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A three-year record of red tides in Chabahar coastal waters (North of Gulf of Oman)

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Abstract

Seven phytoplankton species (Alexandrium sp., *Prorocentrum micans*, *Cochlodinium (aka Margalefidinium) polykrikoides*, *Mesodinium rubrum*, *Akashiwo sanguinea*, *Gonyaulax polygramma*, Ceratium sp.) were found as the main cause of Harmful algal blooms (HABs) in a three-year record of red tides in Chabahar coastal waters (North of Gulf of Oman). Autumnal blooms of *Gonyaulax polygramma* and *Prorocentrum micans* are reported for the first time in the region. The most frequent bloom events were caused by *Akashiwo sanguinea* (i.e. 4 times) and *Mesodinium rubrum* (i.e. 3 times). The highest observed density was at Oct 2017 caused by *Akashiwo sanguinea* ($15.3*10^6$/ litre). The recorded temperature range was from 24.4 to 31.5°C and the DO ranged widely from 3.9 to 11.2 mg/liter. In conclusion, HABs occurrences are not associated with the expansion of one particular species but with multiple taxa and there is a suitable environmental condition for HABs in the autumn and spring in the region.

Keywords: *HABs, Red tide, Chabahar, Gulf of Oman, Akashiwo sanguinea*

1. Introduction

Harmful algal blooms (HABs) are increasing phenomenon in the coastal waters of the world in terms of frequency and intensity (Glibert et al., 2015), causing unfavorable effects on marine ecosystems (Anderson et al., 2015). In the Gulf of Oman, HABs and their impacts have become more widespread and persistent (Al-Azri et al., 2007, Thangaraja et al., 2007). The coastal waters of Chabahar within the northern part of the Gulf are no exception to this pattern. Annual winter bloom of the green *Noctiluca scintillans* constitutes the major HABs of the area. The species has expanded across the Indian Ocean, the Arabian Sea, and the Gulf of Oman over the past few decades (Harrison et al., 2011). Yet, *N. scintillans* is not the only case of HABs and blooms of several other *dinoflagellates* and ciliates are common in this area. In one occasion a large-scale bloom of *Prorocentrum micans,* not only led to shot down of a desalination plant and cut off of the city's tap water for a week, but also imposed damages to one shrimp breeding site in 2017. These events have caused significant concerns

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among government authorities and the public regarding the possible ways for controlling HABs in the area. The *N. scintillans* is not included in this paper because it is seasonally abundant in the area and therefore, is not considered as a sudden and unpredictable event.

2. Materials and Methods

Detection of the HABs was primarily based on the color change in the study area. Usually, a red/brown water discoloration was observed. At the time, three surface water samples (<1 m) were taken from the central part of the bloom patch, using a bottle sampler. The water temperature, pH, salinity and dissolved oxygen (DO) were measured using Hach's multi-probe analyzer at the sampling site.

The collected water samples transferred to the biology laboratory at the Chabahar Oceanography Center where they were initially stored at 6°C for live cell observation. Then, samples were fixed in acidic Lugol's solution at 1% concentration within 8 hours of collection time.

For quantitative analyses of phytoplankton assemblages, 1 mL of regular samples was dispensed onto the Sedgewick-Rafter counting chamber, and counts of the dominant phytoplankton species were recorded at 200x magnification using a light microscopy.

3. Results and discussion

Seven phytoplankton species were found as the main cause of HABs in Chabahar coastal waters. During the study, the most frequent bloom events were caused by *Akashiwo sanguinea* (i.e. 4 times) and *Mesodinium rubrum* (i.e. 3 times). Outbreaks of other species listed in Table 1 were observed only one time as a cause of red tide.

The recorded temperature range was from 24.4 to 31.5 °C and the DO ranged widely from 3.9 to 11.2 mg/L (Table 1). Meanwhile, salinity and pH did not show considerable variation (Table 1). Environmental conditions for the occurrence of red tides were more favorable during autumn with 9 out of 12 blooms recorded in October, November and December (Table 1). Cases of HABs were also recorded in other seasons. For example, an incident Bloom of *Ceratium sp.* occurred during the monsoon season in 2018. Also, the spring-time blooms of *A. sanguinea* and *M. rubrum* were recorded during April 2017 and May 2019 (Table 1).

