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Review

Marine health of the Arabian Gulf: Drivers of pollution and assessment approaches focusing on desalination activities

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ABSTRACT

The Arabian Gulf is one of the most adversely affected marine environments worldwide, which results from combined pollution drivers including climate change, oil and gas activities, and coastal anthropogenic disturbances. Desalination activities are one of the major marine pollution drivers regionally and internationally. Arabian Gulf countries represent a hotspot of desalination activities as they are responsible for nearly 50% of the global desalination capacity. Building desalination plants, up-taking seawater, and discharging untreated brine back into the sea adversely affects the biodiversity of the marine ecosystems. The present review attempted to reveal the potential negative effects of desalination plants on the Gulf's marine environments. We emphasised different conventional and innovative assessment tools used to assess the health of marine environments and evaluate the damage exerted by desalination activity in the Gulf. Finally, we suggested effective management approaches to tackle the issue including the significance of national regulations and regional cooperation.

1. Introduction

Marine environments are highly valuable as they host productive ecosystems. These ecosystems provide important goods (e.g. consumable fish, water, and raw materials) and services (e.g. tourism, flood and pollution control, and transportation) for humans (Barbier, 2017). However, marine environments are being continuously altered under the action of different stressors, such as climate change, anthropogenic disturbance, and chemical contamination (Chapman, 2017). Marine pollution and the introduction of exogenous substances have the potential to affect water quality, harm various marine organisms, and affect human health (Beiras, 2018). Therefore, marine ecosystems are currently highly threatened because of marine pollution (Baztan et al., 2016).

The concerns with marine pollution are highly significant because different forms of pollution input to the marine environment lead to changes in the physiochemical and biological properties of the sea, which consequently alter its ecosystems affecting the health and diversity of organisms (Wowk, 2013). A recent study revealed that both biomass-specific primary production and chlorophyll content were significantly reduced due to heavy fuel oil pollution (Lemcke et al., 2019). Furthermore, increasing nutrient concentration in the Gulf of Mexico promoted eutrophication followed by acidification affecting marine ecosystems (Laurent et al., 2017).

Desalination activities are important drivers of marine pollution especially in the Arabian Gulf owing to the high dependency on desalination processes to produce freshwater (Sharifinia et al., 2019). According to Ibrahim and Eltahir (2019), nearly 50% of worldwide seawater desalination is processed in the countries surrounding the Arabian Gulf including Kingdom of Saudi Arabia, Emirates, Kuwait, Qatar, and Bahrain. Desalination processes harm marine habitats owing to the construction of plants, water intake, and brine discharge altering community composition and loss of biodiversity (Sharifinia et al., 2019). Desalination activity in the Arabian Gulf is an emerging issue that must be investigated. Thus, we herein reviewed the most important drivers of pollution in the Arabian Gulf with particular emphasis on desalination plants and their effect on marine health. We also reviewed the different methods that can be used to assess marine health. Finally, several management approaches were proposed to minimise the negative effects of desalination plants in the region.

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2. Drivers of pollution affecting marine health in the Arabian Gulf

The continuous variation in sea temperature and high salinity exert natural stress on the marine environment of the Arabian Gulf (Naser, 2017). According to Joydas et al. (2015), water temperature increases to as high as 36 °C during hot periods of summer and as low as 15 °C in winter, with a salinity that could surpass 43 ppt. Human activities exert an even higher level of stress on the marine environment. In fact, the Arabian Gulf is one of the most anthropogenically affected regions (Halpern et al., 2008). The increasing pollution in the Arabian Gulf poses a great threat to marine habitats and aquatic biodiversity in the region (Sharifinia et al., 2019). The drivers of pollution in the Arabian Gulf are diverse, but climate change, oil and gas industry, coastal anthropogenic disturbance, and desalination plants are considered to be the most important sources of pollution (Fig. 1).

2.1. Climate change

Climate change is a global issue threatening aquatic ecosystems (Henson et al., 2017). It is an undeniable phenomenon altering the biogeochemistry of seas, which is triggered by increased temperature (Gattuso et al., 2015). Ocean warming is coupled with increasing stratification of the sea, which prevents nutrients from moving to the upper photic layers to support photosynthetic microorganisms (Steinacher et al., 2010). Climate change also induces the solubility of CO_2 into the seas due to its high concentration in the air (Henson et al., 2017). This results in decreasing the pH of oceans and negatively affecting calcareous organisms (Doney et al., 2012). Besides, oxygen solubility in the water will decrease as water temperature increases affecting aquatic organisms (Vaquer-Sunyer and Duarte, 2008).

Marine organisms are able to cope with such changes to some extent through physiological and phenological adaptation, as well as shifting population distribution and dynamics (Wabnitz et al., 2018). The result of these changes is reflected in species richness (Jones and Cheung, 2015), and also affects the structure of marine communities (MacNeil et al., 2010). According to Wabnitz et al. (2018), climate change is increasing the pressure on the Arabian Gulf, resulting in the survival of certain organisms that tolerate extreme temperature and high salinity. Despite the high adaptability of some organisms, climate change still exerts negative effects on them. For instance, increased sea temperature in the Arabian Gulf resulting from climate change caused enormous bleaching followed by death in corals in 1996 and 1998 (Naser, 2014).

2.2. Desalination plant discharges

Arabian Gulf countries are characterised by an arid climate with a scarcity of freshwater (Elasha, 2010). Supplying the needed freshwater to the region is achieved by depending on desalination plants. Even though desalination processes are beneficial as they provide an important source of freshwater, they have a significant negative environmental effect on the marine chemistry and health with increasing the salinity, temperature, heavy metal concentration which ultimately alter the marine biodiversity (Roberts et al., 2010). With increasing populations and economies, desalination plants, as well as combined water and power production plants, are increasing in coastal areas of the Gulf. In fact, coastal infrastructure for water, energy, and food supply is becoming increasingly coupled with some mega plants supplying major cities in the region, thus posing several risks to coastal populations and marine ecosystems (Al-Saidi and Saliba, 2019). This is an emerging issue threatening the health of the Arabian Gulf.

2.3. Oil and gas activities

Arabian Gulf countries are the largest producers of oil and gas globally, and it is estimated that 65% of proven crude oil reserves belong to Arabian Gulf littoral countries (Modarress et al., 2016). By 2035, oil exports from the region are expected to exceed 43 million barrels per day (Modarress et al., 2016). The development of oil and gas industry has caused destruction in the Arabian Gulf's marine environment. This is especially true when considering the activities associated with such developments, such as the construction of platforms, extraction of oil and gas, refining, and transportation.

As many spills and oil-related accidents go undocumented, it is difficult to quantify the effects of these events (Meshkati et al., 2016). Nonetheless, one of the largest oil spills happened in 1991 when 10

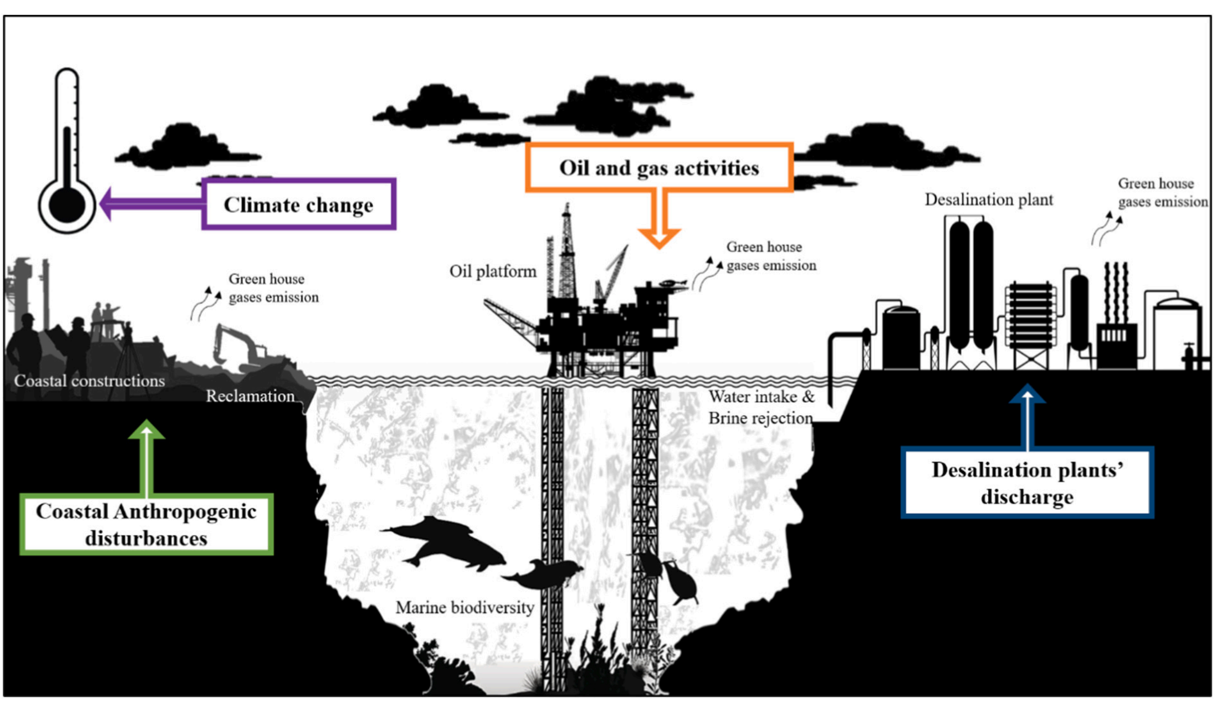

Fig. 1. Drivers of pollution in the Arabian Gulf.

million barrels of oil were spilled during the Gulf War resulting in a long oil slick covering the Kuwaiti and Saudi coasts (Alhanaee et al., 2017). Oil pollution is believed to have an important effect on biota and biodiversity (Azevedo-Santos et al., 2016). Acute oil pollution causes mass mortality of organisms (McGenity et al., 2012) as well as substantial decreases in species richness (De La Huz et al., 2005). In their review, Pashaei et al. (2015) indicated that oil pollution and spills in the Arabian Gulf severely damaged mangrove forests, killing more than 500 sea turtles, decreasing 25% of shrimp fisheries, and polluting sediments.

