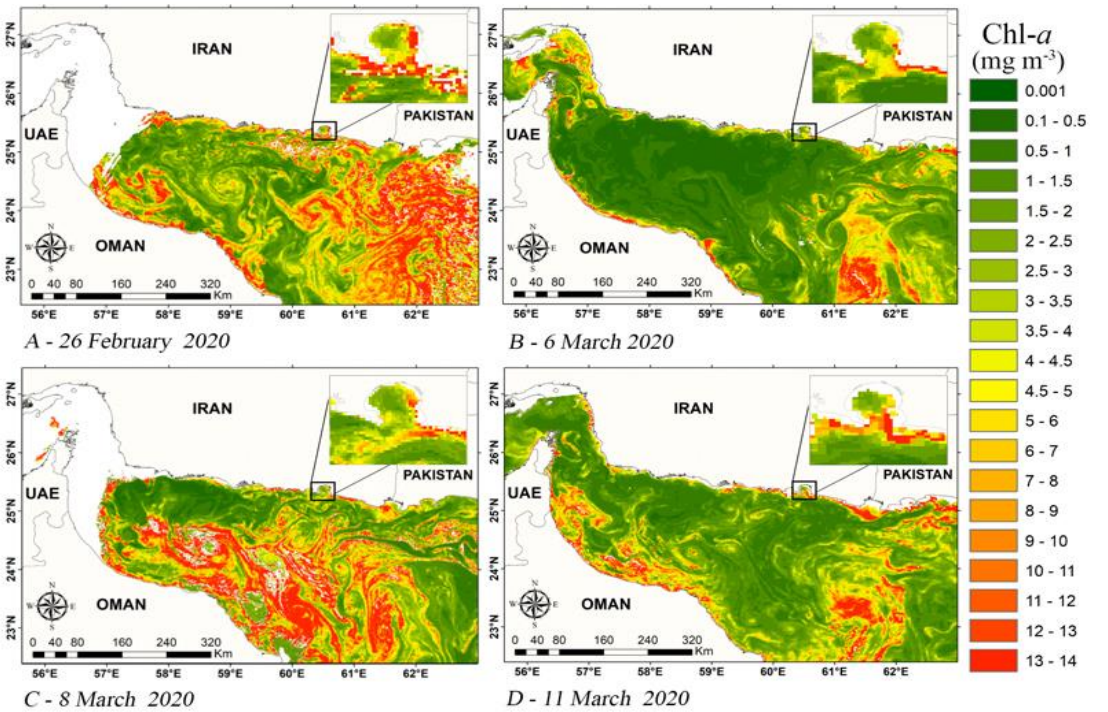

Figure 2: Chl-*a* change under the influence of *N. scintillans* in mg m^{-3} in the Oman Sea -Modis sensor.

Weekly satellite data revealed that Chl-*a* spread from February 18 to March 4, 2020, in different parts of the Oman Sea (~ 3.5-14 µg/L^{-1}) and stretched until near the Strait of Hormuz (Fig. 3). Surface chlorophyll from February 10 to 17, 2020; It moves from the north and northwest of the Arabian Sea towards the Oman Sea according to the model of ocean currents. Between February 18 and 25, the increase in chlorophyll density affected the entire region of the Oman Sea, including Chabahar Bay, so that it covers the south and central regions and large areas from the north of the Oman Sea to near the Strait of Hormuz. From February 26 to March 4, 2020, chlorophyll-*a* content in the region decreased, except for the southern strip and small parts of the northern Oman Sea, which had a high density, chlorophyll density in the Oman Sea decreased significantly, and the algal blooms have begun to recede from these areas. The descending trend of algal density continued after March 13, 2020, and the chlorophyll-*a* content of the region returned to normal. This reduction in chlorophyll-*a* indicates a fall in the density of algae and the end of the red tidal phenomenon in this area.

