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A review on harmful algae blooms in Arabian Gulf: causes and impacts on desalination plants

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ABSTRACT

The harmful algal bloom (red tides) (HAB) phenomenon is an issue for desalination facilities. This paper reviews the causes and impacts of HABs on desalination plants. Some HABs are linked to the creation of natural pollutants, dissolved oxygen depletion, and other negative consequences. Because desalination facilities are the principal source of freshwater for communities, agriculture, and industry for middle eastern arid nations, the disruption of plant operations by red tide poses a danger to the availability of drinkable water and can constitute an extraordinary HABs impact. Desalination plants are responsible for pollutants added to the Gulf seawater via outfall systems. Consequently, desalination projects must undergo an environmental impact assessment (EIA), considering accepted environmental characteristics and criteria. EIA assesses the potential effects on air, land, and sea water qualities, techniques to mitigate their impact.

Keywords: Harmful algal blooms; Red tides; Desalination; Arabian Gulf

1. Introduction

Seawater desalination is currently the most common and preferred method in the Arabian Gulf for potable water production, and the Arabian Gulf now has the most significant number of desalination plants. The Gulf Corporation Council (GCC), encompassing Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, Bahrain, and Oman, produces roughly half of the world's desalinating the sea [1,2]. Thermal or membrane-based desalination technologies are the two main methods for seawater desalination. Thermal desalination [i.e., multiple-effect distillation (MED), multi-stage flash distillation (MSF), vapor compression (VC)] is common in oil-rich countries of the Middle East, whereas reverse osmosis (RO) membrane desalination is nearly used across the rest of the world. The most extensively used seawater desalination method is RO, produces drinking and industrial water. The increasing adoption of RO desalination

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technology has been encouraged not only by the constant rise in water demand but also by the falling cost of RO water production, and it's predicted to become more cost-effective and competitive with traditional water treatment methods [3]. In 2010, the Arabian Gulf accounted for 76% of global seawater desalination capacity. Saudi Arabia, the United States, and the United Arab Emirates (UAE) occupy the top list of countries planning substantial investments in desalination technology in 2020 with Qatar and Kuwait in the top fifteen. Between 2000 and 2010, desalination in the UAE increased by more than threefold. In 2013, MSF technology delivered roughly 75% of desalinated water, MED provided 17%, and RO produced the rest 5% [4].

A typical algal bloom is a "population explosion" of microscopic algae that are naturally occurring and caused mainly by seasonal temperature fluctuations, plenty of sunshine, and a nutrient-rich content in the water. Some algal blooms are deemed hazardous as they make harmful metabolites and organic chemicals that can cause disease/death in people and aquatic creatures. On the other hand, many dangerous algal blooms may not create poisonous substances, although the algal organic matter (AOM) and the algae biomass they produce can aggregate in high quantities near the water's surface. Bacterial decomposition of this organic component can cause a dramatic decline in oxygen content dissolved in the water, thus impacting wildlife by killing aquatic flora [5–7].

The amount of hazardous algal blooms, the types of resources impacted, and the reported economic decreases have all grown considerably during the previous few decades. Financial losses mainly impact the fishing and aquaculture sectors, although the desalination business has recently been affected as well [6,8–10].

Algae is becoming more widely recognized as a significant source of operational issues in seawater plants [11]; when harmful algal blooms (HABs) reach a desalination plant, they can pose major operational problems as well as possible health risks to customers.

These problems arise from two factors: first, algal cells create organic matter, which can clog filters and foul membranes, and second, some cells produce poisonous chemicals or taste and odor compounds, which can induce filter clogging and membrane fouling. During a severe "red tide" bloom incident in the Gulf of Oman in 2008–2009, the negative impact of algae on seawater desalination plants began to gain more attention. This "red tide" (also known as a "harmful algal bloom") caused many seawater plants in the area to minimize or cease operations [12]. This event revealed a significant issue that algal blooms could affect the countries that rely highly on desalination plants for water supply, and it emphasizes the importance of proper pre-treatment in such systems.

This review highlights the main factors that aid (harmful) algal blooms in seawater and their growth consequences on desalination plants.

2. Bloom-forming species

UNESCO's international oceanographic commission recognized over 300 species of microalgae that have been observed to create blooms in aquatic settings [13]. An algal bloom occurrence is frequently dominated by a particular species or group of algae. An algal bloom activity can last anywhere from a few days to many weeks, based on the life cycles of the causative species. Diatoms, dinoflagellates, and cyanobacteria are the three principal kinds of algae that are frequently reported to create significant blooms. However, several haptophytes, raphidophytes, and chlorophytes were often recorded (Table 1, Fig. 1).

2.1. Dinoflagellates

Dinoflagellates are bi-flagellated algae that are mainly unicellular, seldom colonial, and have red coloring. Cells of dinoflagellates vary in size from 5 to 2,000 m. Dinoflagellates are primarily photosynthetic; however, some organisms are heterotrophic. On the other hand, some photosynthesizing organisms may absorb bacteria and other algae (including other dinoflagellates as a facultative or distinctive component of their life. Dinoflagellates are better suited to make use of available nutrients than other bloom-forming species of algae [14–17].

They can move up and down the water column using their flagellates to photosynthesize during the day and take advantage of increased nutrition levels at deeper sections during the night. Asexual cell reproduction occurs by binary fission. When growth circumstances are no longer favorable, they produce copious amounts of resting cysts that sink to the bottom and remain dormant until the cysts revert to motile cells the next time growth circumstances are favorable. Dinoflagellates tend to follow diatom blooms since they reproduce more slowly than diatoms, and blooms may often linger for longer periods. *Cochlodinium polykrikoides*, *Noctiluca scintillans* and other species from the genera *Alexandrium*, *Prorocentrum abd Karenia* are among the recognized bloom-forming dinoflagellates [29,30].

2.2. Diatoms

Diatoms are yellowish brown algae that have a distinctive "glass-box" form. Each cell is surrounded by two interacting siliceous frustules, or an exoskeleton. Although their thick frustules are somewhat hefty, Diatom cells may keep buoyant by injecting light-weight ions into their cell vacuole. Diatoms flourish at the water's surface because they rely primarily on photosynthesis for energy. When nutrients are

Table 1
Common bloom-forming species of algae

Bloom-forming algae	Adverse effect	References
Dinoflagellates	Toxic bloom, red tides, oxygen depletion	[14–17]
Diatoms	Toxic bloom, oxygen depletion	[14,18–20]
Cyanobacteria	Toxic bloom, oxygen depletion	[18,21,22]
Haptophytes	Oxygen depletion	[14,23–25]
Raphidophytes	Toxic bloom, red tides, oxygen depletion	[23,26,27]
Chlorophytes	Green tides, oxygen depletion	[8,18,28]