2.4. Coastal anthropogenic disturbances

Coastal anthropogenic disturbances are a set of all human activities that induce damage to the aquatic habitats. They include coastal modification, dredging, land reclamation, and other activities that result in water pollution and habitat destruction (Naser, 2017). Arabian Gulf countries have experienced substantial development in economic and industrial sectors, which have resulted in considerable modification of the Gulf coastline to accommodate ports, artificial islands, marinas, coastal hotels, and even maritime cities, all of which increased marine pollution (Naser, 2015). For instance, high concentrations of heavy metals and hydrocarbons were reported in areas of active shipping in the Arabian Gulf (de Mora et al., 2010). Another study done in Saudi Arabian coasts of the Arabian Gulf revealed that the concentrations of heavy metals including zinc, copper, chromium, and lead were enriched due to anthropogenic activities (Almasoud et al., 2015). Also, studying the PAHs concentrations in Qatari coastal sediments revealed moderate to high pollution in Al-wakrah port harbour (Soliman et al., 2014).

The introduction of such toxicants into coasts often promotes losing richness and biodiversity of marine species (Johnston and Roberts, 2009). Abd El-Wahab and Al-Rashed (2014) indicated that coastal habitats of Kuwait are negatively affected by human activities as both species composition and diversity of plants were considerably altered over the last five decades. In addition, based on Loughland et al. (2012), around 90% of native saltmarshes in the Arabian Gulf were lost due to coastal development and urbanisation. Baby et al. (2014) suggested that the carrying capacities of Kuwaiti's coastal habitats are decreasing due to urbanisation and industrialisation.

3. Desalination plants in the Arabian Gulf

Freshwater is a finite resource. Owing to the rapid increase in human population, unsustainable consumption, and the global changes in climatic conditions, water scarcity threatens many parts of the world (Odhiambo, 2017). The Arabian Peninsula has some of the scarcest freshwater resources worldwide (Elasha, 2010). This increased demand compared to the limited supply of freshwater drove the Arabian Gulf countries and especially the Gulf Cooperation Council (GCC) to rely on seawater desalination. It is estimated that the Arabian Gulf countries have a desalination capacity of 11 million m^3 per day. The region accommodates 213 actively operating desalination plants, and 51 others are expected to be commissioned in the near future (Sharifinia et al., 2019). Saudi Arabia (45%) and the United Arab Emirates (22%) are the two biggest contributors to desalination activities in the region.

3.1. Types of desalination plants

Desalination plants differ based on the separation technique used. There are two main classifications of desalination plants, namely thermal-based or membrane-based separation (Table 1). Globally, the most widely used desalination systems are based on reverse osmosis (RO) followed by multi-effect distillation (Miller et al., 2015). RO alone accounts for more than 60% of globally produced desalinated water. There are only three types of desalination plants present in the Arabian Gulf. These are RO, multi-effect distillation, and multi-stage flash. Multi-stage flash distillation accounts for 81% of water desalination, multi-

Table 1
Types of desalination technologies adopted by the desalination plants.

Desalination technology	Principles of the desalination technology	References
Thermal-based desalination		
Vapor compression distillation (VC)	- Based on evaporating the incoming water using heat that comes from vapor compression. - Mechanical compressors are often utilised for heat generation. - Usually have small capacities and they could be coupled with multi-effect distillation (MED).	(Krishna, 2004)
Multi-Stage Flash distillation (MSF)	- The influent water is heated to 120 °C under high pressure. Heated water passes through successive flash units. - Each unit has a lower pressure compared to the one before allowing the hot water to evaporate as it flows through the flash units. - The evaporated portion is cooled and condensed on heat exchanger tubes. - Condensed water is collected as freshwater while the brine leaves the flash units to be discharged.	(Khoshrou et al., 2017)
Multi-Effect Distillation (MED)	- Based on passing heated water through successive effect units with low pressures. - It resembles the MSF except that it functions at lower temperatures reaching a maximum of only 75 °C. - Condensation of vapor occurs as a result of exchanging heat with liquid. - Both MSF and MED produce freshwater of high quality with total dissolved solids of less than 10 mg/L and are efficient in brine treatment.	(Elsayed et al., 2018) (Chua and Rahimi, 2017) (Mabrouk and Fath, 2015)
Membrane-based desalination		
Reverse osmosis (RO)	- RO is the most commonly used membrane-based desalination processes. - It is a filtration process in which water is forced into a membrane that separates freshwater from brine. - In definition, osmosis is the movement of water through a semi-permeable membrane from a solution having fewer salts to a solution having more salts. - In reverse osmosis, pressure is applied to reverse the direction of water flow, which produces freshwater and concentrated brine.	(Miller et al., 2015) (Krishna, 2004)
Electrodialysis (ED)	- Based on the fact that dissolved salts are ions bearing either a negative or a positive charge. - ED utilises selective membranes that allows positively charged ions or negatively charged ions to pass through upon receiving electric currents. - Anion selective membranes and cation selective membranes are arranged alternatively in the desalination plant to separate all salts from freshwater.	(Krishna, 2004)
Electrodialysis Reversal (EDR)	- EDR process was launched after the ED. - It is very similar to EDR in terms of operation principle. - The main difference is that the polarity of the direct current is reversed several times an hour. - This attracts ions to the opposite direction of the membrane. Afterwards, the freshwater is collected. Both ED and EDR are mostly used for brackish water rather than seawater.	(Buros, 2000) (Valero and Arbós, 2010) (Krishna, 2004)

effect distillation accounts for 13%, and RO accounts for only 6% (Sharifinia et al., 2019). Thermal desalination is the predominant technology due to the abundance of fossil fuels in GCC countries, making fossil-fuel-dependent powerplants the most economically attractive method for generating energy to drive desalination processes (Dawoud and Al Mulla, 2012).

3.2. Effect of desalination on marine environments

The effect of desalination activities on the marine environment has not been widely studied. In fact, according to Kress et al. (2020), the majority of the existing publications present predicted, potential impacts which are not based on observed or experimental data. In spite of that, based on the existing data, the effects could be categorised into two categories based on the intake of seawater and discharge of brine. Generally, desalination activities alter the structure and function of marine ecosystems, which is visualized by the affected marine communities and changes in the trophic interactions (Grossowicz et al., 2020).

3.2.1. Intake of seawater

Desalination plants rely on water from different sources, e.g. cooling water used in power plants, aquifers, ground water, and most commonly, open seas. When desalination plants are being constructed, pipes are installed to transport water from the sea. This step disrupts the seabed causing resuspension of sedimented particles, including pollutants (Dawoud and Al Mulla, 2012). Disturbance and alteration of the seabed leads to habitat destruction, death of marine species, release of toxic pollutants from sediments, and increase in water turbidity.

Once plants are operating, massive volumes of water are pumped into the plants directly from the sea. These volumes are estimated to be double the amounts being produced (Kress et al., 2018). Along with water, many organisms are taken into the system that either get impinged (crash into the screens of the intake pipes) or entrained (travel with water reaching the plant) (Dawoud and Al Mulla, 2012). Entrainment and impingement result in severe injury and death of marine organisms (National Research Council, 2008). According to Missimer and Maliva (2018), assessing the effect on the marine environment resulting from entrainment and impingement is difficult. Parameters such as screen mesh size, pipe size, and volume of water intake, should be considered when designing the plant to reduce entrainment and impingement (National Research Council, 2008). Subsurface water intake reflects another potential solution (Missimer et al., 2013).

3.2.2. Discharge of the brine

Desalination processes result in the production of brine, which is a waste fluid characterised by high salinity and dissolved minerals (Danoun, 2007). The fate of the brine is usually disposal into the sea, considering it as one of the least costly disposal approaches (Fernández-Torquemada et al., 2019). The desalination process goes through various phases; thus, the produced brine contains different chemicals and agents. The first important aspect to consider is the high salinity of the brine, which is at least 1.6–2 times higher than that of seawater (35 g/L average) (Panagopoulos et al., 2019). Furthermore, depending on the technology used (i.e. thermal technologies) brine can exceed seawater ambient temperature by 1.37 to 1.82 times (Missimer and Maliva, 2018). The brine can also contain different chemicals, such as chlorine, cationic and anionic coagulants, acids, anti-scalants, heavy metals, and anti-foaming agents that are added during the desalination process (Alameddine and El-Fadel, 2007; Frank et al., 2019). Once discharged into the sea, these chemicals are considered to be toxic pollutants. Furthermore, the brine is highly alkaline as a result of calcium carbonates and sulfates (Danoun, 2007). The discharge of brine with these characteristics into the sea leads to significant changes in the physiochemical and biological parameters of the sea which ultimately affect marine life.

High temperature and salinity inhibit the growth of aquatic organisms (Wiltshire et al., 2010). Salinity elevations affect marine organisms such as planktons, microbes, and benthic species (Wood et al., 2020). In addition studies have shown that increasing the salinity of aquatic environments slightly above ambient conditions disrupts the osmotic regulatory abilities of some marine organisms resulting in dehydration and consequently death (Al-Shammari and Ali, 2018; Matsumoto and Martin, 2008). In addition, increasing the temperature of seawater increases the toxicity of some chemicals and metals, which adversely affects aquatic life (Uddin, 2014). Research has focused on seagrasses given the importance of seagrass habitats, which comprise diverse organisms and are sensitive to fluctuations in environmental conditions (Kress et al., 2018). Table 2 summarises research on the effect of increased salinity and temperature as a result of brine discharge into the sea.