The sites of HAB occurrences are presented in Figure 1. *A. sanguinea* blooms were detected both inside and outside of the Bay, the *Cochlodinium (aka Margalefidinium) polykrikoides* bloom was only observed inside the Bay and the outbreaks of other species were only seen outside of the Bay.

Table 1: Mean density of bloom species and physical-chemical properties of water in time of sampling

Date	**Species/Genus**	**Mean Density** ($*10^6$)/litre	**Temp** (°C)	**Sal** (ppt)	**pH**	**DO** (mg/litre)
26 October 2016	Alexandrium sp.	1.5	24.4	36.3	8.10	8.30
04 November 2016	*Prorocentrum micans*	1.53	25.5	37.8	8.00	5.10
09 November 2016	*Cochlodinium polykrikoides*	1.7	27.0	36.4	8.40	11.20
03 December 2016	*Mesodinium rubrum*	3.1	25.5	36.6	8.25	9.50
14 April 2017	*Mesodinium rubrum*	0.37	27	36.4	8.06	4.4
19 September 2017	*Akashiwo sanguinea*	2.93	31.5	36.8	8.23	5.33

03 October 2017	*Akashiwo sanguinea*	15.3	28.4	36.2	8.10	4.34
21 October 2017	*Gonyaulax polygramma*	1.5	27.9	36.1	8.18	6.12
24 October 2017	*Akashiwo sanguinea*	8.6	28	36.2	8.16	6.08
18 August 2018	*Ceratium sp.*	0.00095	30.8	36.6	8.22	5.67
10 December 2018	*Mesodinium rubrum*	1.18	25.8	36.4	7.92	3.9
21 May 2019	*Akashiwo sanguinea*	2.9	28.2	36.3	*	5.12

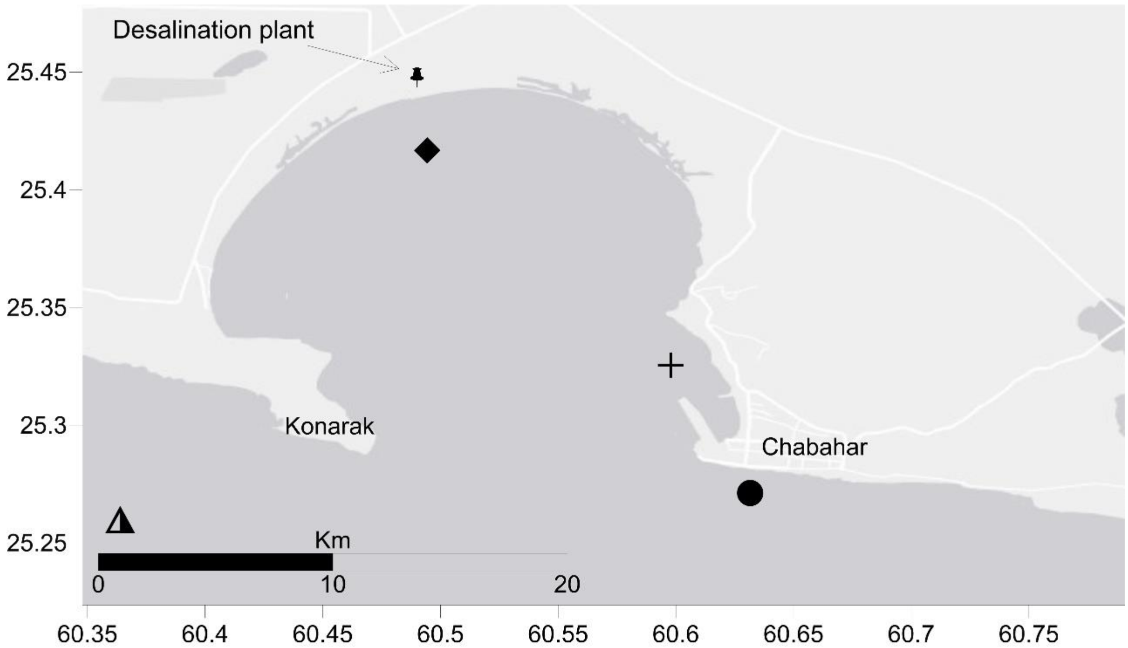

Fig 1: Locations of red tides at the times of sampling

● : Alexandrium sp., Prorocentrum micans, Mesodinium rubrum, Akashiwo sanguinea, Gonyaulax polygramma, Ceratium sp.