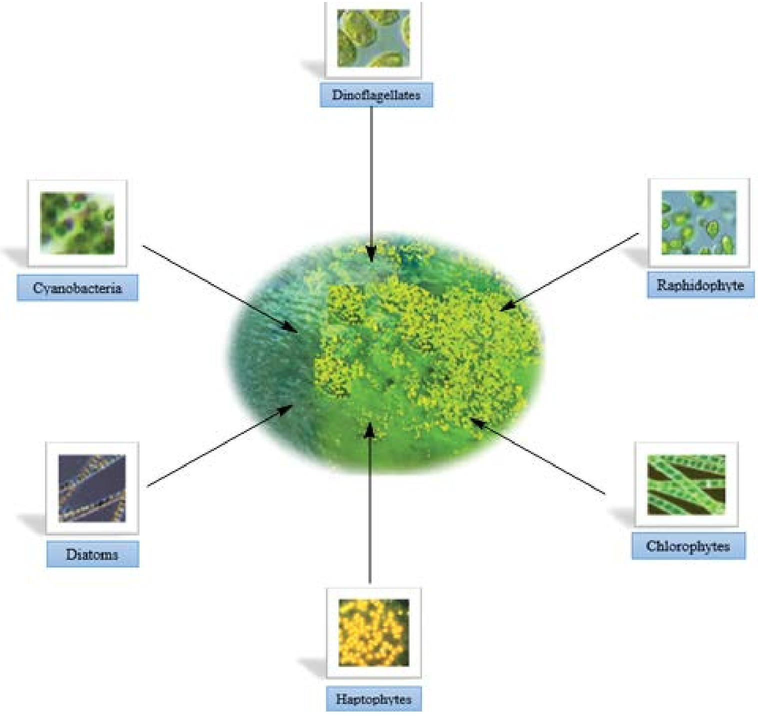

Fig. 1. Determinantal algal bloom causative species.

reduced, they frequently dive to the bottom of the body of water, where they stay until fresh food and light are available. In diatoms, asexual reproduction occurs by binary fission.

When nutrition, light, and temperature conditions are ideal, diatom blooms frequently occur around the spring season's beginning, but they are difficult to predict in other locations. The genera *Chaetoceros*, *Skeletonema*, and *Thalassiosira* are the most commonly observed bloom-forming marine diatoms. Because diatoms require silicates to construct their exoskeletons, silicate depletion is frequently indicated by the end of a bloom episode. Because diatoms are the first vital nutrients to be depleted when the first bloom occurs in spring, silicates are the first critical nutrients to be lost (in addition to oxygen reduction). In addition to nutrient depletion, a diatom bloom can be stopped by predation by other aquatic creatures like dinoflagellates.

2.3. Cyanobacteria (blue-green algae)

Cyanobacteria is a bacterium that obtains its energy from photosynthesis and is known as cyanobacteria, sometimes referred to as blue-green algae. Most cyanobacteria are obligatory phototrophs, meaning they prefer to grow in places of the water column that receive plenty of light. Their cells can be between 0.5 and 60 m, but they can also form colonies that are a few centimeters long. Like diatoms, cyanobacteria can modify their buoyancy, enabling them to move vertically through the water column. They are found in freshwater and marine settings, where they may produce seasonal blooms, and are sometimes regarded as the most successful group of bacteria worldwide. Cyanobacterial blooms may cover a large surface area and be thick [18,21,22].

2.4. Haptophytes

Massive blooms of algae in the phylum haptophytes are possible. *Emiliania huxleyi*, a frequent example, has been recorded to generate extensive blooms (up to 250,000 km^2 of surface area) in the North Sea, North Atlantic Ocean, Black Sea, and Norwegian fiords. Due to the light reflection of the calcite discs surrounding the algal cells, intense *E. huxleyi* blooms may make a large region of the water milky in color. Another noteworthy haptophyte that may regularly create blooms in coastal saltwater is *Phaeocystis*. For example, in the coastal parts of the North Sea, foam accumulation produced by *Phaeocystis* bloom is a common occurrence throughout the spring season, and it has occasionally resulted in the death of local aquatic wildlife [14,23–25].

2.5. Raphidophytes

A subtype of bi-flagellated, unicellular algae known as raphidophytes lacks rigid cell walls. They are photosynthetic autotrophs that include both saltwater species and freshwater. Toxic "red tide" blooms can be caused by a various of marine raphidophytes [23,26,27].

2.6. Chlorophytes (green algae)

Chlorophytes, sometimes called green algae, are a diverse group of phototrophic organisms ranging in size from microscopic seaweeds to unicellular algae. Green algal blooms created by many types of tiny chlorophytes are typical in stagnant freshwater bodies (e.g., lakes, and ponds). On the other hand, green algal blooms in saltwater are dominated by macroscopic chlorophytes. The seaweed *Ulva* *prolifera* generated the greatest previously recorded "green tide" event in the Yellow Sea (near Qingdao, China). Since then, such occurrences have occurred throughout the area, probably due to increased human activity [8,18,28].

3. Marine algae bloom

Cochlodinium polykrikoides Margalef, a marine ichthyotoxic dinoflagellate, is one of the taxa responsible for the ecologically and economically relevant phenomena known as harmful algal blooms (HABs), also known as "red tides". In late August 2008, spots of red water (discoloration) were first noticed in the port of Dibba Al-Hassan on the UAE's east coast. Almost two months later from the 21 to 23 of October 2008, red tide blooms and fish kills were found there; after entering the Arabian Gulf via the Strait of Hormuz, the bloom spread to the UAE, Qatar, and Iran's coastal waters. It also extended southwards across the UAE's east coast, reaching Fujairah and then Oman. The bloom was vast and extreme, impacting more than 1,200 km of coastline in the region, killing millions of wild and farmed fishes, and causing significant coral reef damage. During the bloom season, cell counts of $1.1–2.1 \times 10^7$ cells/L were reported from surface waters near Fujairah, UAE; salinity was 39 PSU at the time of the highest cell counts, and the water temperature was 27°C [12]. These blooms impacted the desalination plants in the UAE and forced five seawater desalination plants to shut down because of clogged intake filters, foul reverse osmosis membranes irreversibly, or other operational problems caused by the thick blooms [31,32]. There was also fear that red tide contaminants would end up in the finished water, which would be unsafe to drink. Coastal recreation and tourism were impacted, partly due to an unpleasant odor associated with the bloom that pervaded coastal communities, and partly due to concerns about the possible danger to swimmers. According to regional news agencies, thousands of tons of fish and marine mammals were killed; over 650 tons of dead fish have washed ashore in Dibba Al-Hassan, and over 700 tons in Khor Fakkan [31]. Traditional fishing practices were prohibited within eight miles of the UAE's eastern coast and three miles of the west coast due to the bloom [32]. Since desalination plants are the primary source of fresh water for residents, agriculture, and industry in the Arabian Gulf, the disruption of plant operations by recurrent *Cochlodinium* blooms poses a severe threat to the region's drinking water supply and is an unprecedented HAB impact. The sudden appearance of *C. polykrikoides* in the Arabian Gulf, as well as the devastating effects of the 2008–2009 bloom, highlight the need for coordinated HAB species monitoring, as well as the production and testing of protocols and/or technologies to avoid desalination plant closures during extreme HAB blooms [4,33,34].