Brine disposal also causes hypoxia resulting from decreasing concentrations of dissolved oxygen, which affect all marine organisms (Ahmed and Anwar, 2012). Increasing salinity is inversely proportional to the concentration of dissolved oxygen in the sea (Krayer et al., 2017). In addition, increasing water temperature through input of hot brine decreases oxygen solubility (Ahlgren et al., 2017). Oxygen-depleted water bodies experience mass mortality of mussels, bivalves, and fish, and also disruption to coral reef functionality, invasion of opportunistic jellyfishes, and loss of biodiversity (Isensee and Valdes, 2018). The significance of brine discharge is arguably high in the Arabian Gulf considering that the Gulf is shallow and semi-enclosed with weak water circulation and limited freshwater input (Uddin et al., 2011). Such conditions accommodate adapted native species, which are resistant to fluctuations in the physiochemical parameters of the sea. Therefore, the extensive desalination activity in the region greatly threatens sensitive species, possibly leading to their extinction.

4. Methods for assessing marine ecosystem response to stressors

Increased population and associated activities are exerting huge amounts of pressure on the marine environment (Halpern et al., 2015). Despite realising the importance and fragility of marine resources, we continue to exploit, destroy, and pollute the oceans, which leads to losses in functionality and biodiversity of aquatic ecosystems (Claudet and Fraschetti, 2010; McCauley et al., 2015). As a counter measure, many laws and regulations have been implemented globally aiming to protect the marine environment and conserve its ecosystems. Such regulations rely on our ability to assess marine health using different interconnected tools (Boyes and Elliott, 2014).

Assessing the health of the marine environment requires combining different parameters to reach a realistic conclusion. It is essential to adopt different assessment approaches including incorporating physical, chemical, and biological parameters. Borja et al. (2016) insisted on the significance of including biotic and abiotic factors, as well as human and social intervention when assessing environmental status. To develop a complete perspective of diversity indicators, biotic components should be incorporated into ecosystem assessments at various levels, including genus, species, population, and community levels (Haase et al., 2018). Considering that the assessment of each level serves a different objective, combining more than one would increase the objectivity of judgments of ecosystem health. In this context, various tools are implemented to assess marine health, most of which are oriented towards studying the diversity of marine organisms. There are two main categories of assessment tool comprising conventional methods and innovative recently developed strategies (Fig. 2).

4.1. Conventional tools for the assessment of marine health

Conventional tools are those that were historically used to monitor environmental health. They include several methods and approaches that were extensively used until the beginning of the 21st century.

Table 2
The effect of increased salinity and temperature as a result of brine discharge.

Cause	Study duration and location	Desalination technique	Affected organism/ parameter	Result	Reference
Increased salinity, 68 psu discharged brine	From June 2003 to August 2004 Alicante Spain near RO desalination plant	RO	Seagrass *Posidonia oceanica*	Decline in the growth of the leaves. Increasing necrosis and mortality	(Fernández-Torquemada et al., 2005)
Increased salinity, 37, 39, 41 and 43 psu	lab simulation for 47 days, mimicking the Mediterranean natural conditions when exposed to brine discharge.	Not Applicable	Seagrass *Cymodocea nodosa*	Weakening photosynthetic rates	(Sandoval-Gil et al., 2012)
Increased salinity, 40, and 46 psu	June 2015 and December 2015. Near Hadera desalination plant, Israel	RO	Benthic bacteria	Reduction of 60% in the abundance of bacterial species	(Frank et al., 2017)
Increased salinity, 55.6 and 54.7 ppt discharged brine	Near Marsa Humira and Shalateen desalination plants, Egypt.	RO	Coral reefs	Coral bleaching and death	(Nasr et al., 2019)
Increased salinity by 10% and anti-sealants	June 2016. Northern Gulf of Aqaba, Israel	RO	Corals *Stylophora pistillata*, *Acropora tenuis* and *Pocillopora verrucosa*	Partial bleaching of corals. Reduction in the abundance of bacteria and symbiotic algae	(Petersen et al., 2018)
Increased temperature 5–6 °C above ambient	June 2016 to April 2017. Ashkelon, Israel	RO	Benthic foraminifera	Low species abundance and richness	(Kenigsberg et al., 2020)
Increased salinity, 43.45 ± 0.40 psu	August 2015. Bousfer plant located in Oran Bay	RO	Marine gastropod mollusc *Patella rustica*	Increased activity of antioxidant defense enzymes, as well as molecular damage of the tissue	(Benaissa et al., 2017)

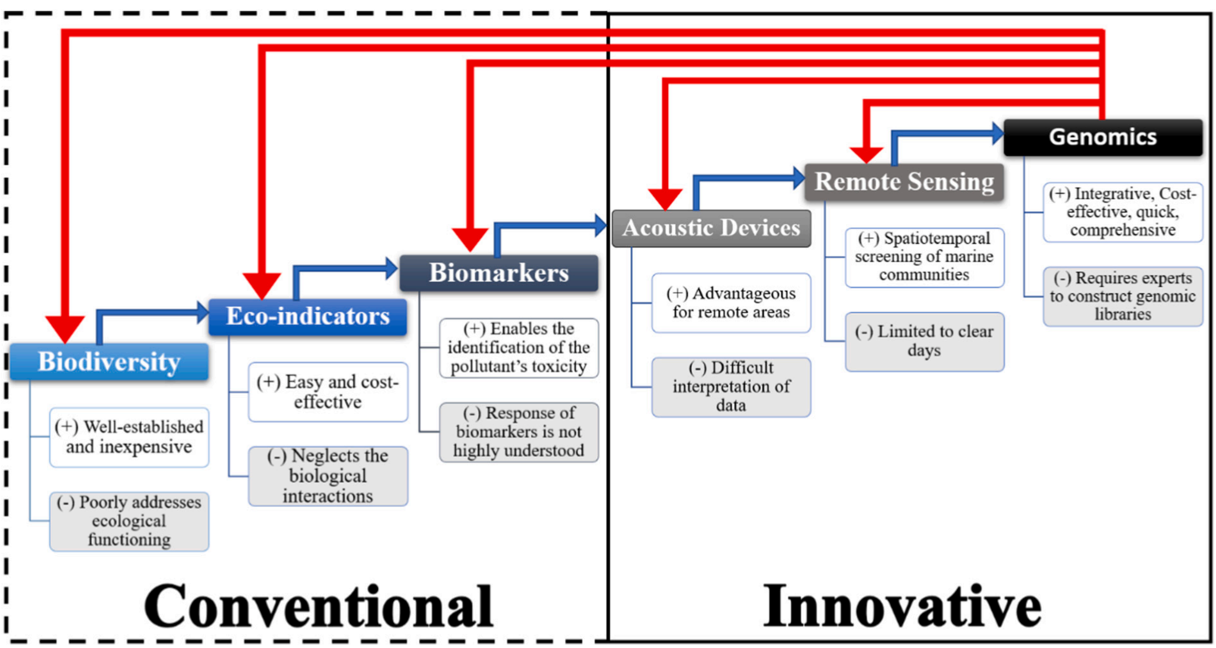

Fig. 2. Different approaches adopted for the assessment of environmental effect of desalination on marine health.

Thereafter, such approaches were amended by innovative methods owing to the development of methods to avoid the limitations of conventional techniques.

4.1.1. Biodiversity and abundance of faunal communities

Diversity is one of the most important parameters for examining the effect of human activities on marine ecosystems. Many diversity indices have been developed to interpret the data collected and relate these to assessments (Yoccoz et al., 2001). Indices are mostly based on the relative abundance of each species (Yoccoz et al., 2001). Shannon-Wiener and Simpson are the most widely used biodiversity indices (Mendes et al., 2008) even though they are highly influenced by sample size, making them biased and, thus, less reliable (Hewitt et al., 2005).

Determining the biomass and abundance of faunal species has been widely used to monitor the marine environment. According to Pagola-Carte and Saiz-Salinas (2001), studying benthos can reveal important information about environmental conditions. Analysing the biomass and abundance of benthic species depends on primitive and simple protocols which involve divers collecting all benthos that fall within a quadrant of known area and quantifying and identifying the benthos (e.g. Barnes and Brockington, 2003). Strong et al. (2015) considered that these structural indicator studies are widely used for environmental monitoring because they are well established and inexpensive. However, indices are not yet highly informative regarding the functionality of the ecosystems. Similarly, Bremner et al. (2003) indicated that such studies can provide information on human effects on marine ecosystems at the community level, even though, they poorly address ecological functioning.

4.1.2. Ecological indicators

Ecological indicators are species that are either highly sensitivity or tolerant to changes in an ecosystem. Studying the richness and abundance of indicator species provides rich information on marine health and response to pollution (Aguirre and Tabor, 2004; Parmar et al., 2016). On the one hand, sensitive species are usually dominant in marine systems and a reduction in their abundance indicates an altered ecosystem. On the other hand, tolerant species are opportunistic and highly resistant to environmental changes. Increase in the number of tolerant species is an indication of an altered ecosystem (Simboura and Zenetos, 2002). Fish are informative indicators as they are mobile, long lived, and they are present in all aquatic environments (Whitfield and Elliott, 2002). Indicator species are used to study the effect of human activities on marine ecosystems. For example, phytoplankton are informative bioindicators of eutrophicated waterbodies, where they tend to grow rapidly (Singh et al., 2013). As indicated by Anttila et al. (2018), blooms of cyanobacteria in the Baltic Sea always indicate anthropogenic increase in the nutrients inputs leading to eutrophication.

Furthermore, as described by Hosmani (2014), zooplankton are sensitive to changes in the physiochemical conditions of water (e.g. chemical composition, dissolved oxygen, pH, and temperature), which is why they are used as bioindicators. Algae were also used as indicators of organic pollution in lakes and freshwater bodies (Hosmani, 2013). Even though relying on indicator species for the assessment of environmental health is relatively easy and cost-effective, there are many shortcomings associated with these methods (Siddig et al., 2016). Firstly, considering a single population would not sufficiently represent the effect on the ecosystem as a whole. Secondly, using this approach neglects the biological interactions and its influence on the population of the indicator species. Finally, environmental factors other than the studied pollution (e.g. global warming) might influence the indicator species.