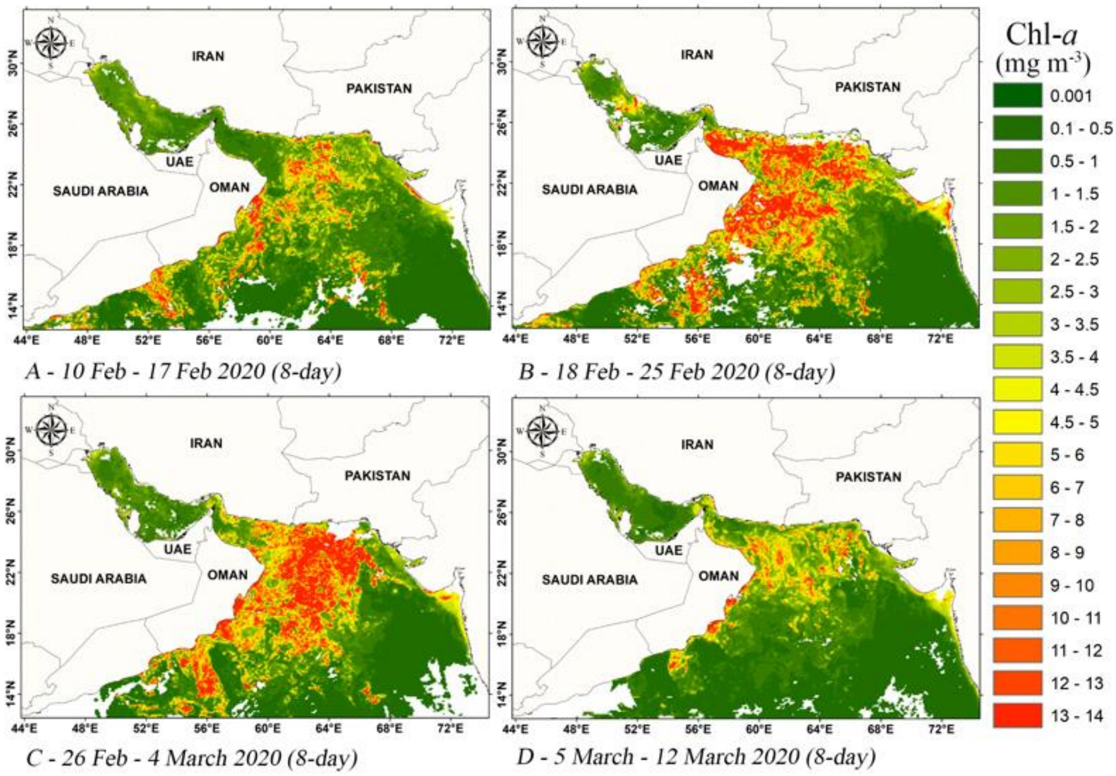

Figure 3: the fluctuation of Chl-*a* in the Oman Sea at 8-day intervals based on Modis.

Sensor data

According to satellite images (Fig. 4), the highest surface temperature was recorded between 24℃ and 27.0℃. On February 26, 2020, in the northern waters of the Oman Sea However, after

13 March, the temperature at Chabahar Bay had a diminishing trend as the surface temperature in the mentioned area dropped below 23℃. According to the satellite data, temperature changes are related to changes in Chl-*a*, so with increasing temperature, an increase in Chl-*a* was recorded and vice versa.

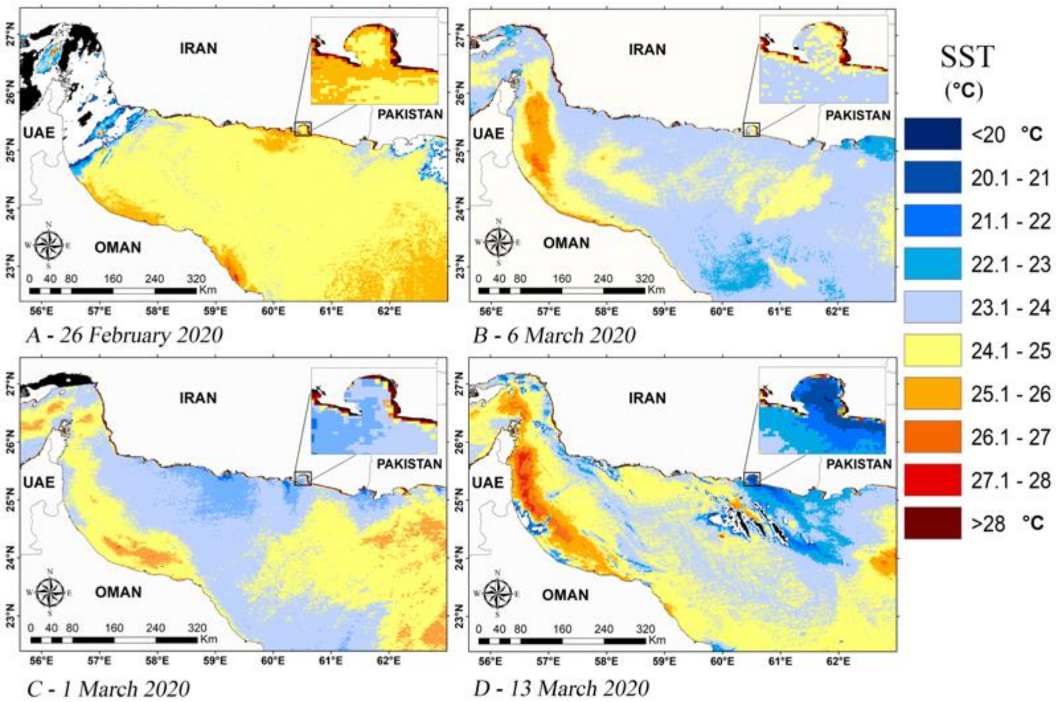

Figure 4: Water surface temperature in the Oman Sea using Modis sensor.

Field studies

An infrequent algal bloom was observed in the study area after SWM. The blooming period was recorded from 25 February to 14 March 2020. Experimental results showed that the observed green mass and color on the water surface (Fig. 5) was due to the blooming of *N. Scintillans* and its symbiotic *Pedinomonas noctilucae* (Parsinophyceae).

The species bloomed in the study area from late February to mid-March. The density of *Noctiluca Scintillans* and symbiont *Pedinomonas noctilucae* in the different stations on February 26 are in Table 2. The measurement results of the relevant environmental parameters, also including nutrients of the water sample are presented in Table 3. In addition to *N. scintillans* and its endosymbiosis cells (Fig. 6), 20 phytoplankton species comprising 10 dinoflagellates, 9 diatoms, and 1 chlorophyta were observed during the present study (Fig. 7).