3.1. Causative factors

For decades, scientists have been trying to figure out what causes harmful algae to grow and produce toxins. The goal of these studies was to figure out what factors in the environment cause HAB and toxin formation. The overall findings from many years of research were divided into three categories: (1) causes and conditions that lead to phytoplankton blooms in general, (2) factors that contribute to the proliferation of HAB species specifically, and (3) factors that lead to toxin production. Phytoplankton blooms develop naturally due to deep, nutrient-rich waters mixing vertically with illuminated surface waters. In temperate climates, this process happens seasonally due to winter storm events and coastal upwelling occurrences triggered by proper regional wind conditions. Although there is no reason to believe that these 'natural' sources of nutrients cannot cause HABs, the global increase in the frequency and severity of HABs suggests that human activities may be a contributing factor. Natural physicochemical variations (e.g., current, temperature, nutrient load, salinity, etc.) may significantly influence the distribution and concentration of algae in the ocean and sunlight [35]. Many trace metals and vitamins, as well as nitrogen (N), phosphorus (P), and silicon (S) are among the most significant of these influences, with two primary sources – natural and anthropogenic. Storm events can increase nutrient discharges into the sea from rivers, while strong winds can cause the mixing and transfer of nutrients from the lower water column to the surface, where algae can use them [36]. Coastal upwelling, generated by a mixture of wind, Coriolis impact, and Ekman drift, is a crucial component in nutrient delivery from the bottom to the surface [37]. Human activities can also contribute to algal blooms by raising nutrient loadings in coastal seawater through direct/indirect discharge of untreated/poorly treated wastewater and runoff of untreated livestock wastes and residual fertilizers from agricultural areas. Increased HAB incidence has been linked to rising human populations, increased fertilizer use, and increased livestock production [35,38]. Many areas worldwide have seen localized reductions in algal blooms after enacting tighter environmental legislation to restrict anthropogenic nutrient discharges to rivers, such as the Seto Inland Sea in Japan [39].

Desalination facilities produce two products: pure water and concentrated salt water (reject or residual stream). Proponents acknowledge that cost-effective and environmentally friendly concentrate handling can be significant roadblocks to the widespread adoption of desalination systems. The impact of concentrate on receiving water habitats and groundwater aquifers can be mitigated by incorporating proper concentrate disposal and construction methods into the plant's design. In SWRO plants, operational problems are mostly caused by biological development in membrane modules and the build-up of particle and organic material from saltwater [3,11]. Another factor that aids in the growth of HAB in SWRO plants is the brine discharge into the seawater if such discharge products are released into surface seawater, which includes untreated chemicals, it can cause problems for marine ecosystems and receiving water environments. In addition, due to the constant, high-quality water produced by membrane filtration, especially when compared to traditional methods, microfiltration and ultrafiltration membrane pretreatment have recently been highlighted as a component of a desirable pretreatment train. However, one significant disadvantage of implementing these modern pretreatment technologies is that they are just as susceptible to sudden algal blooms, if not even more. Therefore, desalination projects necessitate an environmental impact assessment (EIA), which must define all critical environmental criteria and determine possible impacts on the air, soil, and marine ecosystems [33].

3.1.1. Temperature

In the water ecosystem, the temperature typically plays an important role in HAB production which influences the lgTN/lgTP and lgChla relationships [40,41]. An increase in temperature could dramatically increase Chlorophyll-a concentration, implying that the marine system could establish a dominating population of cyanobacteria under warmer conditions [42], Few experimental data exist that demonstrate direct mechanistic links between rising temperatures and HAB bloom [20,43]. The temperature may also have an indirect impact on HAB physiology by influencing the optimum prey species of mixotrophic HAB species [42]. Temperature maxima, as well as the rate of seasonal temperature fluctuation, can affect the magnitude and timing of overwintering HAB stage excystment [44]. More broadly, even minor changes in HAB phenology and surface water spring transitions can affect the potential biomass of HAB species [45] changes in cellular growth rates caused by temperature can also alter cellular toxin concentrations, implying that future HAB impacts must be anticipated in terms of both HAB growth and cellular toxin production rates [46] many HAB scientists believe that, with a few exceptions, warming will increase the possibility of HAB prevalence and intensity in future oceans [47]. The majority of desalination plants in GCC countries are paired with a power plant, which means that the water temperature of the power plant's effluents will be high, raising the seawater temperature of the ambient water in the plant's proximity. In the summer, the surrounding seawater temperature is around 35°C, and power and desalination facilities raise the temperature in the area by roughly 7°C–8°C over the ambient temperature. MSF and other forms of thermal distillation have the largest impact on intake water temperature and can produce brines that are 10°C–15°C warmer than oceanic intake waters. RO procedures are becoming more popular, and they frequently result in temperature plumes in the surrounding environment. Therefore, the HAB will grow surrounding the desalination facility that warmer temperature allows algae to grow thicker and faster.

3.1.2. HABs and nutrients

Nutrients such as nitrogen (N), phosphorus (P), silicon (S) and many other trace elements and vitamins are among the most important factors that aid algal growth also carbon dioxide appears to play a role in algal blooms, and algae used carbon dioxide for photosynthesis and growth. This carbon dioxide supply helps algae grow and form dense populations by delaying the depletion of dissolved carbon dioxide in water and when there are excessive quantities of nitrogen and phosphorus in the water, the problem becomes even worse [48–50].

3.1.2.1. Nitrogen

Nitrogen dynamics in the marine system play an important role in understanding HAB biomass trends and possible toxicity. In water, N can be found in a variety of dissolved forms in water. These N forms have a variety of effects on algae and cyanobacteria populations, owing to their ability to convert different N forms into biomass and compete with other species, cyanobacteria must convert N to ammonium (NH^{4+}) within the cell before they can use it for biomass or toxin production. Ammonium is also the simplest form of nitrogen for primary producers to get and move into the cell. Nitrate and nitrite (NO^{3-}/NO^{2-}) must be actively carried into the cell and converted to ammonium, necessitating energy and micronutrients like iron. For atmospheric nitrogen gas (N_2) gas fixation performed by some HABs, this is high energy demand which can limit the size and toxicity of the bloom. Increased nitrogen concentrations usually increase algal productivity, unless the culture becomes light-limited. In addition, a previous study in 1987 proved that N is an essential nutrient for algae growth in mass culture, and productivity increased with an increase in the supply of N [48–51].

3.1.2.2. Phosphorus

Beside temperature and nitrogen, algae require phosphorus to grow, lipid biosynthesis, fatty acid output, and metabolic processes like energy transmission, signal transduction, and photosynthesis. Phosphorous is an essential nutrient that accounts for less than 1% of total algal biomass and is required in the medium at a concentration of 0.03%–0.06% to maintain algae development also it is necessary for the formation of cellular components, such as phospholipids, DNA, RNA, and ATP as well as metabolic pathways involving energy transfer and nucleic acid synthesis in microalga cells. Microalgae can absorb phosphorus in polyphosphate or orthophosphate to boost their development and nutritional value. In microalgae, polyphosphate can combine with incoming metals to produce a detoxified complex, which protects cells from metal toxicity. For example, in polyphosphate-rich circumstances, *C. reinhardtii* collected copper (Cu) and cadmium (Cd) and survived the metals' harmful effects. However, because orthophosphate (PO_4^{3}) and polyphosphate can be converted to ATP under poor dietary conditions, some microalgae may collect more phosphorus than that required for development [52,53]. The pumping of polyphosphate into the microalgae cell and the conversion of phosphorus to polyphosphate require ATP. The photosynthetic process, as well as respiration, provide energy for ATP. The optimum phosphorus content for microalgae, according to Roopnarain et al. [54], is between 0.001 and 0.179 g/L.