4.1.3. Biomarkers

In definition, biomarkers are changes that occur biologically, biochemically, or physiologically to organisms as a result of exposure to xenobiotic compounds (Hahn, 2002). Biomarkers have been incorporated in the ecotoxicological tests, where the existence of pollutants in a certain environment could be measured at the molecular level of affected organisms (Moore et al., 2004). This method enables the identification of pollutant toxicity in exposed organisms (Galloway et al., 2002). It is necessary to develop standards and define norms of biomarkers for every organism (Viarengo et al., 2000) to be able to compare experimental data with reference values. It is more advantageous to study multi-biomarkers to understand the effect of stressors on organisms at the molecular level (Downs et al., 2002). This technique is not routinely used due to the difficulties associated with interpreting the acquired data because the response of biomarkers is not completely understood at different biological levels (Brown et al., 2004). Furthermore, biomarkers tend to be influenced by different factors other than pollution, e.g. organism age, salinity, and water temperature (Brown et al., 2004). Therefore, it can be difficult and complicated to link the pollution with its effect on biomarkers (Viarengo et al., 2000). Additionally, there are difficulties associated with selecting the biomarker that is representative of the changes occurring.

4.2. Innovative and novel methods for the assessment of marine health

Marine monitoring has always been challenging owing to the difficulties associated with providing impartial data, knowing that marine ecosystems are highly complex structurally and functionally (de Jonge et al., 2006). Traditional methods of monitoring are widely used as they are cost effective, widely accepted, and well established, although they still have many limitations (Bourlat et al., 2013; Strong et al., 2015). Conventional monitoring strategies are usually restricted by the sampling site, and are usually limited by the fact that the monitoring focuses on specific organisms that are easily monitored, which leads to inaccurate and biased results (Bourlat et al., 2013). When using conventional methods, marine environment health is assessed by targeting a certain taxonomic group during a certain life stage. Other interactions are mostly neglected, thus causing a lack in understanding of ecosystem interactions, and consequently, a poor understanding of the effect of the studied stressor on the marine ecosystem as a whole. Consequently, innovative strategies for monitoring and assessing the health of marine environments had to be developed. There have been different marine assessment tools emerging recently, and they are very promising as they overcome the shortcomings of conventional approaches. The main methods that fall under this category are acoustic devices, remote sensing, and genomics (Borja et al., 2016).

4.2.1. Acoustic devices

An advanced method for monitoring marine ecosystems involves utilising acoustic devices to detect changes caused by human activity. Marine mammals are known for their acoustic specialisation where they rely on sound waves to communicate and navigate (Sousa-Lima et al., 2013). Owing to technological developments, we now have devices that can record underwater sounds produced by marine mammals. Following these developments, passive acoustic monitoring (PAM) devices were developed as non-invasive tools for better understanding marine mammals and the sounds they produce (Kalan et al., 2015). PAM is used to monitor animals by utilising remote acoustic tools such as hydrophones, stereo-phones, microphone arrays, and other auto-recording technologies (Marques et al., 2013). Species richness and community composition could be determined using PAM (Blumstein et al., 2011). PAM has proven to be highly beneficial when it comes to marine mammals because they are especially difficult to monitor optically because light cannot penetrate oceans for long distances. PAM systems can detect and classify marine mammals (Bittle and Duncan, 2013), which is why they are useful for studying the effect of human activities on marine health. Even though they are highly useful, PAM devices comprise continuous real-time monitoring systems that are associated with the long-term recording of vast amounts of data (Lammers et al., 2008). This is considered to be a major limitation as it requires extensive inspection and analysis of these data, which is usually unfeasible (Swiston and Mennill, 2009).

As an alternative, underwater fixed autonomous, sound recorders were developed in the early 1990s which addressed the limitations of PAM. These new systems are characterised by lower costs, and they do not require experts for continuous sound monitoring (Sousa-Lima et al., 2013; Wiggins et al., 2012). Autonomous sound recorders record soundwaves and store the collected data within the device without being connected to reception stations (Wiggins et al., 2012). They do not require running and monitoring in person as they are installed on buoys or fixed to the sea floor where they record continuously. They could also be incorporated into autonomous underwater vehicles like ocean gliders (Fucile et al., 2006). After a defined period of time, the devices must be retrieved to analyse the acquired data (Sousa-Lima et al., 2013).

Using autonomous sound recorders could be highly advantageous for remote areas (e.g. polar regions) or when access to the location is difficult (e.g. deep sea or harsh weather) (Širović et al., 2009; Soldevilla et al., 2010). sing these acoustic devices could be an efficient means to indirectly measure the biodiversity of acoustic mammals to assess ecosystem health (Sueur et al., 2008). Acoustic data could be analysed and interpreted through a variety of ways serving different purposes. For example, biodiversity could be assessed by quantifying spectral and temporal entropy H (Sueur et al., 2008). Parks et al. (2014) discovered that using noise compensated entropy (H_N) was the most representative index that reflects biological patterns and diversity in the marine environment. Despite the advantages of acoustic assessment, there remain issues concerning the interpretation of complex data. Besides, it is an indirect measure of biodiversity which is not always able to provide representative results.

4.2.2. Remote sensing

Remote sensing is an innovative approach recently used to assess marine health. Remote sensing, including optical, thermal, and radar sensors, provides new prospects for studying species, habitat distribution, and biodiversity (Pettorelli et al., 2014; Turner et al., 2003). This approach was previously used to monitor terrestrial ecosystems (Gross et al., 2009). However, recently, this technology was developed to include monitoring aquatic environments and was successfully implied for studying, monitoring, and managing mangrove (Kuenzer et al., 2011), coral reef (Hamel and Andréfouët, 2010), and even seagrass (Dekker et al., 2006) ecosystems.

According to van der Wal and Herman (2007), radar imaging is efficient at determining the composition of saltmarshes and intertidal habitats. Remote sensing proved to be cost effective for in-situ sampling, which provides data based on spatial and temporal screening of marine communities enabling scientists to understand the effect of human activities on the dynamics of marine communities (Rivas et al., 2006). According to Blondeau-Patissier et al. (2004), the development of remote sensing enabled spanning temporal and spatial recordings of sites, which overcomes the disadvantages of conventional in-situ marine monitoring techniques.

4.2.2.1. Assessing productivity. Owing to the large size of the seas and oceans, it is difficult to rely only on buoys and ships for monitoring purposes. Remote sensing is more informative, especially when it comes to assessing primary productivity. Since chlorophyll *a* is the main pigment for photosynthesis, its concentration could reflect primary productivity. The concentration of the pigment is determined using different remote sensing techniques, which operate in the visible region of the light spectrum (Klemas, 2010). Multispectral and hyperspectral imagers are used to measure chlorophyll concentration and thereby assess primary productivity using sensors like SeaWiFS and MODIS (Oliver et al., 2004). Chlorophyll is measured based on atmospheric spectral radiance, which is used to derive the spectral radiance of ocean surfaces (Bagheri et al., 2002). Derived surface radiance is then used to calculate the reflectance which is important for chlorophyll identification and measurement (Philpot, 2007). According to Klemas (2010), obtaining accurate and calibrated data requires coupling the remote sensing data with data collected using ocean gliders, ships, and buoys.

4.2.2.2. Assessing the health of coral reefs. Remote sensing has been efficiently used to monitor coral reefs. Since coral reefs are highly fragile environments, it is important to monitor the effects of human activities on such ecosystems (Klemas, 2010). Coral studies using remote sensing could be direct in which data are related to the reef itself (Wabnitz et al., 2010), or indirect in which data represent the environmental conditions of the reef. Direct measurements include the location of reefs, patchiness, cover, and diversity of the habitat (Hamel and Andréfouët, 2010). Conversely, indirect measurements refer to temperature, turbidity, chlorophyll concentration, and organic matter concentration of the oceans, and also wind, rain, and cloud cover in the atmosphere (Hamel and Andréfouët, 2010). Coral reefs and submerged vegetation can be mapped by both hyperspectral and multispectral imagers (Akins et al., 2009).

Even though remote sensing represents a promising technique, there are still limitations that prevent such techniques from operating at full efficiency. Firstly, remote sensing observations and data are restricted to clear days because the presence of clouds restricts the collection of data especially in tropical and high-latitude areas (Peters et al., 2005). Furthermore, measuring the concentration of chlorophyll *a* to estimate the biomass of phytoplankton for productivity assessment is based on conversion factors which could be misleading (Rivas et al., 2006).

4.2.3. Genomics

Genomic assessment of marine environments provides information on marine ecosystems at the cellular and microbial levels. This type of assessment provides information about micro-communities, their interactions, and the involved metabolic pathways, which allows a comprehensive evaluation of the functionality of an ecosystem (Bourlat et al., 2013), and provides a representation of the ecosystem's current and future response to stressors in terms of the effect on organisms and their interactions. Consequently, this will represent changes in populations and communities (Borja et al., 2016). Genomics techniques are considered to be an emerging tool and have shown promise for environmental monitoring. They essentially provide cost-effective and reliable measurements, which is why they are expected to substitute traditional methods (Bourlat et al., 2013).

As genomic approaches are becoming more widely applied owing to the technological advancement of sequencing tools (Mardis, 2008), genetic information for different species and habitats has become widely available in databases (Bik et al., 2012; Hajibabaei et al., 2011), which has facilitated the analysis of genetic data acquired from different ecosystems, including the marine environment. Following these developments, the methodologies of molecular analysis are constantly being refined, developing novel methods for different purposes (Leese et al., 2016).

4.2.3.1. DNA barcoding and meta barcoding. DNA barcoding involves sequencing and analysing standard short fragments of DNA known as DNA barcodes to identify the species of an unknown biological sample (Hebert et al., 2003). This type of genomic analysis is simple and does not require taxonomic experts as the sequenced barcodes are simply compared with other barcode sequences in a database to identify the species of the unknown sample. This technique is advantageous as it could be applied not only to biological specimens and tissues but also environmental samples for identifying all taxa in an area by metabarcoding (Bourlat et al., 2013). With metabarcoding, it is possible to analyse DNA present in water, biofilms, and even sediment samples, which is referred to as environmental DNA (eDNA) (Leese et al., 2016).