+ : Akashiwo sanguinea

◆ : Cochlodinium polykrikoides, Akashiwo sanguinea

4. Conclusions

In the past three years, *A. sanguinea* has caused red tides inside and outside of the Bay. The dinoflagellate *A. sanguinea* is a eurythermal and euryhaline organism that exhibits maximum growth rate at 25°C (Chen et al., 2015, Matsubara et al., 2007). The temperatures above 30°C have been found to inhibit growth in *A. sanguinea* (Chen et al., 2015). In our study, blooms of *A. sanguinea* generally occurred at 28°C. However, one out of four observed bloom cases occurred at 31°C. Ou et al. (2017) suggested that *A. sanguinea* will benefit from future climate changes, and the interactive effects of ocean acidification, warming, and high irradiance would bring about more blooms of *A. sanguinea*. The Indian Ocean is highly influenced by climate change (Turner and Annamalai, 2012). Hence, the increase in intensity *A. sanguinea* blooms can be considered as an indicator of the effects of climate change in the region.

M. rubrum is an obligate mixotroph requiring autotrophic and heterotrophic acquisition of matter for sustained growth. The ciliate is well known for its ability to form dense red tides worldwide (Hansen et al., 2012). It has caused three severe red tides in Chabahar coastal waters. Although, the presence of *M. rubrum* was reported by Dr. Hamid Rezai (unpublished data), Ghazilou et al. (2017) published the first record of *M. rubrum* in the northern Gulf of Oman which is also mentioned in this paper.

The presence of *Gonyaulax polygramma* and *Prorocentrum micans* has been reported in Chabahar coastal waters and like *M. rubrum* autumnal bloom of these dinoflagellates are reported for the first time.

Cochlodinium polykrikoides is a toxic algal species (Dorantes-Aranda et al., 2010). It has become a major HAB problem across the world (Kim et al., 2007, Gárate-Lizárraga et al., 2004, Kudela and Gobler, 2012) and caused catastrophic red tide in the Persian Gulf region during 2008–2009 which probably started from Gulf of Oman and spread through the Strait of Hormuz (Richlen et al., 2010). It has been commonly reported as a red tide-causing species in Chabahar Bay (Attaran-Fariman and Sharifian, 2014, Attaran-Fariman, 2010). The last bloom of *C. polykrikoides* occured in November 2016.

The intensity of red tide events in the autumn seems to be due to extensive enrichment of the euphotic zone with macronutrients during Southwest Monsoon (SWM) (Hitchcock et al., 2000). As a result, there would be a relative increase in nutrient load from September (after SWM) which improves the probability of bloom occurrence during autumn. However, nutrients are not the only limiting factor that insert meaningful control over the blooms and other factors such as iron (Fe^{+2}) supply (i.e. by dust) may trigger these blooms which, in turn, leads to the removal of Fe from the surface layer (Naqvi et al., 2010). Among the variables considered in this study, the temperature and the dissolved oxygen showed greater temporal and spatial variations. The temperature (as the main factor affecting physiological processes) showed a good relationship with two major species of bloom (~25-27 for *Mesodinium rubrum* and ~28 for *Akashiwo sanguinea*). However, in order to prove its statistical significance, it is necessary to increase the number of samples and/or to assess the subject in a controlled environment (In vitro). Since, chemical, physical and biochemical activities can affect the levels of dissolved oxygen in water (Dodds et al., 2017), high range of variation is expected. In addition, DO is considered as a linked variable to red tide phases and its level significantly differ between early and late bloom (Crawford et al., 1997). Therefore, time of sampling from the bloom could have meaningful effects on DO values in this study.

Although the Chabahar Bay is directly influenced by the physical and chemical changes of the Oman Sea, its omega shape and low depth relative to the outlying areas of the Persian Gulf limit its water circulation (Agah et al., 2016) which subsequently causes differences in currents pattern (Soltanpour and Dibajnia, 2015), temperature slope and granulation of sediments (Unpublished data). These differences can be effective at the origin of bloom events and the possibility of transporting them inside or outside of the Bay.

In conclusion, HABs occurrences are not associated with the propagation of one particular species, but with simultaneous reproduction of multiple taxa, particularly in the autumn and spring in the region.

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