In any corner of the planet, a combination of nutrients and light will induce photosynthesis-capable organisms to create chlorophyll which may be monitored by satellite due to its ability to reflect green light, which is a strong indicator of the ideal geographic regions for (unfertilized) algae development [51,53,55].

3.1.2.3. Contaminants

Desalination plants are well known for being sources of potentially harmful pollutants and energy intensive and create a potential environment-harming waste called brine which is made up of concentrated salt and chemical residues [56]. The type of desalination process employed determines the characteristics of the produced brine. The impact of brine disposal was divided by Roberts et al. [57] into physiochemical and ecological aspects. The physicochemical influence is linked to salinity, temperature, and substances that could modify the receiving water's physicochemical qualities. The salt concentration in concentrate produced by seawater reverse osmosis (SWRO) facilities can be up to two times higher than the receiving water. While the concentrated product of a distillation process may only have a 10% higher salt content than the receiving water, the system mixes the concentrate with once-through cooling water to dilute the salt concentration in the distillation processes. Distillation concentrates are typically warmer, 8°C–10°C higher than ambient water. The temperature of the concentrated water from the reverse osmosis process is the same as the ambient water temperature. Every day, 11 and 20 million m^3 of desalinated water and brine effluent are produced in the Arabian Gulf (a historical "hotspot" of global desalination efforts). According to a synthesis of chemical discharge data from 21 plants in the Red Sea, desalination processes release 2,708 kg chlorine, 36 kg copper, and 9,478 kg anti-scalants per day into the Red Sea alone.

Another aspect contributing to the global rise in HABs is that we have drastically increased aquaculture activities worldwide, which inevitably leads to enhanced product quality and safety monitoring, uncovering indigenous harmful algae that were most likely present. HAB species distributions can also be affected by climate change, either directly through temperature variations or storms, or indirectly by periodic or long-term effects on oceanographic conditions, such as changes in stratification or water circulation patterns. Another key reason for the increased frequency of HAB occurrences in some areas is nutrient enrichment [57,58]. Manipulating coastal watersheds for agriculture, industry, housing, and recreation has resulted in much higher nutrient loadings in coastal seas, promoting HABs. Nutrient enrichment of such systems frequently results in excess organic matter production (eutrophication) and increase in the frequency and amplitude of phytoplankton blooms, including HABs. There is no doubt that this is happening in some parts of the world where pollution levels have skyrocketed. The Arabian Gulf, surrounded by many desalination plants, is likewise plagued by nutrient contamination and eutrophication [59]. As a result, it's no wonder that HABs are becoming more common in the Gulf, with cases documented from practically every region [60–63]. Mariculture, for example, caused a HAB crisis in Kuwait Bay in 1999, which killed captive and wild fish [64].

4. Effect of HAB on desalination plants

During HAB episodes, there were fouling difficulties in the SWRO facility.

4.1. Fouling in SWRO desalination plants

During algal blooms, the high AOM content in raw water can cause fouling issues in both the pre-treatment and RO systems of an SWRO desalination plant. RO membranes are primarily intended to remove dissolved components from water, most notably inorganic ions (dissolved salts). Membrane systems can become blocked and polluted [65]. Fouling occurs as a result of particle deposition and/or bacterial growth on the membrane surface, resulting in an increase in hydraulic resistance. Typically, this resistance is accounted for by raising the input pressure, and membranes are then chemically cleaned in situ [66,67].

TEPs with a high charge density that are formed during HABs can adhere to and aggregate on the surface of the SWRO membranes and spacers. TEPs accumulated may operate as a "conditioning layer," providing a favorable substrate for efficient attachment and initial colonization by bacteria, which may then speed up biofilm formation. TEPs are also (partially) biodegradable and can be utilized as a bacterial substrate [68,69].

4.2. HAP effect on thermal desalination plants

In the Middle East, the most often used technologies for desalinating saltwater for municipal usage and drinking water supply are MSF and MED. MSF and MED thermal desalination contribute to 60% of the region's total saltwater desalinated capacity (20 $mm^3 \cdot d$) [70,71]. Thermal desalination facilities have been found to be influenced by seaweed (microalgae) blinding of input screens but are normally highly forgiving of source water quality in contrast to SWRO desalination facilities, phytoplankton blooms have negligible effect on thermal desalination plants [72,73].

During the Gulf of Mexico's lengthy algal bloom in 2008, the high quantity of the marine dinoflagellate *Cochlodinium polykrikoides* had no influence on thermal plants (Tang and Gobler [74]). The MSF plants at Fujairah 1 in the UAE continued to run normally, while the SWRO desalination plant had to be shut down for more than a week. A temporary shutdown of thermal desalination facilities in Sharjah, UAE (less than 24 h) occurred owing to odor concerns with the product water. This was addressed by increasing chlorination. Another thermal desalination facility (MED) on Kish Island in Iran experienced higher saltwater pH during the bloom, necessitating additional treatment operations to avoid alkaline scaling [75].

5. General HAB control strategy

According to studies, the dynamics and consequences of HABs are typically controlled by physiological responses of the causative dinoflagellate to local environmental circumstances, as well as interactions between biological and physical processes that occur at multiple temporal and geographical dimensions [75,76]. HAB-producing dinoflagellates have been demonstrated to be sensitive to physical and chemical changes in the environment, such as temperature and salt. In reaction to environmental stressors, dinoflagellates frequently develop either permanent or transitory cysts that gradually settle out of the water column. Dinoflagellates adopt temporary encystment as a survival strategy to respond to short-term or large-scale environmental changes. A variety of variables impact the formation of a temporary cyst, including variations in salinity; temperature changes, light; nutrient depletion; and dissolved oxygen changes [20,77,78].

5.1. Salinity level

All dinoflagellate species have a limited range of salt tolerance. A floating desalination plant's hypersaline and hyposaline discharges can both exceed the upper and lower limits of this salinity tolerance range. Discharges in highly stratified waters may be sufficient to violate these tolerance limits. It could not, for example, be acclimated to salinities more than 45 practical salinity units (PSU); it could not be acclimated to salinities less than 25 PSU, and it grew poorly at salinities greater than 36 PSU when associated with water temperatures greater than 23°C. Hypersaline discharges from desalination plants can produce salinities greater than the maximum limit, whereas hyposaline discharges can produce salinities less than the minimum [79–81].

Although a water pumping facility cannot reach the extremes of a desalination plant, considerable salinity changes can be produced. The salinity of desalination plant outputs may be strong enough to harm other marine species. The salinity of the discharges, on the other hand, may be changed to perturb the HAB without killing other marine organisms [57,78].

5.2. Temperature level

A desalination plant that uses a distillation process that is fueled by heating the water would produce water discharges that could be significantly higher than the temperature limitations permitted by the species constituting a HAB. For example, in laboratory trials, all attempts to raise the water temperature over 30°C resulted in the death of *Karenia brevis* cells. Furthermore, *Karenia brevis* did not grow well in water with a salinity greater than 36 psu and a temperature higher than 23°C. As a result, hot discharges, either alone or in conjunction with changed salinity levels, may disrupt HABs at temperatures and salinities that do not induce mortality in other marine creatures [79].