Using this approach allows the assessment of ecosystem's biodiversity through monitoring multiple communities at once (Zhang et al., 2020). DNA barcoding and metabarcoding require a DNA barcode library that contains information about different species. Constructing such reference libraries requires expert taxonomists and extensive effort. In their review, Taylor and Harris (2012) mentioned that the main resources for DNA barcodes are Consortium for the Barcode of Life (CBOL), International Barcode of Life (iBOL), and the Barcode of Life Data System (BOLD).

4.2.3.2. Metagenomics. The conventional study of microbial species is restricted to culturable species, which are in the minority in the microbial world. Metagenomics offer an innovative approach to study culturing-recalcitrant microbial fractions through the DNA sequencing of any environmental sample (Culligan and Sleator, 2016). This approach is promising especially with the development of next-generation sequencing (DiBattista et al., 2020; Schuster, 2008). It allows rapid environmental monitoring through relative abundance estimation (Günther et al., 2018). There are mainly two types of metagenomic method involving either 16S rRNA amplicons or whole genome shotgun sequencing.

- 16S rRNA amplicons

Combining the phylogenetic diversity approach with metagenomics would simplify assessments of the biodiversity of environmental samples using marker genes. According to McDonald et al. (2013), determining phylogenetic diversity depends on studying marker genes such as 16S rRNA to know the similarity between microbial communities. As with DNA barcoding, metagenomics relies on reference libraries of genetic data of species. 16S rRNA techniques have been recently developed following the advancements in next-generation sequencing strategies that utilise 16S rRNA primers, such as the Illumina sequencer and 454 pyro-sequencer (Shah et al., 2011). Despite its efficiency in studying microbial diversity, the results provided by 16S rRNA metagenomic studies might not always be reliable since DNA extraction and PCR amplification procedures can produce biased data (Brooks et al., 2015).

- Whole-genome shotgun

This type of metagenomic technique sequences eDNA using random primers which results in overlapping genomic sequences (Ranjan et al., 2016). Such studies provide information about the genomic and metabolic characteristics of environmental samples (Kalyuzhnaya et al., 2008) Whole-genome shotgun sequencing could be favoured over amplicon sequencing because it is more objective and less biased. However, it is not widely used because it is expensive and requires analysis of vast amounts of data (Luo et al., 2014; Sims et al., 2014). It is important to mention that whole-genome shotgun sequencing has other limitations, such as lacking the ability to detect rare species (Kalyuzhnaya et al., 2008).

4.2.3.3. Microarrays. Microarrays are chips that contain a collection of labelled DNA probes, each probe representing a different species (Bourlat et al., 2013). DNA from environmental samples hybridises with a probe forming a complex, which will fluoresce upon subjecting it to UV radiation. Such techniques represent an innovative strategy for assessing environmental health (He et al., 2007), and allow for the detection of harmful microbes, or can infer the absence of locally dominant species in environmental samples, which could occur as a result of stressors. For example, studies have used microarrays as efficient and rapid ways for identifying toxic algal species that are responsible for harmful algal blooms (Bricker et al., 2008; Doucette et al., 2009).

4.2.3.4. Quantitative real-time PCR. This method is based on quantifying a certain gene sequence belonging to a specific organism. DNA is quantified by comparing it to known values from standards curves and then it is correlated with the number of individuals of that species (Bourlat et al., 2013). This is a simple assessment tool for marine health, where knowing the abundance of a species allows us to determine whether that species is being affected by pollution. This technique can also be used to assess the genetic diversity in the affected environment (Smith and Osborn, 2009). Real-time PCR assays have high sensitivity and quantification power, making it a reliable marine monitoring tool (LeBlanc et al., 2020) However, even though this method is helpful for assessing marine health, it can only be applied to unicellular organisms with a known number of copies of the gene being quantified (Bourlat et al., 2013).

4.2.3.5. Transcriptomics. Transcriptomics is the study of gene expression. In the context of environmental monitoring, this study provides a comprehensive view of organisms' responses to stress at the molecular level (Devens et al., 2020). Gene expression can be studied through different techniques, such as using real-time PCR to quantify the concentration of RNA or through RNAseq (Bourlat et al., 2013).

In the Arabian Gulf, out of all of the assessment tools reviewed, genomics seems to be the most promising approach because it overcomes many of the limitations associated with the conventional assessment tools, complexity of interpreting acoustic data, and restrictions of remote sensing. Genomics approaches will provide an overall evaluation of marine ecosystems including their functionality. It will reveal the current status of the Arabian Gulf and possible future responses through DNA analysis.

5. Management approaches for future coastal development

Since marine environments comprise complex interacting ecosystems that provide extensive goods and services (Barbier, 2017), it is important to protect them. The extensive desalination activity in the Arabian Gulf is a potential threat to marine health. The effects of desalination plants can be limited by applying effective mitigation measures. Some of the important management approaches are presented in this section.

5.1. Optimisation of plant design

The negative effect of the desalination process could be reduced by optimising the design of the plant. Using membrane-based desalination could be less destructive to marine habitats since thermal-based desalination produces hot brine that adversely affects marine life when discharged. Besides, the inlet of the intake pipes should be located in places with low species abundance, avoiding productive areas to reduce the negative effect. Furthermore, the entrainment and impingement of organisms could be minimised by optimising the velocity of water flowing through the intake pipes and by optimising the mesh size of the screens in the intake pipes (Sharifinia et al., 2019). In addition, developing and using environmentally friendly desalination processes should be emphasised. For instance, solar-based desalination processes are being developed to increase their efficiency and applicability. Palenzuela et al. (2015) proposed coupling concentrated solar power plants with desalination plants in the Arabian Gulf to produce electric power and freshwater.

5.2. Treatment of brine before discharge

To minimise the negative effect of brine discharge, it is possible to treat the brine to remove hazardous chemicals used during the desalination process. Chlorine is an example of a hazardous chemical used during desalination since it has a biocide activity. Lattemann and Höpner (2008) indicated that chlorine could be removed using sodium bisulfite for RO plant effluents, and hydrogen peroxide for thermal plant effluents. Source control is even more effective where hazardous chemicals are not used during the desalination process. Such chemicals have substitutes that are less environmentally destructive. In addition, many studies have focused on treating produced brine by enhancing water recovery. As reviewed by Panagopoulos et al. (2019), brine treatment technologies could be membrane based, thermal based, or zero liquid discharge based. These technologies work principally on producing pure water and compressed solids, which reduces brine volume.

5.3. National regulation

National monitoring and regulation are required for assessing the health of ecosystems and setting guidelines and rules for plant design and discharge parameters. For example, in response to the increasing pollution in the Arabian Gulf region, Kuwait established the Kuwait Environment Public Authority (KEPA). KEPA is an independent organisation responsible for maintaining the health of the environment and actively participates in enforcing legislation and setting standards. As a regulatory measure, KEPA monitors the quality of Kuwait's territorial water through continuous collection of data from 13 different stations. The quality of water is assessed based on different parameters to make sure it meets the local standards (Al-Mutairi et al., 2014). To control the increase in salinity of the sea resulting from desalination activities, KEPA set a salinity limit of 42 ppt (Uddin et al., 2011). This is an effective initiative for controlling the direct dumping of brine into the sea.

5.4. Regional cooperation

Since the Gulf waters are shared among several littoral countries, a regional approach to the control of marine pollution is indispensable. In this sense, Gulf littoral countries adopted a legal instrument in 1979, namely the Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution (short Kuwait Convention). Based on this convention, the Regional Organisation for the Protection of Marine Environment (ROPME) was established in 1979 as an intergovernmental organisation encompassing all Gulf littoral countries. A cornerstone of ROPME policy includes an action plan (the Kuwait Action Plan) for monitoring and assessing the health of the Gulf. Furthermore, several additional protocols to the Kuwait Convention have been signed over the years, targeting pollution control from sources such as oil, exploration activities, land-based activities, shipping, and the disposal of hazardous materials. An additional protocol for biodiversity and protected areas has been discussed since the early 2000s but has not yet been implemented.

ROMPE has been important for promoting cooperation on marine pollution and initiating joint action, e.g. through ROPME Marine Emergency Mutual Aid Center (ROMPE/MEMAC) in Bahrain focusing on coordinating the Gulf's response to oil spills. The issue of brine discharge is part of the additional protocol on pollution from land-based sources adopted in the 1990s, which stipulates that regional regulations, programs, timetables, and measures need to be implemented to address pollution. However, regional action through ROPME has been limited to monitoring and analyses supported by international organisations. Integrating the increasingly important issue of brine discharge into future cooperative frameworks is an important step to effectively address this issue at the Gulf-wide scale. This also means shifting focus from analysing pollution and promoting protection to adopting more comprehensive measures including joint monitoring and regulation (Van Lavieren and Klaus, 2013). Further broader approaches that incorporate biodiversity protection and ecosystem management have been part of the original mandate of ROPME but are not yet reflected in the practice of regional cooperation (Hamza and Munawar, 2009; Khan, 2008).

6. Final remarks

The Arabian Gulf is considered one of the most anthropogenically affected seas. It is facing different types of stressors inducing marine pollution, which affect the health of the marine environment. It is undeniable that climate change, oil and gas activities, and coastal reclamation are major contributors to this problem. However, recent desalination has been a debatable contributor to marine pollution. Owing to the scarcity of freshwater resources, Arabian Gulf countries rely on desalinating seawater to produce freshwater, which is used for drinking, agriculture, and other purposes. For the longest time, desalination was thought to be a solution for the water scarcity issue in the region. However, recently, negative environmental effects of extensive desalination activity have been revealed. The Arabian Gulf mostly uses thermal-based desalination processes, which result in discharging huge amounts of hot, salt-concentrated brine directly into the sea. Discharge of the brine became a forefront of policy debates after it was neglected, especially in the Gulf area where desalination is extensive, and the natural environmental conditions are harsh.