The percentage of contribution of each species in the said blooming separately in each sampling station is shown in Table 4. Following the bloom of *N. scintillans* in Chabahar Bay, few fish, a significant number of jellyfish, a small number of crabs, and the Portuguese man of war (*Physalia physalis*), and three Green Sea turtles (*Chelonia mydas*) were dead (Fig. 8).

Figure 5: Seawater color change to green at three stations. The Rocky Shore of The Great Sea (A and B aerial photography of the area using a DJI Mavic 2 Pro - Drone Quadcopter UAV with Hasselblad Camera), Coast of Chabahar Maritime University (CMU), E: Coast of Lipar (C and D).

Table 2: Density of *Noctiluca scintillans* and *Pedinomonas noctilucae* cells in the sampling stations.

Station	*N. scintillans* Cell no. l^{-1}	*P. noctilucae* Cell no. l^{-1}	Sea Bottom	Depth of Sampling (m)
Coast of CMU*	2.37×10^5	1.2×10^6	Silt Sandy	0–1.5
Coast of Lipar	32×10^3	163×10^3	Silt Sandy	0–1
The Rocky Shore of the Great Sea	48×10^3	309×10^3	Rocky	0–3

* Chabahar Maritime University

Table 3: Physicochemical parameters in different stations.

Parameter	Coast of CMU*	Coast of Lipar	The Great Sea
NO_3 (mg/L)	0.20	0.25	0.26
NO_2 (mg/L)	0.05	0.06	0.06
Temperature (°C)	27.2	27.5	27.0
Turbidity (NTU)	85	86	82
SO_4^{2-} (mg/L)	155	157	158
Salinity (ppt)	42	42	40

* Chabahar Maritime University

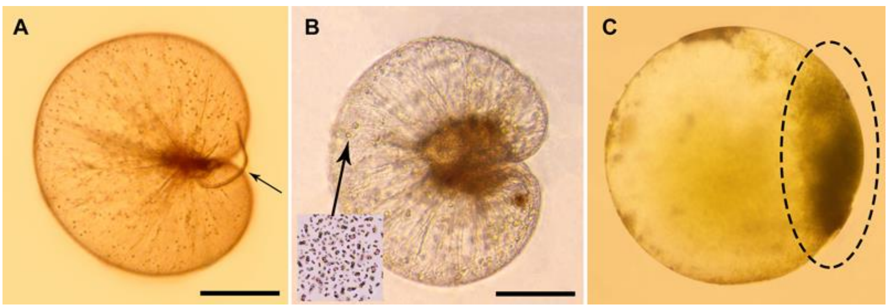

Figure 6: Microscopic magnification of *Noctiluca scintillans* cells using 100 X. A cell with a small number of symbiosis, the arrow shows a tentacle (A), a cell with a high number of symbiosis (B), cross-sections: The final stage of reproductive cell formation (gametogenesis) (C).