A water pumping facility may be able to modify the water temperature sufficiently without the requirement for desalination by pumping water in from one side of a thermocline and dumping the water into the other side of the thermocline. As with salinity, a worry with desalination plant outputs is that the water temperature may be high enough to kill other marine creatures. The temperature of the discharges, like salinity, can be controlled to levels that disrupt the HAB without causing death in other marine organisms [82].

6. Desalination strategy to overcome HAB

Strict planning and monitoring are required for desalination plants to function properly. The location of desalination plants should be carefully chosen and away from residential areas, particularly if future expansions are planned. The challenges encountered by existing facilities were typically attributed to poor planning or less detailed environmental impact assessments. Authorities should conduct feasibility and environmental impact assessments of the proposed desalination facility and site. Current plants have prompted concerns about noise pollution, visual pollution, reduced recreational fishing and swimming areas, material emissions into the atmosphere, and, most importantly, pollution caused by product discharge and disposal practices [83]. The concentrate is predominantly composed of brine with concentrations up to twice those of seawater. This discharge also contains cleaning chemical residues as well as any anticorrosion agents used in the facility. This discharge concentration must be treated before release to proper levels of each chemical; however, allowed amounts may vary depending on recipient waterways and state laws. Disposal is frequently carried out on surface waterways, sometimes by surface piping and occasionally via underground pipe. In any case, the high density of such discharge reaches the receiving waters' lowest levels, potentially harming marine life, especially in the bottom layers or borders. The long-term consequences of such discharge concentrations are unknown [84,85].

It is advantageous to utilize some of the control monitoring methods that can aid the detection and monitoring of red tide outbreaks and the algal biomass. Microfiltration (MF) and ultrafiltration (UF) had been utilized as pretreatment scales to typically eliminate the intracellular toxic metabolites via size exclusion of the HAB cells and subsequent intracellular toxin abstraction [75]. Moreover, molecular-based techniques could provide significant progress in monitoring causal HABs in the general outlook. However, the initial treatment system and/or the intake must also be trustworthy and durable to guarantee performing issues to diminish breakthroughs of growth products relating to red tide-forming algae to downstream desalination process. Typical molecular probes have been expanded for the swift revelation and recording of many HAB species; but these probes are overwhelmingly either short segments of DNA or antibodies that are specified for the studied HAB species. Nowadays, oligonucleotide probes have been utilized to mark HAB species using synthetic, short DNA that electively links to sequences specified for a particular organism [86]. Quantitative polymerase chain reaction (qPCR) had provided a useful quantification gadget in setting the typical ratio of toxic and non-toxic genotypes in mischievous algal blooms and could provide immediate relief alleviating their environmental, and economic impacts, including fitting the appropriate caution of HABs approach [87–90]. The preliminary environmental impact assessment should be comprehensive enough to identify critical parameters for monitoring throughout discharge processes. It should also recommend ongoing monitoring utilizing devices linked to structures developed during plant construction.

7. Conclusion

Desalination plant managers are facing many challenges due to the highly variable HABs with regard to bloom dynamics, morphology, toxicity, and cell size. These variations need to be realized when implementing or promoting mitigation measures. Nutrient-rich content has been linked to detrimental blooms in many protected bays, although the link between human-mediated nutrient flows and many HAB episodes is yet unknown. Of course, the value of nutrient discharge into coastal waters is contingent on the number of nutrients available for phytoplankton growth from natural sources. Before effective models for predicting toxic occurrences can be developed, further research is needed. This is because we need a full understanding of the exact components and circumstances that favor detrimental algal blooms and toxin production in coastal waters. Until then, effective monitoring tools to detect impending bloom occurrences and the ability to trace the progress of an active bloom, as well as an understanding of the possible toxins produced, their chemistry, and their rejection by seawater reverse osmosis membranes, are required. The by-product is commonly referred to as the concentrate, and it predominantly comprises brine, often in amounts up to double that of saltwater. In addition, this discharge contains residues of cleaning chemicals, as well as any anti-corrosion compounds employed in the plant. Before being discharged, this discharge concentrate must be processed to achieve acceptable amounts of each chemical, which may vary based on the receiving waters and state requirements. Most of the disposal is done in surface waters, sometimes with surface pipes and sometimes with subsurface plumbing. In either case, the high density of the discharge reaches the receiving waters' bottom layers, potentially affecting marine life, particularly in the base layers or borders. The long-term impacts of such discharge concentrates have not been studied, but it is plausible that even small amounts of toxic compounds employed in the desalination process cleaning could harm marine species and the ecosystem in general. There are a variety of methods for detecting HABs and reacting in time to limit their impact on desalination plants. To achieve this goal, local and regional phytoplankton composition and monitoring are required. A variety of strategies are advised for such monitoring such as water sampling near or at the desalination plant on a regular basis. This could include manual sampling in the plant's water supply or samples from adjacent ships and boats. Automated sampling of the water entering a plant, or on fixed platforms located outside the intake. Operators and managers of desalination plants are being advised to take a more active role in understanding the nature of the algae populations in the waters surrounding their intakes. This can directly aid in the discovery of early and effective mitigation methods.

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Conflict of interests

The authors declare no conflict of interest.

References

[1] C. Amante, B.W. Eakins, ETOPO1 Global Relief Model converted to PanMap Layer Format, NOAA-National Geophysical Data Center, PANGAEA, 2009.

[2] S. Lattemann, T. Höpner, Environmental impact and impact assessment of seawater desalination, Desalination, 220 (2008) 1–15.

[3] L.O. Villacorte, S.A.A. Tabatabai, N. Dhakal, G. Amy, J.C. Schippers, M.D. Kennedy, Algal blooms: an emerging threat to seawater reverse osmosis desalination, Desal. Water Treat., 55 (2015) 2601–2611.

[4] E.K. Paleologos, M.T. Al Nahyan, S. Farouk, Risks and threats of desalination in the Arabian Gulf, IOP Conf. Ser.: Earth Environ. Sci., 191 (2018) 012008, doi: 10.1088/1755-1315/191/1/012008.

[5] E. Zohdi, M. Abbaspour, Harmful algal blooms (red tide): a review of causes, impacts and approaches to monitoring and prediction, Int. J. Environ. Sci. Technol., 16 (2019) 1789–1806.

[6] J.M. Burkholder, Harmful Algal Blooms, G.E. Likens, Ed., Encyclopedia of Inland Waters, Academic Press, Oxford, 2009, pp. 264–285.

[7] Y.S. Li, X. Chen, O.W. Wai, B. King, Study on the dynamics of algal bloom and its influence factors in Tolo Harbour, Hong Kong, Water Environ. Res., 76 (2004) 2643–2654.

[8] S.B. Watson, B.A. Whitton, S.N. Higgins, H.W. Paerl, B.W. Brooks, J.D. Wehr, Chapter 20 – Harmful Algal Blooms, J.D. Wehr, R.G. Sheath, J.P. Kociolek, Eds., Freshwater Algae of North America (Second Edition), Academic Press, Boston, 2015, pp. 873–920.