Considerable effects of brine discharge have been reported worldwide necessitating the adoption of efficient monitoring systems in the Arabian Gulf. Monitoring should develop beyond simple measurements into more integrative, adaptive, and multivariate technologies. For that, genomic monitoring is the most efficient in terms of ease, applicability, and objective representation. Since the Arabian Gulf is considered a hot spot of desalination activities, it is important to implement management approaches at different levels to reduce the negative effect on marine ecosystems. Firstly, optimisation of plant design is a promising approach where many engineering parameters should be considered. Secondly, instead of direct discharge, brine should be treated pre-discharge. Finally, following in the footsteps of KEPA, laws and regulations for desalination activities should be implemented to prevent further damage to the Gulf's environment. Monitoring tools and assessment of the desalination activities should be incorporated into the regulations and policies to prevent future destruction of marine ecosystems.

CRediT authorship contribution statement

Hoda Hosseini: Writing - Original Draft, Conceptualization, Visualization; **Imen Saadaoui**: Supervision; Conceptualization; Writing - Review & Editing, Project administration; Funding acquisition; **Navid Moheimani**: Writing - Review & Editing; **Mohammad Al Saidi**: Writing - Review & Editing; **Fahad Al Jamali**: Writing - Review & Editing; **Hareb Al Jabri**: Resources.

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References

Abd El-Wahab, R.H., Al-Rashed, A.R., 2014. Conservation condition of Haloxylon salicornicum (Moq.) Bunge ex Boiss. in degraded desert habitats of northern Kuwait influence of disturbance intensitiy on plant diversity in coastal habitats view project the conservation and sustainable use of medicina. Int. J. Curr. Microbiol. App. Sci. 3, 310–325.

Aguirre, A.A., Tabor, GaryM, 2004. Introduction: marine vertebrates as sentinels of marine ecosystem health. EcoHealth 1. https://doi.org/10.1007/s10393-004-0091-9.

Ahlgren, J., Grimvall, A., Omstedt, A., Rolff, C., Wikner, J., 2017. Temperature, DOC level and basin interactions explain the declining oxygen concentrations in the Bothnian Sea. J. Mar. Syst. 170, 22–30. https://doi.org/10.1016/j.jmarsys.2016.12.010.

Ahmed, M., Anwar, R., 2012. An assessment of the environmental impact of brine disposal in marine environment. Int. J. Mod. Eng. Res. 2, 2756–2761.

Akins, E.R., Wang, Y., Zhou, Y., 2009. EO-1 advanced land imager data in submerged aquatic vegetation mapping. In: English Remote Sensing of Coastal Environments, pp. 297–312. https://doi.org/10.1201/9781420094428-c15.

Alameddine, I., El-Fadel, M., 2007. Brine discharge from desalination plants: a modeling approach to an optimized outfall design. Desalination 214, 241–260. https://doi.org/10.1016/j.desal.2006.02.103.

Alhanaee, G., Sanders, K., Meshkati, N., 2017. Rising Temperatures, Rising Risks: The Food-Energy-Water Nexus in the Persian Gulf. https://doi.org/10.1021/acs.est.7b00688.

Almasoud, F.I., Usman, A.R., Al-Farraj, A.S., 2015. Heavy metals in the soils of the Arabian Gulf coast affected by industrial activities: analysis and assessment using enrichment factor and multivariate analysis. Arab. J. Geosci. 8, 1691–1703. https://doi.org/10.1007/s12517-014-1298-x.

Al-Mutairi, N., Abahussain, A., Al-Battay, A., 2014. Environmental assessment of water quality in Kuwait Bay. Int. J. Environ. Sci. Dev. 5, 527–532. https://doi.org/10.7763/ijesd.2014.v5.539.

Al-Saidi, M., Saliba, S., 2019. Water, energy and food supply security in the Gulf Cooperation Council (GCC) countries-a risk perspective. Water. https://doi.org/10.3390/w11030455.

Al-Shammari, S.B., Ali, L., 2018. Effect of brine disposal on seawater quality at Az-Zour desalination plant in Kuwait: physical and chemical properties. J. Environ. Sci. Eng. A 7. https://doi.org/10.17265/2162-5298/2018.05.001.

Anttila, S., Fleming-Lehtinen, V., Attila, J., Junttila, S., Alasalmi, H., Hällfors, H., Kervinen, M., Koponen, S., 2018. A novel earth observation based ecological indicator for cyanobacterial blooms. Int. J. Appl. Earth Obs. Geoinf. 64, 145–155. https://doi.org/10.1016/j.jag.2017.09.007.

Azevedo-Santos, V.M., Garcia-Ayala, J.R., Fearnside, P.M., Esteves, F.A., Pelicice, F.M., Laurance, W.F., Benine, R.C., 2016. Amazon aquatic biodiversity imperiled by oil spills. Biodivers. Conserv. https://doi.org/10.1007/s10531-016-1192-9.

Baby, S., Nathawat, M.S., Al-Sarawi, M.A., 2014. Major impacts from anthropogenic activities on landscape carrying capacity of Kuwaiti coast. Pol. J. Environ. Stud. 23, 7–17.

Bagheri, S., Rijkeboer, M., Gons, H.J., 2002. Inherent and apparent optical measurements in the Hudson/Raritan estuary. Aquat. Ecol. 36, 559–562. https://doi.org/10.1023/A:1021114112617.