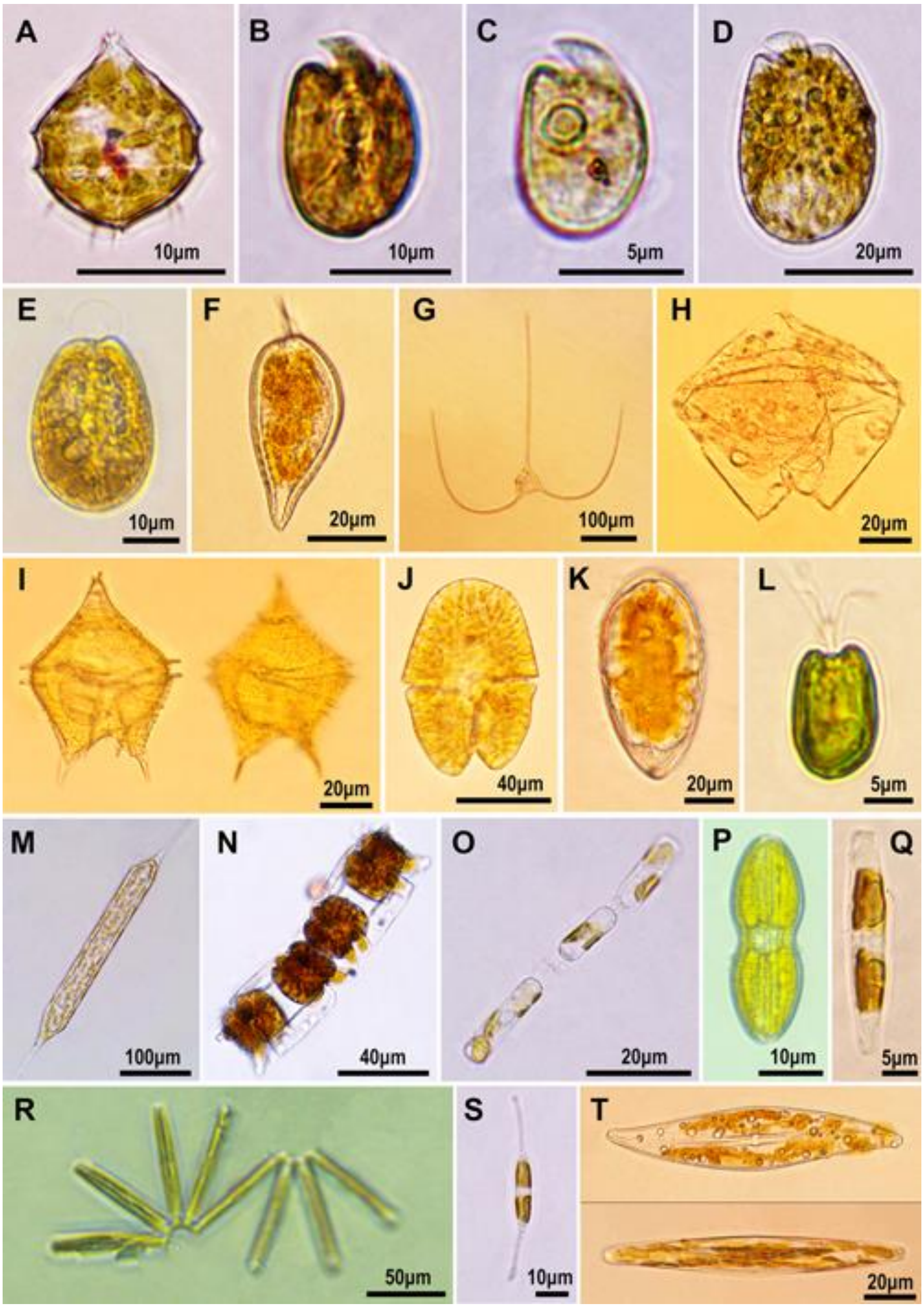

Figure 7: Lateral species of *Noctiluca scintillans*. *Peridinium quadridentatum* (F.Stein) Gert Hansen, 1995 (A), *Amphidinium* sp. (B), *Amphidinium carterae* Hulburt, 1957 (C), *Amphidinium operculatum* (Claparède and Lachmann, 1859) (D), *Prorocentrum lima* (Ehrenberg) F. Stein, 1878 (E), *Prorocentrum micans* Ehrenberg, 1834 (F), *Tripos trichoceros* (Ehrenberg) Gómez, 2013 (G), *Protoperidinium* sp.1 (H), *Protoperidinium* sp. 2 (I), *Akashiwo sanguinea* (K. Hirasaka) (Hansen and Moestrup, 2000) (J), *Surirella* sp. (K), *Tetraselmis* sp. (L), *Rhizosolenia* sp. (M), *Odontella* sp. (N), *Skeletonema costatum* (Greville) Cleve, 1873 (O), *Nitzschia* sp. (P), *Diploneis* sp. (Q), *Thalassionema* sp. (R), *Cylindrotheca* sp. (S), *Gyrosigma* sp. (T).

Table 4: Species present and abundance (%) in the algal bloom of *Noctiluca scintillans* in Chabahar Bay in February and March 2020.

Species	Coast of CMU* %	Coast of Lipar %	The Great Sea %
Amphidinium carterae	0.23	0.86	0.2
Amphidinium operculatum	0.02	0.03	-
Amphidinium sp.	0.10	0.14	-
Cylindrotheca sp.	1.05	1.55	0.5
Diploneis sp.	0.17	2.34	0.3
Gyrosigma sp.	0.23	0.27	0.2
Nitzschia sp.	3	3	1.7
Noctiluca scintillans	93	86	96
Odontella aurita	0.07	-	-
Peridinium quinquecorne	1.13	3.83	0.2
Prorocentrum lima	0.07	-	-
Prorocentrum micans	2.66	2	0.4
Protoperidinium sp. 1	0.002	-	-
Protoperidinium sp. 2	0.14	0.25	-
Rhizosolenia sp.	0.03	-	-
Skeletonema costatum	0.07	-	-
Surirella sp.	0.13	0.32	0.05
Tetraselmis sp.	0.06	-	-
Thalassionema sp.	0.02	-	-
Tripos trichoceros	0.01	-	0.02

*Chabahar Maritime University

Figure 8: Mortality of marine organisms with blooms of *Noctiluca scintillans* in the study area, *Crambionella orsini* (Vanhöffen, 1888) (A, B), *Charybdis annulata* (Fabricius, 1798) (C), *Physalia physalis* (D), *Chelonia mydas* (Linnaeus, 1758) (E, F, G).

Discussion

The bloom of *N. Scintillans* has been investigated in many coastal areas in the world (Table 5) these studies show the difference in the chlorophyll content in different areas. In all studies referred to in Table 5 *N. scintillans* were the dominant species that have a big size among other dinoflagellate species.

Table 5: *Noctiluca scintillans* bloom characteristics in different regions.