[9] S. McGowan, Chapter 2 – Algal Blooms, in Biological and Environmental Hazards, Risks, and Disasters, J.F. Shroder, R. Sivanpillai, Eds., Academic Press, Boston, 2016, pp. 5–43.

[10] R.M. Kudela, A. Bickel, M.L. Carter, M.D.A. Howard, L. Rosenfeld, The Monitoring of Harmful Algal Blooms Through Ocean Observing: The Development of the California Harmful Algal Bloom Monitoring and Alert Program, Y. Liu, H. Kerkering, R.H. Weisberg, Eds., Coastal Ocean Observing Systems, Elsevier Inc., 2015, pp. 58–75.

[11] D.A. Caron, M.-È. Garneau, E. Seubert, M.D.A. Howard, L. Darjany, A. Schnetzer, I. Cetinić, G. Filteau, P. Lauri, B. Jones, S. Trussell, Harmful algae and their potential impacts on desalination operations off southern California, Water Res., 44 (2010) 385–416.

[12] M.L. Richlen, S.L. Morton, E.A. Jamali, A. Rajan, D.M. Anderson, The catastrophic 2008–2009 red tide in the Arabian Gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate *Cochlodinium polykrikoides*, Harmful Algae, 9 (2010) 163–172.

[13] IOC-UNESCO, What are Harmful Algae?, 2013, Retrieved January 2022. Available at: http://hab.iocunesco.org/.

[14] R.-C. Yu, S.-H. Lü, Y.-B. Liang, Harmful Algal Blooms in the Coastal Waters of China, P.M. Glibert, E. Berdalet, M.A. Burford, G.C. Pitcher, M. Zhou, Eds., Global Ecology and Oceanography of Harmful Algal Blooms, Springer International Publishing, Cham, 2018, pp. 309–316.

[15] H. Ben Gharbia, O. Kéfi-Daly Yahia, P. Cecchi, E. Masseret, Z. Amzil, F. Herve, G. Rovillon, H. Nouri, C. M'Rabet, D. Couet, H. Zmerli Triki, M. Laabir, New insights on the species-specific allelopathic interactions between macrophytes and marine HAB dinoflagellates, PLoS One, 12 (2017) e0187963, doi: 10.1371/journal.pone.0187963.

[16] R.M. Kudela, C.J. Gobler, Harmful dinoflagellate blooms caused by *Cochlodinium* sp.: global expansion and ecological strategies facilitating bloom formation, Harmful Algae, 14 (2012) 71–86.

[17] A. Kremp, T. Tamminen, K. Spilling, Dinoflagellate bloom formation in natural assemblages with diatoms: nutrient competition and growth strategies in Baltic spring phytoplankton, Aquat. Microb. Ecol., 50 (2008) 181–196.

[18] N. Kashulin, T. Kashulina, A. Bekkelund, Long-term eutrophication and dynamics of bloom-forming microbial communities during summer HAB in large arctic lake, Environments, 8 (2021) 82, doi: 10.3390/environments8080082.

[19] B. Durán-Vinet, K. Araya-Castro, T.C. Chao, S.A. Wood, V. Gallardo, K. Godoy, M. Abanto, Potential applications of CRISPR/Cas for next-generation biomonitoring of harmful algae blooms: a review, Harmful Algae, 103 (2021) 102027, doi: 10.1016/j.hal.2021.102027.

[20] M.L. Wells, V.L. Trainer, T.J. Smayda, B.S.O. Karlson, C.G. Trick, R.M. Kudela, A. Ishikawa, S. Bernard, A. Wulff, D.M. Anderson, W.P. Cochlan, Harmful algal blooms and climate change: learning from the past and present to forecast the future, Harmful Algae, 49 (2015) 68–93.

[21] S.E. Papoulis, S.W. Wilhelm, D. Talmy, E.R. Zinser, Nutrient loading and viral memory drive accumulation of restriction modification systems in bloom-forming cyanobacteria, mBio, 12 (2021) e0087321, doi: 10.1128/mBio.00873-21.

[22] H.K. Hudnell, Q. Dortch, A Synopsis of Research Needs Identified at the Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms (ISOC-HAB), H.K. Hudnell, Ed., Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs, Springer New York, New York, NY, 2008, pp. 17–43.

[23] S. Sakamoto, W.A. Lim, D. Lu, X. Dai, T. Orlova, M. Iwataki, Harmful algal blooms and associated fisheries damage in East Asia: current status and trends in China, Japan, Korea and Russia, Harmful Algae, 102 (2021) 101787, doi: 10.1016/j.hal.2020.101787.

[24] R.I. Figueroa, M. Estrada, E. Garcés, Life histories of microalgal species causing harmful blooms: haploids, diploids and the relevance of benthic stages, Harmful Algae, 73 (2018) 44–57.

[25] D.L. Roelke, R.H. Pierce, Effects of inflow on harmful algal blooms: some considerations, J. Plankton Res., 33 (2010) 205–209.

[26] I. Imai, Interactions Between Harmful Algae and Algicidal and Growth-Inhibiting Bacteria Associated with Seaweeds and Seagrasses, S. Ohtsuka, T. Suzaki, T. Horiguchi, N. Suzuki, F. Not, Eds., Marine Protists: Diversity and Dynamics, Springer Japan, Tokyo, 2015, pp. 597–619.

[27] L. Peperzak, Climate change and harmful algal blooms in the North Sea, Acta Oecologica, 24 (2003) S139–S144.

[28] M.P. Nolan, B.J. Cardinale, Species diversity of resident green algae slows the establishment and proliferation of the cyanobacterium *Microcystis aeruginosa*, Limnologica, 74 (2019) 23–27.

[29] C.J. Gobler, W.G. Sunda, Ecosystem disruptive algal blooms of the brown tide species, *Aureococcus anophagefferens* and *Aureoumbra lagunensis*, Harmful Algae, 14 (2012) 36–45.

[30] D.M. Anderson, E. Fensin, C.J. Gobler, A.E. Hoeglund, K.A. Hubbard, D.M. Kulis, J.H. Landsberg, K.A. Lefebvre, P. Provoost, M.L. Richlen, J.L. Smith, A.R. Solow, V.L. Trainer, Marine harmful algal blooms (HABs) in the United States: history, current status and future trends, Harmful Algae, 102 (2021) 101975, doi: 10.1016/j.hal.2021.101975.

[31] T. Pankrantz, Red Tide Close Desalination Plants, Water Desalination Report, 2008. Available at: www.desalination.com/wdr/44/44/red-tides-close-desal-plants

[32] A. Berktay, Environmental approach and influence of red tide to desalination process in the Middle East Region, Int. J. Chem. Environ. Eng., 2 (2011) 183–188.

[33] H.D. Ibrahim, E.A.B. Eltahir, Impact of brine discharge from seawater desalination plants on Persian/Arabian Gulf salinity, J. Environ. Eng., 145 (2019) 04019084, doi: 10.1061/(ASCE)EE.1943-7870.0001604.

[34] L. Wonhyun, M.K. James, Effects of desalination on hydrodynamic process in Persian Gulf, Coastal Eng. Proc., 1 (2018), doi: 10.9753/icce.v36.papers.3.