Barbier, E.B., 2017. Marine ecosystem services. Curr. Biol. 27, R507–R510. https://doi.org/10.1016/j.cub.2017.03.020.
Barnes, D.K.A., Brockington, S., 2003. Zoobenthic Biodiversity, Biomass and Abundance at 249, pp. 145–155.
Baztan, J., Jorgensen, B., Pahl, S., Thompson, R., 2016. MICRO 2016: Fate and Impact of Microplastics in Marine Ecosystems: From the Coastline to the Open Sea.
Beiras, R., 2018. Marine Pollution: Sources, Fate and Effects of Pollutants in Coastal Ecosystems.
Benaissa, M., Rouane-Hacene, O., Boutiba, Z., Guibbolini-Sabatier, M.E., Faverney, C.R.-D., 2017. Ecotoxicological impact assessment of the brine discharges from a desalination plant in the marine waters of the Algerian west coast, using a multibiomarker approach in a limpet, Patella rustica. Environ. Sci. Pollut. Res. 24, 24521–24532. https://doi.org/10.1007/s11356-017-0081-4.
Bik, H.M., Porazinska, D.L., Creer, S., Caporaso, J.G., Knight, R., Thomas, W.K., 2012. Sequencing our way towards understanding global eukaryotic biodiversity. Trends Ecol. Evol. https://doi.org/10.1016/j.tree.2011.11.010.
Bittle, M., Duncan, A., 2013. A review of current marine mammal detection and classification algorithms for use in automated passive acoustic monitoring. In: Annual Conference of the Australian Acoustical Society 2013. Acoustics 2013: Science, Technology and Amenity, pp. 208–215.
Blondeau-Patissier, D., Tilstone, G.H., Martinez-Vicente, V., Moore, G.F., 2004. Comparison of bio-physical marine products from SeaWiFS, MODIS and a bio-optical model with in situ measurements from Northern European waters. J. Opt. A Pure Appl. Opt. 6, 875–889. https://doi.org/10.1088/1464-4258/6/9/010.
Blumstein, D.T., Mennill, D.J., Clemins, P., Girod, L., Yao, K., Patricelli, G., Deppe, J.L., Krakauer, A.H., Clark, C., Cortopassi, K.A., Hanser, S.F., McCowan, B., Ali, A.M., Kirschel, A.N.G., 2011. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. J. Appl. Ecol. 48, 758–767. https://doi.org/10.1111/j.1365-2664.2011.01993.x.
Borja, A., Elliott, M., Andersen, J.H., Berg, T., Carstensen, J., Halpern, B.S., Heiskanen, A. S., Korpinen, S., Stewart Lowndes, J.S., Martin, G., Rodriguez-Ezpeleta, N., 2016. Overview of integrative assessment of marine systems: the ecosystem approach in practice. Front. Mar. Sci. https://doi.org/10.3389/fmars.2016.00020.
Bourlat, S.J., Borja, A., Gilbert, J., Taylor, M.I., Davies, N., Weisberg, S.B., Griffith, J.F., Lettieri, T., Field, D., Benzie, J., Glöckner, F.O., Rodríguez-Ezpeleta, N., Faith, D.P., Bean, T.P., Obst, M., 2013. Genomics in marine monitoring: new opportunities for assessing marine health status. Mar. Pollut. Bull. 74, 19–31. https://doi.org/10.1016/j.marpolbul.2013.05.042.
Boyes, S.J., Elliott, M., 2014. Marine legislation - the ultimate "horrendogram": international law, European directives & national implementation. Mar. Pollut. Bull. 86, 39–47. https://doi.org/10.1016/j.marpolbul.2014.06.055.
Bremner, J., Frid, C.L.J., Rogers, S.I., 2003. Assessing marine ecosystem health: the long-term effects of fishing on functional biodiversity in North Sea benthos. Aquat. Ecosyst. Health Manag. 6, 131–137. https://doi.org/10.1080/14634980301470.
Bricker, S.B., Longstaff, B., Dennison, W., Jones, A., Boicourt, K., Wicks, C., Woerner, J., 2008. Effects of nutrient enrichment in the nation's estuaries: a decade of change. Harmful Algae 8, 21–32. https://doi.org/10.1016/j.hal.2008.08.028.
Brooks, J.P., Edwards, D.J., Harwich, M.D., Rivera, M.C., Fettweis, J.M., Serrano, M.G., Reris, R.A., Sheth, N.U., Huang, B., Girerd, P., Strauss, J.F., Jefferson, K.K., Buck, G. A., 2015. The truth about metagenomics: quantifying and counteracting bias in 16S rRNA studies ecological and evolutionary microbiology. BMC Microbiol. 15 https://doi.org/10.1186/s12866-015-0351-6.
Brown, R.J., Galloway, T.S., Lowe, D., Browne, M.A., Dissanayake, A., Jones, M.B., Depledge, M.H., 2004. Differential sensitivity of three marine invertebrates to copper assessed using multiple biomarkers. Aquat. Toxicol. 66, 267–278. https://doi.org/10.1016/j.aquatox.2003.10.001.
Buros, O.K., 2000. The ABCs of Desalting. International Desalination Association, Topsfield, Mass, pp. 1–32.
Chapman, P.M., 2017. Assessing and managing stressors in a changing marine environment. Mar. Pollut. Bull. https://doi.org/10.1016/j.marpolbul.2016.10.039.
Chua, H.T., Rahimi, B., 2017. Low Grade Heat Driven Multi-effect Distillation and Desalination. Elsevier.
Claudet, J., Fraschetti, S., 2010. Human-driven impacts on marine habitats: a regional meta-analysis in the Mediterranean Sea. Biol. Conserv. 143, 2195–2206. https://doi.org/10.1016/j.biocon.2010.06.004.
Culligan, E.P., Sleator, R.D., 2016. Editorial: from genes to species: novel insights from metagenomics. Front. Microbiol. https://doi.org/10.3389/fmicb.2016.01181.
Danoun, R., 2007. Potential impacts of brine discharge on marine life. Desalin. Plants 59.
Dawoud, M.A., Al Mulla, M., 2012. Environmental impacts of seawater desalination: Arabian Gulf case study. Int. J. Environ. Sustain. 1, 22–37. https://doi.org/10.24102/ijes.v1i3.96.
De La Huz, R., Lastra, M., Junoy, J., Castellanos, C., Viéitez, J.M., 2005. Biological impacts of oil pollution and cleaning in the intertidal zone of exposed sandy beaches: preliminary study of the "prestige" oil spill. Estuar. Coast. Shelf Sci. 65, 19–29. https://doi.org/10.1016/j.ecss.2005.03.024.
Dekker, A., Brando, V., Anstee, J., Fyfe, S., Malthus, T., Karpouzli, E., 2006. Remote sensing of seagrass ecosystems: use of spaceborne and airborne sensors. In: Seagrasses: Biology, Ecology and Conservation, pp. 347–359. https://doi.org/10.1007/978-1-4020-2983-7_15.
Devens, H.R., Davidson, P.L., Deaker, D.J., Smith, K.E., Wray, G.A., Byrne, M., 2020. Ocean acidification induces distinct transcriptomic responses across life history stages of the sea urchin *Heliocidaris erythrogramma*. Mol. Ecol. 29, 4618–4636. https://doi.org/10.1111/mec.15664.
DiBattista, J.D., Reimer, J.D., Stat, M., Masucci, G.D., Biondi, P., De Brauwer, M., Wilkinson, S.P., Chariton, A.A., Bunce, M., 2020. Environmental DNA can act as a biodiversity barometer of anthropogenic pressures in coastal ecosystems. Sci. Rep. 10, 8365. https://doi.org/10.1038/s41598-020-64858-9.
Doney, S.C., Ruckelshaus, M., Emmett Duffy, J., Barry, J.P., Chan, F., English, C.A., Galindo, H.M., Grebmeier, J.M., Hollowed, A.B., Knowlton, N., Polovina, J., Rabalais, N.N., Sydeman, W.J., Talley, L.D., 2012. Climate change impacts on marine ecosystems. Annu. Rev. Mar. Sci. 4, 11–37. https://doi.org/10.1146/annurev-marine-041911-111611.
Doucette, G.J., Mikulski, C.M., Jones, K.L., King, K.L., Greenfield, D.I., Marin, R., Jensen, S., Roman, B., Elliott, C.T., Scholin, C.A., 2009. Remote, subsurface detection of the algal toxin domoic acid onboard the environmental sample processor: assay development and field trials. Harmful Algae 8, 880–888. https://doi.org/10.1016/j.hal.2009.04.006.
Downs, C.A., Shigenaka, G., Fauth, J.E., Robinson, C.E., Huang, A., 2002. Cellular physiological assessment of bivalves after chronic exposure to spilled Exxon Valdez crude oil using a novel molecular diagnostic biotechnology. Environ. Sci. Technol. 36, 2987–2993. https://doi.org/10.1021/es011433k.
Elasha, B.O., 2010. Mapping of climate change threats and human development impacts in the Arab region. In: Arab Human Development Report. UNDP Arab Development Report–Research Paper, 51.
Elsayed, M.L., Mesalhy, O., Mohammed, R.H., Chow, L.C., 2018. Effect of disturbances on MED-TVC plant characteristics: dynamic modeling and simulation. Desalination 443, 99–109. https://doi.org/10.1016/j.desal.2018.05.021.
Fernández-Torquemada, Y., Sánchez-Lizaso, J.L., González-Correa, J.M., 2005. Preliminary results of the monitoring of the brine discharge produced by the SWRO desalination plant of Alicante (SE Spain). Desalination 182, 395–402. https://doi.org/10.1016/j.desal.2005.03.023.
Fernández-Torquemada, Y., Carratalá, A., Sánchez Lizaso, J.L., 2019. Impact of brine on the marine environment and how it can be reduced. DWT 167, 27–37. https://doi.org/10.5004/dwt.2019.24615.
Frank, H., Rahav, E., Bar-Zeev, E., 2017. Short-term effects of SWRO desalination brine on benthic heterotrophic microbial communities. Desalination 417, 52–59. https://doi.org/10.1016/j.desal.2017.04.031.
Frank, H., Fussmann, K.E., Rahav, E., Bar Zeev, E., 2019. Chronic effects of brine discharge from large-scale seawater reverse osmosis desalination facilities on benthic bacteria. Water Res. 151, 478–487. https://doi.org/10.1016/j.watres.2018.12.046.
Fucile, P.D., Singer, R.C., Baumgartner, M., Ball, K., 2006. A self contained recorder for acoustic observations from AUV's. OCEANS 2006. https://doi.org/10.1109/OCEANS.2006.306975.
Galloway, T.S., Sanger, R.C., Smith, K.L., Fillmann, G., Readman, J.W., Ford, T.E., Depledge, M.H., 2002. Rapid assessment of marine pollution using multiple biomarkers and chemical immunoassays. Environ. Sci. Technol. 36, 2219–2226. https://doi.org/10.1021/es010300w.
Gattuso, J.P., Magnan, A., Billé, R., Cheung, W.W.L., Howes, E.L., Joos, F., Allemand, D., Bopp, L., Cooley, S.R., Eakin, C.M., Hoegh-Guldberg, O., Kelly, R.P., Pörtner, H.O., Rogers, A.D., Baxter, J.M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., Sumaila, U.R., Treyer, S., Turley, C., 2015. Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. Science. https://doi.org/10.1126/science.aac4722.
Gross, J.E., Goetz, S.J., Cihlar, J., 2009. Remote sensing of environment application of remote sensing to parks and protected area monitoring: introduction to the special issue. Remote Sens. Environ. 113, 1343–1345. https://doi.org/10.1016/j.rse.2008.12.013.
Grossowicz, M., Ofir, E., Shabtay, A., Wood, J., Biton, E., Belkin, N., Frid, O., Sisma-Ventura, G., Kress, N., Berman-Frank, I., Gal, G., 2020. Modeling the effects of brine outflow from desalination plants on coastal food-webs of the Levantine basin (eastern Mediterranean Sea). Desalination 496, 114757. https://doi.org/10.1016/j.desal.2020.114757.
Günther, B., Knebelsberger, T., Neumann, H., Laakmann, S., Martínez Arbizu, P., 2018. Metabarcoding of marine environmental DNA based on mitochondrial and nuclear genes. Sci. Rep. 8, 14822. https://doi.org/10.1038/s41598-018-32917-x.
Haase, P., Tonkin, J.D., Stoll, S., Burkhard, B., Frenzel, M., Geijzendorffer, I.R., Häuser, C., Klotz, S., Kühn, I., McDowell, W.H., Mirtl, M., Müller, F., Musche, M., Penner, J., Zacharias, S., Schmeller, D.S., 2018. The next generation of site-based long-term ecological monitoring: linking essential biodiversity variables and ecosystem integrity. Sci. Total Environ. 613–614, 1376–1384. https://doi.org/10.1016/j.scitotenv.2017.08.111.
Hahn, M.E., 2002. Biomarkers and bioassays for detecting dioxin-like compounds in the marine environment. Sci. Total Environ. 289, 49–69. https://doi.org/10.1016/S0048-9697(01)01016-6.
Hajibabaei, M., Shokralla, S., Zhou, X., Singer, G.A.C., Baird, D.J., 2011. Environmental barcoding: a next-generation sequencing approach for biomonitoring applications using river benthos. PLoS One 6. https://doi.org/10.1371/journal.pone.0017497.
Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952. https://doi.org/10.1126/science.1149345.
Halpern, B.S., Frazier, M., Potapenko, J., Casey, K.S., Koenig, K., Longo, C., Lowndes, J. S., Rockwood, R.C., Selig, E.R., Selkoe, K.A., Walbridge, S., 2015. Spatial and temporal changes in cumulative human impacts on the world's ocean. Nat. Commun. 6, 7615. https://doi.org/10.1038/ncomms8615.
Hamel, M.A., Andréfouët, S., 2010. Using very high resolution remote sensing for the management of coral reef fisheries: review and perspectives. Mar. Pollut. Bull. 60, 1397–1405. https://doi.org/10.1016/j.marpolbul.2010.07.002.