Area	Abundance (Cells L^{-1})	Size (µm)	Salinity (‰)	Temperature (°C)	pH	Chl-*a* (µg L^{-1})	Time	Mortality	Reference
Mazatlán Bay, México	1.3×10^6	220-500	-	19.3	-	-	January	N/A	Rodríguez *et al.* (2005)
The Red Sea, southwestern Saudi Arabia	$2.5\text{-}3\times10^6$ 2.7×10^6	-	37-38 >38	22-24 24-25	6-8.5	-	February March	N/A	Mohamed and Mesaad (2007)
Central coastal waters of Tanzania:	3×10	-	34.5-36	25-29.5	-	-	July 2003-June 2004	No mortality	Lugomela (2008)
Gulf of Mannar, India	13.5×10^5	400-1200	34.2	29.5	6-8	-	October	Moray eels, sea turtles, seahorses, fish, sea snakes, clams, jellyfish, crabs, squids	Gopakumar *et al.* (2009)
Sagami Bay, Japan	2.3×10^6	-	>30	17-18	-	>2	April	N/A	Baek *et al.* (2009)
Southwest coast of India	8.1×10^8	500-1000	34.11	26 -27	-	12.34	August	No mortality	Padmakumar *et al.* (2010)
Rio Grande do Sul, Brazil	144×10^3	600-1000	-	18	-	-	December	No mortality	Cardoso (2012)
Sea of Marmara, Turkey	2.2×10^5	-	~23	~12	-	~3.5	May	N/A	Turkoglu (2013)
Coastal waters of the southeastern Black Sea	6.81×10^6	425-800	15.67	10.98	-	2.64	April	No mortality	Kopuz *et al.* (2014)
Dubai, UAE	5.4×10^3	-	37.7-38.5	21-22	7-8	-	January	N/A	Murugesan *et al.* (2017)
Chabahar Bay, Iran	2.37×10^5	150-500	40-42	27.0-27.5	6.5	~14	February March	Crab, fish, sea turtles, jellyfishes	Present study

Variability in Chl-*a* depends on the life form of the predominant species and the cell size. Smaller cell size has a relatively higher chlorophyll content compared with larger cells (Jeffrey *et al.*, 1975; Malone, 1980). However, the amount of this photosynthetic pigment depends on internal and external factors such as cell physiology, light intensity, species composition in the bloom area, temperature, and nutrient concentration (Reynolds, 1984; Riemann *et al.*, 1989).

The present study investigated the blooming of green *N. scintillans* in the Iranian waters of the Oman Sea. Based on the data obtained from this study, it can be concluded that the date of reporting and sighting of the Red Tide in the region is consistent with initial observations and satellite information, as in both field observation and satellite data, almost the same date. Remote sensing is a valuable technology in estimating the concentration of surface Chl-*a*. Due to the blooming conditions with reduced temperature and increasing nutrients in cold seasons, the red tide phenomenon could spread and be present in the region for about a month. Diminishing temperatures and changing climatic conditions as well as seasonal currents in winter in the Oman Sea and, naturally, increasing nutrients can be effective in the blooming and the density of this species. Based on studies by Saito and Furuya (2006) and Murugesan *et al.* (2017), the red *N. scintillans* is usually found in temperate and subtropical waters within the temperature range of 10-25°C with high salinity, while green *N. scintillans* is mainly found in tropical waters with a temperature range of 25-30°C in the western Pacific and the Indian Ocean. Elbrachter and Qi (1998) also reported the bloom of this species at temperatures below zero degrees to 30°C. The highest *N. scintillans* density was recorded in the Iranian coastal strip of the Oman Sea at 27.5°C in mid-March. However, Uhlig (1995) reported the maximum density of this species at 24°C and stated that if the water temperature is less than 15 °C, the maximum population density will not occur.

Some strains of green *N. scintillans* can grow and survive as successive generations in the form of photoautotrophs through their photosynthetic endosymbiosis (Furuya *et al.*, 2006). Endosymbiosis with *N. scintillans* ensures the survival of this dinoflagellate in times of nutrient deficiencies (Saito *et al.*, 2006), but when phytoplankton food is plentiful, it can feed phagotrophically like the red *N. scintillans* form (Saito *et al.*, 2006; Lugomela, 2008). In the present study, at the beginning of *N. scintillans* algal bloom, the density and diversity of other microalgae species increased, which could confirm a relationship between the enhanced density of *N. scintillans* and other species, especially diatoms. The bloom of this species often follows the bloom of diatoms. The present study indicated the co-occurrence of microalgae cells with the *N. scintillans* bloom in Chabahar Bay. According to the researchers, *N. scintillans* plays an important role in controlling the dynamics of diatoms during blooming (Nakamura, 1998; Zhang *et al.*, 2017), and it can be hypothesized that *N. scintillans* can act as a modulator of the dynamics of harmful algal blooms (Frangópulos *et al.*, 2011). Such a wide range of food sources makes this dinoflagellate flexible in its feeding strategy and causes red tides in many parts of the world (Lirdwitayaprasit *et al.*, 2006; Mohamed and Mesaad, 2007; Harrison *et al.*, 2011). Due to its ability to reproduce rapidly, along with its polyphagous feeding behavior, this species is prone to population explosions during blooming under favorable conditions (Uhlig and Sahling, 1990; Shanks and Walters, 1996). However, once the bloom reaches its final stage, the population collapses and the bloom quickly disappears (Song *et al.*, 2020). The breakdown of *N. scintillans* cells can usually be attributed to a lack of nutrients (Nakamura, 1998).

