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Potentially harmful microalgae and algal blooms in the Red Sea: Current knowledge and research needs

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ABSTRACT

Harmful algal blooms (HABs) have increased throughout the world's coastal oceans during the last century mostly due to water eutrophication and climate change. These blooms are often accompanied by extreme extensive negative impacts to fisheries, coastal resources, public health and local economies. However, limited studies have reported HAB events in Red Sea coastal waters. This article reviews potentially harmful microalgae in the Red Sea, based on available published information during the last 3 decades. Five harmful algal blooms were recorded in the Red Sea; of which 3 blooms are formed by dinoflagellates (*Noctiluca scintillans*, *Pyrodinuium bahamense*, *Protoperidinium quinquecorne*), one by raphidophytes (*Heterosigma akashiwo*) and one by cyanobacteria (*Trichodesmium erythraeum*). Additionally, mangrove swamps in the Red Sea were occupied by cyanobacterial mats, which contain microcystin and saxitoxin-producing species. The existing data in this review could be a catalyst for the establishment of monitoring and management program for HABs and their toxins in Red Sea coastal waters. This review also identifies current research gaps and suggests future research directions.

1. Introduction

The Red Sea is a semi-enclosed narrow tropical sea separating northern Africa from the Arabian subcontinent (Western Asia), extending from (12.5°N) to about (30°N) over a distance of about 2250 km with an average width of 280 km (Acker et al., 2008). At the northern end, it separates into the Gulf of Aqaba (Eliat) and the Gulf of Suez, which is connected to the Mediterranean Sea via the Suez Canal. At the southern end, it is connected to the open Indian Ocean through the Gulf of Aden, and Arabian Sea via the Strait of Bab-el-Mandeb (Zhai et al., 2011). The Red sea is bordered by seven countries, namely Egypt, Sudan, Eritrea, Yemen, Saudi Arabia, Jordan and Israel. However, the region is sparsely populated, and no more than 5 million people are estimated to live along the coast. The Red Sea is considered as a region of high biodiversity, providing habitats for a wide range of marine organisms (Nassar et al., 2014). It is an oligotrophic sea without reverine inputs (Acker et al., 2008; Raitsos et al., 2015). The nutrients supply in the Red Sea occurs through water intrusion from the Arabian Sea via Bab-el-Mandeb (Churchill et al., 2014; Dreano et al., 2017), the subsurface mixing below the nutricline in the Northern Red Sea (Triantafyllou et al., 2014) or via dust deposition (Brindley et al., 2015). Generally, nutrient concentrations in the southern Red Sea are higher than those in the central and northern regions Acker et al., 2008). The southern part of the Red Sea, therefore exhibits the highest phytoplankton productivity. However, the distribution of nutrients in the entire Red Sea basin is predominantly controlled by eddy circulations pumping of nutrients from subsurface could sustain higher levels of production over a substantial spread of the Red Sea (Zhan et al. 2014; Wafar et al., 2016). Additional nutrients come from pollution caused by numerous industrial and domestic activities including oil spills and excessive loading of nutrients through addition of fertilizers and industrial wastewater and sewage into the Red Sea water (El-Tahera and Madkour, 2014; Nassar et al., 2014; Mustafa et al., 2016). This increase in nutrient concentrations (e.g. nitrate, ammonium, phosphate, and silicate) in seawater promotes the growth of phytoplankton to the extent that algal blooms may occur at the water surface (Raitsos et al., 2013). The rise in temperature due to climate change might also stimulate the proliferation of some phytoplankton species, particularly cyanobacteria (Rigosi et al., 2014; Chaidez et al., 2017). Based on remotely sensed sea surface temperature data from 1982 to 2006, the Red Sea has experienced rapid warming with average increase in annual temperature of 0.74 °C, comparable to the global average of 0.85 °C (Raitsos et al., 2011). Additionally, Chaidez et al. (2017) showed that the overall rate of warming for the Red Sea during the period 1982–2015 is 0.17 °C $decade^{-1}$. The climate warming in the Red Sea seems to be spatially heterogeneous, where the northern Red Sea, particularly the Gulf of Suez and Gulf of Aqaba, is warming faster (0.4 and 0.45 °C $decade^{-1}$) than central and southern regions ((0.1 and