[35] K.G. Sellner, G.J. Doucette, G.J. Kirkpatrick, Harmful algal blooms: causes, impacts and detection, J. Ind. Microbiol. Biotechnol., 30 (2003) 383–406.

[36] B.M. Smith, P.J. Morrissey, J.E. Guenther, J.A. Nemson, M.A. Harrison, J.F. Allen, A. Melis, Response of the photosynthetic apparatus in *Dunaliella salina* (green algae) to irradiance stress, Plant Physiol., 93 (1990) 1433–1440.

[37] A. Bakun, Global climate change and intensification of coastal ocean upwelling, Science, 247 (1990) 198–201.

[38] O. De Clerck, H.R. Engledow, J.J. Bolton, R.J. Anderson, E. Coppejans, Twenty marine benthic algae new to South Africa, with emphasis on the flora of Kwazulu-Natal, 45 (2002) 413–431.

[39] T. Okaichi, Red Tide Problem in the Seto Inland Sea, Japan, T. Okaichi, D.M. Anderson, T. Nemoto, Eds., Red Tides: Biology, Environmental Science, and Toxicology, Proc. 1st Int. Symposium on Red Tides, Elsevier, Japan, 1989, pp. 131–136.

[40] L. Aljerf, Biodiversity is key for more variety for better society, Biodivers. Int. J., 1 (2017) 4–7.

[41] J. Wang, F. Pan, J. Soininen, J. Heino, J. Shen, Nutrient enrichment modifies temperature-biodiversity relationships in large-scale field experiments, Nat. Commun., 7 (2016) 13960, doi: 10.1038/ncomms13960.

[42] Y. Li, D. Li, Competition between toxic *Microcystis aeruginosa* and nontoxic *Microcystis wesenbergii* with Anabaena PCC7120, J. Appl. Phycol., 24 (2012) 69–78.

[43] A.J. Lewitus, R.A. Horner, D.A. Caron, E. Garcia-Mendoza, B.M. Hickey, M. Hunter, D.D. Huppert, R.M. Kudela, G.W. Langlois, J.L. Largier, E.J. Lessard, R. RaLonde, J.E. Jack Rensel, P.G. Strutton, V.L. Trainer, J.F. Tweddle, Harmful algal blooms along the North American west coast region: history, trends, causes, and impacts, Harmful Algae, 19 (2012) 133–159.

[44] A.D. Fischer, M.L. Brosnahan, D.M. Anderson, Quantitative response of *Alexandrium catenella* cyst dormancy to cold exposure, Protist, 169 (2018) 645–661.

[45] D.J. McGillicuddy Jr., D.W. Townsend, R. He, B.A. Keafer, J.L. Kleindinst, Y. Li, J.P. Manning, D.G. Mountain, M.A. Thomas, D.M. Anderson, Suppression of the 2010 *Alexandrium fundyense* bloom by changes in physical, biological, and chemical properties of the Gulf of Maine, Limnol. Oceanogr., 56 (2011) 2411–2426.

[46] L. Basti, H. Uchida, R. Matsushima, R. Watanabe, T. Suzuki, T. Yamatogi, S. Nagai, Influence of temperature on growth and production of pectenotoxin-2 by a monoclonal culture of *Dinophysis caudata*, Mar. Drugs, 13 (2015) 7124–7137.

[47] C.J. Gobler, O.M. Doherty, T.K. Hattenrath-Lehmann, A.W. Griffith, Y. Kang, R.W. Litaker, Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans, Proc. Natl. Acad. Sci., 114 (2017) 4975–4980.

[48] P.M. Glibert, Eutrophication, harmful algae and biodiversity – challenging paradigms in a world of complex nutrient changes, Mar. Pollut. Bull., 124 (2017) 591–606.

[49] N. Ji, Z. Zhang, J. Huang, L. Zhou, S. Deng, X. Shen, S. Lin, Utilization of various forms of nitrogen and expression regulation of transporters in the harmful alga *Heterosigma akashiwo* (*Raphidophyceae*), Harmful Algae, 92 (2020) 101770, doi: 10.1016/j.hal.2020.101770.

[50] R.M. Kudela, J.Q. Lane, W.P. Cochlan, The potential role of anthropogenically derived nitrogen in the growth of harmful algae in California, USA, Harmful Algae, 8 (2008) 103–110.

[51] A.N. Sharpley, S.J. Smith, J.W. Naney, Environmental impact of agricultural nitrogen and phosphorus use, J. Agric. Food Chem., 35 (1987) 812–817.

[52] J.A. Borchardt, H.S. Azad, Biological extraction of nutrients, J. Water Pollut. Control Fed., 40 (1968) 1739–1754.

[53] S.T. Larned, Nitrogen- versus phosphorus-limited growth and sources of nutrients for coral reef macroalgae, Mar. Biol., 132 (1998) 409–421.

[54] A. Roopnarain, V.M. Gray, S.D. Sym, Phosphorus limitation and starvation effects on cell growth and lipid accumulation in *Isochrysis galbana* U4 for biodiesel production, Bioresour. Technol., 156 (2014) 408–411.

[55] Y. Chisti, Biodiesel from microalgae, Biotechnol. Adv., 25 (2007) 294–306.

[56] A. Panagopoulos, K.-J. Haralambous, Environmental impacts of desalination and brine treatment - challenges and mitigation measures, Mar. Pollut. Bull., 161 (2020) 111773, doi: 10.1016/j.marpolbul.2020.111773.

[57] D.A. Roberts, E.L. Johnston, N.A. Knott, Impacts of desalination plant discharges on the marine environment: a critical review of published studies, Water Res., 44 (2010) 5117–5128.

[58] P.M. Glibert, M. Zhou, M. Zhu, M.A. Burford, Preface to the special issue on eutrophication and HABs: the GEOHAB approach, Chin. J. Oceanol. Limnol., 29 (2011) 719–723.

[59] C. Sheppard, M. Al-Husiani, F. Al-Jamali, F. Al-Yamani, R. Baldwin, J. Bishop, F. Benzoni, E. Dutrieux, N.K. Dulvy, S.R.V. Durvasula, D.A. Jones, R. Loughland, D. Medio, M. Nithyanandan, G.M. Pilling, I. Polikarpov, A.R.G. Price, S. Purkis, B. Riegl, M. Saburova, K.S. Namin, O. Taylor, S. Wilson, K. Zainal, The Gulf: a young sea in decline, Mar. Pollut. Bull., 60 (2010) 13–38.

[60] A. Al-Azri, S. Piontkovski, K. Al-Hashmi, H. Al-Gheilani, H. Al-Habsi, S. Al-Khusaibi, N. Al-Azri, The occurrence of algal blooms in Omani coastal waters, Aquat. Ecosyst. Health Manage., 15 (2012) 56–63.

[61] M.S. D'Silva, A.C. Anil, R.K. Naik, P.M. D'Costa, Algal blooms: a perspective from the coasts of India, Nat. Hazards, 63 (2012) 1225–1253.

[62] H. Saeedi, E. Kamrani, K. Matsuoka, Catastrophic impact of red tides of *Cochlodinium polykrikoides* on the Razor Clam *Solen dactylus* in coastal waters of the Northern Persian Gulf, J. Persian Gulf (Mar. Sci.), 2 (2011) 13–20.