Studies in the Arabian Sea by Goes *et al.* (2020) using field data and satellite imagery showed that the emergence of *N. scintillans* bloom was directly related to climate change and that the melting of glaciers and weak monsoon winters are contributing to these blooms. The warming of winter monsoon winds with humidity reduces the mixing of the surface waters of the Arabian Sea, and these changes lead to increased heat transfer from the atmosphere into the surface waters of the Arabian Sea, these changes are the right time for the huge proliferation of *N. scintillans* cells and the subsequent blooming of this dinoflagellate. According to this research, two important factors in the blooming of this dinoflagellate, which are superior to many other microalgae, include the following: A) Surviving in harsh environmental conditions by feeding on other microorganisms, B) No being hunted by large zooplankton (except salps and jellyfishes), These cases indicate its high blooming capacity in the tropics. In this study, the highest algal density was recorded at the Chabahar Maritime University station (2.37×10^5). The semi-enclosed waters of this station, shallowness, lack of water flow, a high concentration of pollution, and the lack of wind direction to the coast can be considered the main reasons for the high algal density. However, the highest aquatic animal mortality was observed at the Great Sea Station. With the favorable environmental conditions and the increase of nutrients in the water column, especially after the winter monsoon, which carries nutrients from the Indian Ocean to the Oman Sea, the annual blooming of *N. Scintillans* is found in the waters of the Oman Sea in autumn and early spring. The prosperity of this species in coastal marine habitats causes the loss of marine life, including fish, which can also adapt to environmental conditions.

Studying the abundance and blooms of red tidal species, including *N. scintillans*, can lead to a better understanding of the relationship between bloom species and other algal species, as well as the physico-chemical parameters of water during blooms. For this reason, it is necessary to carry out more extensive investigations in the field of control and monitoring of areas where there is a possibility of blooming and environmental risks. In this regard, remote sensing method, examination of marine biological parameters, field experiments, and daily monitoring of sea, and regular monitoring of blooms are useful for controlling and assessing the possible risks of algal blooms in the water bodies, and it will help us to understand the bloom mechanism. In addition, to understand the blooming mechanism and the role of climate change on the density of harmful algal communities in the marine ecosystem, it is necessary to carry out similar studies, especially on *N. scintillans*, comprehensively in tropical areas such as the Arabian Sea, the Oman Sea, and the Persian Gulf.

Acknowledgments

We should say thanks and appreciation to Professor Yasuwo Fukuyo for reading the primary version of the manuscript and his valuable comments and suggestions. The cooperation of the head and experts of the Chabahar Environment Department and the assistance of the officials and hard-working experts of Chabahar Maritime University Laboratory are sincerely thanked and appreciated. Also, the authors would like to say thanks to Dr. Rouhollah Zare for the sampling of stations, Dr. Reza Naderloo to help identify species of crabs killed by the algal bloom, and Dr. Keivan Kabiri for his guidance in drawing satellite maps of the study area.

References

Al-Azri, A., Al-Hashmi, K., Goes, J., Gomes, H., Rushdi, A.I., Al-Habsi, H., Al-Khusaibi, S., Al-Kindi, R. and Al-Azri, N., 2007. Seasonality of the bloom-forming heterotrophic dinoflagellate *Noctiluca scintillans* in the Gulf of Oman in relation to environmental conditions. *International Journal of Oceans and Oceanography*, 2, 51-60.

Al-Hashmi, K., Sarma, Y., Piontkovski, S.E.R.G.E.Y., Harrison, P. and Al-Habsi, H., 2019. Response of phytoplankton to changes in Hydrographic properties in a subtropical embaymentin the Oman Sea. *International Journal of Ecology and Environmental Sciences*, 45, 71-84.

Attaran-Fariman, G., 2010. Initial Assessment on Dispersion of Harmful Algae Bloom Along South-East Coast of Oman Sea. Department of the Environment, I.R.Iran, Division of Marine Environment, Sistan and Baluchestan, Chabahar, Iran. 88 P. [in Persian].

Attaran-Fariman, G. and Asefi, M.A., 2022. Checklist of phytoplankton of the tropical Persian Gulf and Sea of Oman. *Nova Hedwigia*, 114, 251-301. DOI: 10.1127/nova_hedwigia/2022/0687

Baek, S.H., Shimode, S., Kim, H.-C., Han, M.-S. and Kikuchi, T., 2009. Strong bottom–up effects on phytoplankton community caused by a rainfall during spring and summer in Sagami Bay, Japan. *Journal of Marine Systems*, 75, 253-264. DOI: 10.1016/j.jmarsys.2008.10.005

Cardoso, L.D.S., 2012. Bloom of *Noctiluca scintillans* (Macartney) kofoid & swezy (dinophyceae) in southern Brazil. *Brazilian Journal of Oceanography*, 60, 265-268.

D'silva, M.S., Anil, A.C., Naik, R.K. and D'costa, P.M., 2012. Algal blooms: a perspective from the coasts of India. *Natural hazards*, 63, 1225-1253. DOI: 10.1007/s11069-012-0190-9

Elbrachter, M. and Qi, Y. Z., 1998. Aspects of *Noctiluca* (Dinophyceae) population dynamics. *Physiological ecology of harmful algal blooms, (DM Anderson, AD Cembella, GM Hallegraeff, eds) Springer, Berlin, Heidelberg*, 315-335.