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0.2 °C decade^{-1}) (Chaidez et al. (2017). Climate warming may have a twofold impact on phytoplankton growth in tropical marine ecosystems including reduction in phytoplankton abundance and alterations in the timing of seasonal phytoplankton blooms (Gittings et al., 2018). In light of this, climate warming reduced phytoplankton abundance and shortened their bloom time in the northern Red Sea (Gittings et al., 2018). However, the rest of the Red Sea seems to experience higher biomass during warmer climate phases like El Nino (Raitsos et al., 2015). These conditions may favor HABs abundance, and add an extra pressure to the ecosystem especially during El Nino phases. Given that all coastal countries in the world can be affected by HABs (Villacorte et al., 2015), the Red Sea coasts are most likely plagued with HABs. Some of these blooms may be toxic leading to illness and death of marine organisms and humans as well (Anderson et al., 2012). Other blooms are non-toxic, but can cause ecological impacts such as oxygen depletion and damage of fishery resources, besides their impacts on commercial and recreational activities such as beach fouling and retardation of desalination plants (Anderson et al., 2012). There have been many studies concerning phytoplankton populations in the Red Sea. Most of these studies however, have provided information about phytoplankton species composition and community structure in relation to environmental factors (El-Tahera and Madkour, 2014; Ismael, 2015), and only a few studies have focused on harmful algal blooms in the Red Sea (Mohamed and Mesaad, 2007; Mohamed and Al-Shehri, 2012, Alkawri et al., 2016a,b; Banguera-Hinestroza et al., 2016). This paper reviews available information on the occurrence of potentially harmful and/or bloom-forming microalgae in the Red Sea (Fig. 1). This review also identifies research gaps and emphasizes the need for harmful algae monitoring programs in the Red Sea coastal waters.

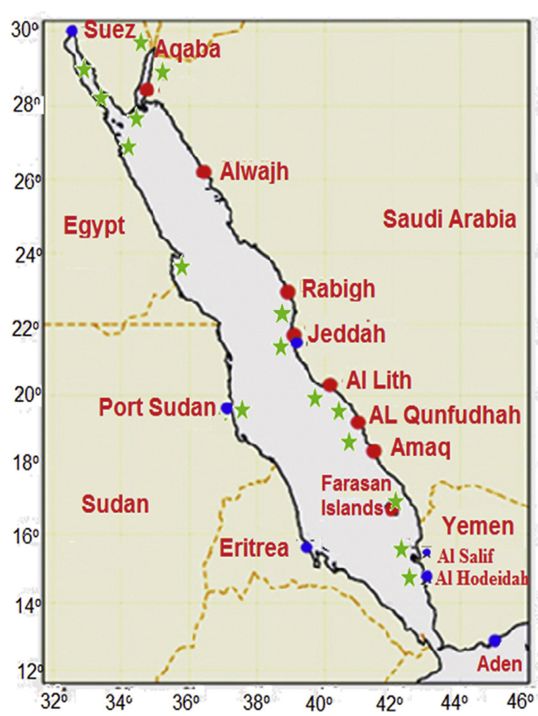

Fig. 1. Distribution map of potentially harmful microalgae in Red Sea coastal waters off different bordering countries. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