[63] M. Thangaraja, A. Al-Aisry, L. Al-Kharusi, Harmful algal blooms and their impacts in the middle and outer ROPME sea area, Int. J. Oceans Oceanogr., 2 (2007) 85–98.

[64] P.M. Glibert, J.H. Landsberg, J.J. Evans, M.A. Al-Sarawi, M. Faraj, M.A. Al-Jarallah, A. Haywood, S. Ibrahem, P. Klesius, C. Powell, C. Shoemaker, A fish kill of massive proportion in Kuwait Bay, Arabian Gulf, 2001: the roles of bacterial disease, harmful algae, and eutrophication, Harmful Algae, 1 (2002) 215–231.

[65] R.H. Idais, A.A. Abuhabib, S. Hamzah, Recent Advances in Measuring and Controlling Biofouling of Seawater Reverse Osmosis SWRO: A Review, M. Ince, O.K. Ince, Eds., Osmotically Driven Membrane Processes., IntechOpen, 2021.

[66] A. Alkhatib, M.A. Ayari, A.H. Hawari, Fouling mitigation strategies for different foulants in membrane distillation, Chem. Eng. Process. Process Intensif., 167 (2021) 108517, doi: 10.1016/j.cep.2021.108517.

[67] T. Nguyen, F.A. Roddick, L. Fan, Biofouling of water treatment membranes: a review of the underlying causes, monitoring techniques and control measures, Membranes (Basel), 2 (2012) 804–840.

[68] L.O. Villacorte, M.D. Kennedy, G.L. Amy, J.C. Schippers, The fate of transparent exopolymer particles (TEP) in integrated membrane systems: removal through pre-treatment processes and deposition on reverse osmosis membranes, Water Res., 43 (2009) 5039–5052.

[69] L.O. Villacorte, Y. Ekowati, H.N. Calix-Ponce, V. Kisielius, J.M. Kleijn, J.S. Vrouwenvelder, J.C. Schippers, M.D. Kennedy, Biofouling in capillary and spiral wound membranes facilitated by marine algal bloom, Desalination, 424 (2017) 74–84.

[70] N. Kress, Marine Environmental Impact of Seawater Desalination: Science, Management, and Policy. Elsevier Inc., Amsterdam, 2019.

[71] A.J. Toth, Modelling and optimisation of multi-stage flash distillation and reverse osmosis for desalination of saline process wastewater sources, Membranes, 10 (2020) 265, doi: 10.3390/membranes10100265.

[72] S.F.E. Boerlage, M.B. Dixon, D.M. Anderson, Case Histories for Harmful Algal Blooms in Desalination, D.M. Anderson, S.F.E. Boerlage, M.B. Dixon, Eds., Harmful Algal Blooms (HABs) and Desalination: A Guide to Impacts, Monitoring and Management, Intergovernmental Oceanographic Commission of UNESCO, Paris, France, 2017, pp. 333–464 (IOC Manuals and Guides No. 78).

[73] P.K. Abdul Azis, I. Al-Tisan, M. Al-Daili, T.N. Green, A.G.I. Dalvi, M.A. Javeed, Effects of environment on source water for desalination plants on the eastern coast of Saudi Arabia, Desalination, 132 (2000) 29–40.

[74] Y.Z. Tang, C.J. Gobler, Allelopathic effects of Cochlodinium polykrikoides isolates and blooms from the estuaries of Long Island, New York, on co-occurring phytoplankton, Mar. Ecol. Prog. Ser., 406 (2010) 19–31.

[75] D.M. Anderson, S.F.E. Boerlage, M.B. Dixon, Harmful Algal Blooms (HABs) and Desalination: A Guide to Impacts, Monitoring and Management (IOC Manuals and Guides No. 78). Intergovernmental Oceanographic Commission of UNESCO, Paris, France, 2017.

[76] D.M. Anderson, A.D. Cembella, G.M. Hallegraeff, Progress in understanding harmful algal blooms: paradigm shifts and new technologies for research, monitoring, and management, Ann. Rev. Mar. Sci., 4 (2012) 143–176.

[77] M.L. Brosnahan, A.D. Fischer, C.B. Lopez, S.K. Moore, D.M. Anderson, Cyst-forming dinoflagellates in a warming climate, Harmful Algae, 91 (2020) 101728, doi: 10.1016/j.hal.2019.101728.

[78] G.S. Committee, Guidelines for the Study of Climate Change Effects on HABs, UNESCO-IOC/SCOR, Paris, France, 2021, 120pp (IOC Manuals and Guides No. 188).

[79] K.C. Owen, J.L. Owen, Floating desalination and water pumping plants as harmful algal bloom control technologies, J. Mar. Sci.: Res. Dev., 3 (2013) 140, doi: 10.4172/2155-9910.1000140.

[80] K. Rengefors, R. Logares, J. Laybourn-Parry, R.J. Gast, Evidence of concurrent local adaptation and high phenotypic plasticity in a polar microeukaryote, Environ. Microbiol., 17 (2015) 1510–1519.

[81] A. Oren, Cyanobacteria in hypersaline environments: biodiversity and physiological properties, Biodivers. Conserv., 24 (2015) 781–798.

[82] K. Cho, M. Ueno, Y. Liang, D. Kim, T. Oda, Generation of reactive oxygen species (ROS) by harmful algal bloom (HAB)-forming phytoplankton and their potential impact on surrounding living organisms, Antioxidants (Basel), 11 (2022) 206, doi: 10.3390/antiox11020206.

[83] T.M. Missimer, R.G. Maliva, Environmental issues in seawater reverse osmosis desalination: intakes and outfalls, Desalination, 434 (2018) 198–215.

[84] Y. Belkacem, R. Benfares, A. Adem, F. Houma Bachari, Evaluation of the impact of the desalination plant on the marine environment: case study in Algeria, LARHYSS J., 14 (2017) 317–331.

[85] J. Leong, J. Tan, J. Charrois, B.P. Ladewig, Review of high recovery concentrate management options, Desal. Water Treat., 52 (2014) 7609–7627.

[86] G.F. Alotaibia, R.S. Alasmari, A.N. Alzowaid, A review of harmful algal blooms (HABs) and their potential impacts on desalination facilities, Desal. Water Treat., 252 (2022) 1–17.

[87] T.A. Lee, G. Rollwagen-Bollens, S.M. Bollens, J.J. Faber-Hammond, Environmental influence on cyanobacteria abundance and microcystin toxin production in a shallow temperate lake, Ecotoxicol. Environ. Saf., 114 (2015) 318–325.

[88] D. Anderson, HABs in a changing world: a perspective on harmful algal blooms, their impacts, and research and management in a dynamic era of climactic and environmental change, Harmful Algae, 2012 (2012), 2014 (2012) 3–17.

[89] E.V. Hull, Climate change and harmful algal blooms: legal and policy responses to protect human health, marine environments, and coastal economies, NYU Envtl. LJ, 29 (2021) 59–117.

[90] G.A. Tularam, M. Ilahee, Environmental concerns of desalinating seawater using reverse osmosis, J. Environ. Monit.: JEM, 9 (2007) 805–813.