Ershadifar, H., Koochaknejad, E., Ghazilou, A., Kor, K., Negarestan, H. and Baskaleh, G., 2020. Response of phytoplankton assemblages to variations in environmental parameters in a subtropical bay (Chabahar Bay, Iran): Harmful algal blooms and coastal hypoxia. *Regional Studies in Marine Science*, 39, 101421. DOI: 10.1016/j.rsma.2020.101421

Frangópulos, M., Spyrakos, E. and Guisande, C., 2011. Ingestion and clearance rates of the red *Noctiluca scintillans* fed on the toxic dinoflagellate *Alexandrium minutum* (Halim). *Harmful Algae*, 10, 304-309. DOI: 10.1016/j.hal.2010.11.002

Fukuda, Y. and Endoh, H., 2006. New details from the complete life cycle of the red-tide dinoflagellate *Noctiluca scintillans* (Ehrenberg) McCartney. *European Journal of Protistology*, 42, 209-19. DOI: 10.1016/j.ejop.2006.05.003

Furuya, K., Saito, H., Sriwoon, R., Omura, T., Furio, E., Borja, V. and Lirdwitayaprasit, T., 2006. Vegetative growth of *Noctiluca scintillans* containing the endosymbiont *Pedinomonas noctilucae*. *African Journal of Marine Science*, 28, 305-308. DOI: 10.2989/18142320609504167

Goes, J.I., Tian, H., Do Rosario Gomes, H., Anderson, O.R., Al-Hashmi, K., Derada, S., Luo, H., Al-Kharusi, L., Al-Azri, A. and Martinson, D.G., 2020. ecosystem state change in the Arabian Sea fuelled by the recent loss of snow over the Himalayan-tibetan plateau region. *Scientific Reports*, 10, 1-8. DOI: 10.1038/s41598-020-64360-2

Gomes, H.D.R., Goes, J.I., Matondkar, S.P., Buskey, E.J., Basu, S., Parab, S. and Thoppil, P., 2014. Massive outbreaks of *Noctiluca scintillans* blooms in the Arabian Sea due to spread of hypoxia. *Nature Communications*, 5, 4862. DOI: 10.1038/ncomms5862

Gopakumar, G., Sulochanan, B. and Venkatesan, V., 2009. Bloom of *Noctiluca scintillans* (Macartney) in Gulf of Mannar, southeast coast of India. *Journal of the Marine Biological Association of India*, 51, 75-80.

Hansen, P.J., Miranda, L. and Azanza, R., 2004. Green *Noctiluca scintillans*: a dinoflagellate with its own greenhouse. *Marine Ecology Progress Series*, 275, 79-87. DOI: 10.3354/meps275079

Harrison, P.J., Furuya, K., Glibert, P.M., Xu, J., Liu, H., Yin, K., Lee, J.H., Anderson, D.M., Gowen, R. and Al-Azri, A., 2011. Geographical distribution of red and green *Noctiluca scintillans*. *Chinese*

Journal of Oceanology and Limnology, 29, 807-831. DOI: 10.1007/s00343-011-0510-z

Huang, C. and Qi, Y., 1997. The abundance cycle and influence factors on red tide phenomena of *Noctiluca scintillans* (Dinophyceae) in Dapeng Bay, the South China Sea. *Journal of Plankton Research*, 19, 303-318. DOI: 10.1093/plankt/19.3.303

Jalili, M., Fallahi, M., Saleh, A., Mashinchian Moradi, A. and Fatemi, M.R., 2022. Short-term variations of phytoplankton communities in response to *Noctiluca scintillans* bloom in the Chabahar Bay (Gulf of Oman). *Iranian Journal of Fisheries Sciences*, 21, 931-947. DOI: 10.22092/IJFS.2022.127442

Jeffrey, S.W., Sielicki, M. and Haxo, F.T., 1975. Chloroplast pigment patterns in dinoflagellates 1. *Journal of Phycology*, 11, 374-384.

Kopuz, U., Feyzioglu, A.M. and Valente, A., 2014. An unusual red-tide event of *Noctiluca scintillans* (Macartney) in the Southeastern Black Sea. *Turkish Journal of Fisheries and Aquatic Sciences*, 14, 261-268. DOI: 10.4194/1303-2712-v14_1_28

Lirdwitayaprasit, T., Meksumpun, S., Rungsupa, S. and Furuya, K., 2006. Seasonal variations in cell abundance of *Noctiluca scintillans* in the coastal waters off Chonburi Province, the upper Gulf of Thailand. *Coastal Marine Science*, 30, 80-84.

Lugomela, C., 2008. *Noctiluca scintillans* (Dinophyceae) in central coastal waters of Tanzania: A new phytoplankton record for the area. *Western Indian Ocean Journal of Marine Science,* 6. DOI: 10.4314/wiojms.v6i1.48231

Maghsoudlou, A., Momtazi, F. and Aghajanpour, F., 2015. Spatial pattern of phytoplankton communities from Iranian waters of the Gulf of Oman in pre-monsoon period. *Journal of the Persian Gulf*, 6, 65-77.

Malone,T.C., 1980. Algal size. In Morris, I. (ed.), The Physiological Ecology of Phytoplankton. Blackwell Scientific Publications, Oxford, UK. pp. 433–446.

Miyaguchi, H., Fujiki, T., Kikuchi, T., Kuwahara, V.S. and Toda, T., 2006. Relationship between the bloom of *Noctiluca scintillans* and environmental factors in the coastal waters of Sagami Bay, Japan. *Journal of Plankton Research*, 28, 313-324. DOI: doi.org/10.1093/plankt/fbi127

Mohamed, Z.A. and Mesaad, I., 2007. First report on *Noctiluca scintillans* blooms in the Red Sea off the coasts of Saudi Arabia: consequences of eutrophication. *Oceanologia*, 49.