2. Occurrence of potentially harmful and bloom-forming microalgae in the Red Sea

2.1. In Egyptian Red Sea waters

Studies on phytoplankton and its productivity in the Red Sea have been carried out since 1900, and several species belonging to different groups (cyanobacteria, dinoflagellates, diatoms, chlorophytes, prymnesiophytes, rhaphidophytes) have been recorded (Ismael, 2015). Furthermore, the name of the Red Sea is attributed to the color of the water, which is thought to be due to red tides of *T. erythraeum* (Hoyt, 1912). Examination of published data from the literature about phytoplankton composition in the Red Sea has revealed the presence of species that have been confirmed as harmful and/or bloom-forming species elsewhere in the world. At Egyptian coasts, many of potentially harmful and bloom-forming species were recorded in the main body of the Red Sea, Gulf of Aqaba and Gulf of Suez. In the main body of the Red Sea, potentially harmful species of the dinoflagellates *Ceratium*, *Protoperidinium*, *Dinophysis* and *Gonyaulax* were recorded in considerable numbers (1–2x 10^3 cells L^{-1}) during spring 2008 at Hurghada and Sharm El-Sheikh coasts (Madkour et al., 2010, Table 1). The harmful diatoms *Pseudonitzschia, Chaetoceros* and *Thalassionema* also dominated phytoplankton population in these sites during winter 2007 (Madkour et al., 2010, Table 1). Recently, harmful species of diatoms (*Chaetoceros, Skeletonema, Proboscia*) and dinoflagellates (*Ceratium furca*) dominated phytoplankton population in Egyptian waters of the main body of the Red Sea at Al-Gemsha, Hurghada, Safaga and Al Qusir regions during winter and autumn 2013, respectively (Nassar et al., 2014). The abundance of such harmful species was correlated with high nutrient concentrations as well as low water salinity in these regions (Nassar et al., 2014). Additionally, potentially harmful dinoflagellates (*C. furca, Dinophysis caudata, Noctiluca miliaris*, *Peridinium cerasus*), Diatoms (*Chaetoceros decipiens, Rhizosolenia alata*) and cyanobacteria (*Oscillatoria limnetica*) were also reported in mangrove ecosystems of the Red Sea at the Southeastern Egypt (Halayib-Shalatin sector), but with low counts (15–117 individual L^{-1}) during summer 2001 (Abel Rahman and Nassar, 2005). Besides harmful dinoflagellates and diatoms, the main body of the Red Sea at Egyptian coasts showed a peak of the toxic cyanobacterium *T. erythraeum* (3×10^3 individual L^{-1}) in summer 2008 (Madkour et al., 2010).

For the Gulf of Aqaba, eutrophication from anthropogenic sources such as sewage and fish farms has contributed significantly to the abundance of potentially harmful algal and cyanobacterial species in the Gulf water (Stambler 2005). A bloom of the potentially toxic cyanobacteria *T. thiebautii* and *T. erythraeum* with > 10^6 colonies m^{-3} was detected in the coastal waters of the Gulf during fall 1997 (Post et al., 2002). Similarly, Al-Najjar et al. (2007) reported that *Trichodesmium* spp. showed an increase in the cell density reaching up to 4×10^4 cells L^{-1} during the summer/autumn 1999. In addition to *Trichodesmium*, *Synechococcus* sp. flourished in the Jordanian coasts of the Gulf of Aqaba with a peak (2×10^7 cells L^{-1}) obtained during early spring 1999. A strain of this species isolated from the Salton Sea has been confirmed as toxic with the capability of microcystin production (Carmichael and Li, 2006). Additionally, the prokaryotic *Prochlorococcus marinus* dominated phytoplankton population in the Gulf of Aqaba with concentrations around 2×10^7 cells L^{-1} during the stratified summer period 1999 (Stambler 2005; Al-Najjar et al., 2007). A strain of this species isolated from Sargasso Sea (Atlantic Ocean) was found to produce the neurotoxic nonprotein amino acid, *b*-N-methylamino-L-alanine (BMAA) (Cox et al., 2005). Some potentially harmful diatoms were also recorded in the Gulf water including *Thalassiosira* spp. which was prevalent throughout the year, with maximum concentrations in winter 1999 (1×10^5 cells L^{-1}), and *Chaetoceros* spp. which formed patchy blooms up to 1×10^5 cells L^{-1} in spring 1999 (Al-Najjar et al., 2007). The diatom *Proboscia alata* also dominated the phytoplankton community in the upper 10 m of the Gulf of Aqaba, with