Murugesan, K., Juma, I.M.I.A. and Khan, S.A., 2017. Blooms of *Noctiluca scintillans* and its Association with *Thalia* sp.(Salps) along Dubai Coastal Waters. *Environmental Sciences*, 11, 101-107. DOI: 10.3923/rjes.2017.101.107

Nakamura, Y., 1998. Biomass, feeding and production of *Noctiluca scintillans* in the Seto Inland Sea, Japan. *Journal of Plankton Research*, 20, 2213-2222. DOI: 10.1093/plankt/20.11.2213

Padmakumar, K., Sreerenjima, G., Fanimol, C., Menon, N. and Sanjeevan, V., 2010. Preponderance of heterotrophic *Noctiluca scintillans* during a multi-species diatom bloom along the southwest coast of India. *International Journal of Oceans and Oceanography*, 4, 55-63.

Rabbaniha, M., Gerami, M.H. and Golsefid, S.A.M., 2018. Temporal phytoplankton diversity patterns and community structure in a monsoonal region, Oman Seawater (Iranian parts). *Regional Studies in Marine Science*, 24, 355-363. DOI: 10.1016/j.rsma.2018.09.011

Reynolds,C.S., 1984. The Ecology of Freshwater Phytoplankton. *Cambridge University Press*, Cambridge.384 P.

Riemann, B., Simonsen, P. and Stensgaard, L., 1989. The carbon and chlorophyll content of phytoplankton from various nutrient regimes. *Journal of Plankton Research*, 11, 1037-1045.

Rodríguez, E.A.P., Borges Yáñez, A., Villavicencio, M. Á.F. and Espinoza, E.V., 2005. Grazing of heterotrophic dinoflagellate *Noctiluca scintillans* (Mcartney) Kofoid on *Gymnodinium catenatum* Graham. *Revista latinoamericana de microbiologia*, 47, 6-10.

Saito, H. and Furuya, K., 2006. Endosymbiosis in microalgae with special attention to *Noctiluca scintillans*. *Bulletin of the Plankton Society of Japan*, 53, 1, 14-21.

Saito, H., Furuya, K. and Lirdwitayaprasit, T., 2006. Photoautotrophic growth of *Noctiluca scintillans* with the endosymbiont *Pedinomonas noctilucae*. *Plankton and Benthos Research*, 1, 97-101.

Saraji, F., Eslami, F., Sanjarani, M., Ebrahimi, M., Shojaie, M., Rabaniha, M., Mousavi, S.A. and Hajmohammadi, F., 2014. Phytoplankton, Zooplankon and Ichthyoplankton Abundance, Distribution and Diversity Investigation in the Iranian Waters of the Oman Sea. Research Project Report Number 0-100- 200000-04-8402-84041, *Persian Gulf and Oman Sea Ecological Research Insitute*, Bandar Abbas, Iran. 99 P.

Shanks, A. and Walters, K., 1996. Feeding by a heterotrophic dinoflagellate (*Noctiluca scintillans*) in marine snow. *Limnology and Oceanography*, 41, 177-181. DOI: 10.4319/lo.1996.41.1.0177

Shen, L., Xu, H. and Guo, X., 2012. Satellite remote sensing of harmful algal blooms (HABs) and a potential synthesized framework. *Sensors*, 12, 7778-7803.

Song, J., Bi, H., Cai, Z., Cheng, X., He, Y., Benfield, M. C. and Fan, C., 2020. Early warning of *Noctiluca scintillans* blooms using in-situ plankton imaging system: An example from Dapeng Bay, PR China. *Ecological Indicators*, 112, 106123. DOI: 10.1016/j.ecolind.2020.106123

Sriwoon, R., Pholpunthin, P., Lirdwitayaprasit, T., Kishino, M. and Furuya, K., 2008. Population Dynamics of Green *Noctiluca Scintillans* (Dinophyceae) Associated with the Monsoon Cycle in the Upper Gulf of Thailand. *Journal of Phycology*, 44, 605-15. DOI: 10.1111/j.1529-8817.2008.00516.x

Thangaraja, M., Al-Aisry, A. and Al-Kharusi, L., 2007. Harmful algal blooms and their impacts in the middle and outer ROPME sea area. *International Journal of Oceans and Oceanography*, 2, 85-98.

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

Uhlig, G. and Sahling, G., 1990. Long-term studies on *Noctiluca scintillans* in the German Bight population dynamics and red tide phenomena 1968–1988. *Netherlands Journal of Sea Research*, 25, 101-112. DOI: 10.1016/0077-7579(90)90012-6

Uhlig, G., 1995. *Noctiluca scintillans*: Zeitliche Verteilung bei Helgoland und raumliche Verbreitung in der Deutschen Bucht (Langzeitreihen 1970-1993). *Ber Biologische Anstalt Helgoland*, 9, 1-127.

Woelkerling, W.J., Kowal, R.R. and Gough, S.B., 1976. Sedgwick-rafter cell counts: a procedural analysis. *Hydrobiologia*, 48, 95-107.

Zhang, S., Harrison, P.J., Song, S., Chen, M., Kung, H.S., Lau, W.K., Guo, C., Wu, C. J., Xu, J. and Liu, H., 2017. Population dynamics of *Noctiluca scintillans* during a bloom in a semi-enclosed bay in Hong Kong. *Marine Pollution Bulletin*, 121, 238-248. DOI: 10.1016/j.marpolbul.2017.06.025