Hamza, W., Munawar, M., 2009. Protecting and managing the Arabian Gulf: past, present and future. Aquat. Ecosyst. Health Manag. 12, 429–439. https://doi.org/10.1080/14634980903361580.
He, Z., Gentry, T.J., Schadt, C.W., Wu, L., Liebich, J., Chong, S.C., Huang, Z., Wu, W., Gu, B., Jardine, P., Criddle, C., Zhou, J., 2007. GeoChip: a comprehensive microarray for investigating biogeochemical, ecological and environmental processes. ISME J. 1, 67–77. https://doi.org/10.1038/ismej.2007.2.
Hebert, P.D.N., Ratnasingham, S., DeWaard, J.R., 2003. Barcoding animal life: cytochrome c oxidase subunit 1 divergences among closely related species. Proc. R. Soc. B Biol. Sci. 270 https://doi.org/10.1098/rsbl.2003.0025.
Henson, S.A., Beaulieu, C., Ilyina, T., John, J.G., Long, M., Séférian, R., Tjiputra, J., Sarmiento, J.L., 2017. Rapid emergence of climate change in environmental drivers of marine ecosystems. Nat. Commun. 8 https://doi.org/10.1038/ncomms14682.
Hewitt, J.E., Anderson, M.J., Thrush, S.F., 2005. Assessing and monitoring ecological community health in marine systems. Ecol. Appl. 15, 942–953. https://doi.org/10.1890/04-0732.
Hosmani, S., 2013. Fresh water algae as indicators of water quality. Univ. J. Environ. Res. Technol. 3, 473–482 www.environmentaljournal.org.
Hosmani, S., 2014. Freshwater plankton ecology: a review. Abhinav Int. Month. J. Res. Manag. Technol. 3, 1–10.
Ibrahim, H.D., Eltahir, E.A.B., 2019. Impact of brine discharge from seawater desalination plants on Persian/Arabian Gulf salinity. J. Environ. Eng. (U. S.) 145, 1–12. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001604.
Isensee, K., Valdes, L., 2018. The ocean is losing its breath: declining oxygen in the world's ocean and coastal waters – summary for policy makers. IOC-UNESCO IOC Techn. Ser. 137, 1–40.
Johnston, E.L., Roberts, D.A., 2009. Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. Environ. Pollut. https://doi.org/10.1016/j.envpol.2009.02.017.
Jones, M.C., Cheung, W.W.L., 2015. Multi-model ensemble projections of climate change effects on global marine biodiversity. ICES J. Mar. Sci. 72, 741–752. https://doi.org/10.1093/icesjms/fsu172.
de Jonge, V.N., Elliott, M., Brauer, V.S., 2006. Marine monitoring: its shortcomings and mismatch with the EU Water Framework Directive's objectives. Mar. Pollut. Bull. 53, 5–19. https://doi.org/10.1016/j.marpolbul.2005.11.026.
Joydas, T.V., Qurban, M.A., Manikandan, K.P., Ashraf, T.T.M., Ali, S.M., Al-Abdulkader, K., Qasem, A., Krishnakumar, P.K., 2015. Status of macrobenthic communities in the hypersaline waters of the Gulf of Salwa, Arabian Gulf. J. Sea Res. 99, 34–46. https://doi.org/10.1016/j.seares.2015.01.006.
Kalan, A.K., Mundry, R., Wagner, O.J.J., Heinicke, S., Boesch, C., Kühl, H.S., 2015. Towards the automated detection and occupancy estimation of primates using passive acoustic monitoring. Ecol. Indic. 54, 217–226. https://doi.org/10.1016/j.ecolind.2015.02.023.
Kalyuzhnaya, M.G., Lapidus, A., Ivanova, N., Copeland, A.C., McHardy, A.C., Szeto, E., Salamov, A., Grigoriev, I.V., Suciu, D., Levine, S.R., Markowitz, V.M., Rigoutsos, I., Tringe, S.G., Bruce, D.C., Richardson, P.M., Lidstrom, M.E., Chistoserdova, L., 2008. High-resolution metagenomics targets specific functional types in complex microbial communities. Nat. Biotechnol. 26, 1029–1034. https://doi.org/10.1038/nbt.1488.
Kenigsberg, C., Abramovich, S., Hyams-Kaphzan, O., 2020. The effect of long-term brine discharge from desalination plants on benthic foraminifera. PLoS One 15, e0227589. https://doi.org/10.1371/journal.pone.0227589.
Khan, N.Y., 2008. Integrated management of pollution stress in the Gulf. In: Protecting the Gulf's Marine Ecosystems from Pollution, pp. 57–92. https://doi.org/10.1007/978-3-7643-7947-6_4. Birkhäuser Basel.
Khoshrou, I., Jafari Nasr, M.R., Bakhtari, K., 2017. New opportunities in mass and energy consumption of the Multi-Stage Flash Distillation type of brackish water desalination process. Sol. Energy 153, 115–125. https://doi.org/10.1016/j.solener.2017.05.021.
Klemas, V., 2010. Remote sensing techniques for studying coastal ecosystems: an overview. J. Coast. Res. 27, 2. https://doi.org/10.2112/jcoastres-d-10-00103.1.
Krayer, A., Michaels, M., Solomon, T., 2017. Salinity impacts on coastal wastewater treatment facilities. In: Major Qualifying Projects (All Years).
Kress, N., Oceanographic, I., Galil, B., 2018. Impact of seawater desalination by reverse osmosis on the marine environment. In: Efficient Desalination by Reverse Osmosis. IWA, London, pp. 175–202.
Kress, N., Gertner, Y., Shoham-Frider, E., 2020. Seawater quality at the brine discharge site from two mega size seawater reverse osmosis desalination plants in Israel (Eastern Mediterranean). Water Res. 171, 115402. https://doi.org/10.1016/j.watres.2019.115402.
Krishna, J., 2004. Introduction to desalination. In: Texas Water Development, 2, pp. 1–37. https://doi.org/10.1002/9781118904855.ch1.
Kuenzer, C., Bluemel, A., Gebhardt, S., Quoc, T.V., Dech, S., 2011. Remote sensing of mangrove ecosystems: a review. Remote Sens. https://doi.org/10.3390/rs3050878.
Lammers, M.O., Brainard, R.E., Au, W.W.L., Mooney, T.A., Wong, K.B., 2008. An ecological acoustic recorder (EAR) for long-term monitoring of biological and anthropogenic sounds on coral reefs and other marine habitats. J. Acoust. Soc. Am. 123, 1720–1728. https://doi.org/10.1121/1.2836780.
Lattemann, S., Höpner, T., 2008. Environmental impact and impact assessment of seawater desalination. Desalination 220, 1–15. https://doi.org/10.1016/j.desal.2007.03.009.
Laurent, A., Fennel, K., Cai, W.J., Huang, W.J., Barbero, L., Wanninkhof, R., 2017. Eutrophication-induced acidification of coastal waters in the northern Gulf of Mexico: insights into origin and processes from a coupled physical-biogeochemical model. Geophys. Res. Lett. 44, 946–956. https://doi.org/10.1002/2016GL071881.
LeBlanc, F., Belliveau, V., Watson, E., Coomber, C., Simard, N., DiBacco, C., Bernier, R., Gagné, N., 2020. Environmental DNA (eDNA) detection of marine aquatic invasive species (AIS) in Eastern Canada using a targeted species-specific qPCR approach. MBI 11, 201–217. https://doi.org/10.3391/mbi.2020.11.2.03.
Leese, F., Altermatt, F., Bouchez, A., Ekrem, T., Hering, D., Meissner, K., Mergen, P., Pawlowski, J., Piggott, J., Rimet, F., Steinke, D., Taberlet, P., Weigand, A., Abarenkov, K., Beja, P., Bervoets, L., Björnsdóttir, S., Boets, P., Boggero, A., Bones, A., Borja, Á., Bruce, K., Bursić, V., Carlsson, J., Čiampor, F., Čiamporová-Zatovičová, Z., Coissac, E., Costa, F., Costache, M., Creer, S., Csabai, Z., Deiner, K., DelValls, Á., Drakare, S., Duarte, S., Eleršek, T., Fazi, S., Fišer, C., Flot, J.-F., Fonseca, V., Fontaneto, D., Grabowski, M., Graf, W., Guðbrandsson, J., Hellström, M., Hershkovitz, Y., Hollingsworth, P., Japoshvili, B., Jones, J., Kahlert, M., Kalamujic Stroil, B., Kasapidis, P., Kelly, M., Kelly-Quinn, M., Keskin, E., Kõljalg, U., Ljubešić, Z., Maček, I., Mächler, E., Mahon, A., Marečková, M., Mejdandzic, M., Mircheva, G., Montagna, M., Moritz, C., Mulk, V., Naumoski, A., Navodaru, I., Padisák, J., Pálsson, S., Panksep, K., Penev, L., Petrusek, A., Pfannkuchen, M., Primmer, C., Rinkevich, B., Rotter, A., Schmidt-Kloiber, A., Segurado, P., Speksnijder, A., Stoev, P., Strand, M., Šulčius, S., Sundberg, P., Traugott, M., Tsigenopoulos, C., Turon, X., Valentini, A., van der Hoorn, B., Várbíró, G., Vasquez Hadjilyra, M., Viguri, J., Vitonytė, I., Vogler, A., Vrålstad, T., Wägele, W., Wenne, R., Winding, A., Woodward, G., Zegura, B., Zimmermann, J., 2016. DNAqua-Net: developing new genetic tools for bioassessment and monitoring of aquatic ecosystems in Europe. Res. Ideas Outcomes 2, e11321. https://doi.org/10.3897/rio.2.e11321.
Lemcke, S., Holding, J., Møller, E.F., Thyrring, J., Gustavson, K., Juul-Pedersen, T., Sejr, M.K., 2019. Acute oil exposure reduces physiological process rates in Arctic phyto- and zooplankton. Ecotoxicology 28, 26–36. https://doi.org/10.1007/s10646-018-1995-4.
Loughland, R.A., Al-Abdulkader, K.A., Wyllie, A., Burwell, B.O., 2012. Anthropogenic induced geomorphological change along the Western Arabian Gulf Coast. In: Studies on Environmental and Applied Geomorphology. IntechOpen. https://doi.org/10.5772/28330.
Luo, C., Rodriguez-R, L.M., Konstantinidis, K.T., 2014. MyTaxa: an advanced taxonomic classifier for genomic and metagenomic sequences. Nucleic Acids Res. 42 https://doi.org/10.1093/nar/gku169.
Mabrouk, A.N., Fath, H.E.S., 2015. Technoeconomic study of a novel integrated thermal MSF-MED desalination technology. Desalination 371, 115–125. https://doi.org/10.1016/j.desal.2015.05.025.
MacNeil, M.A., Graham, N.A.J., Cinner, J.E., Dulvy, N.K., Loring, P.A., Jennings, S., Polunin, N.V.C., Fisk, A.T., McClanahan, T.R., 2010. Transitional states in marine fisheries: adapting to predicted global change. Philos. Trans. R. Soc. B Biol. Sci. https://doi.org/10.1098/rstb.2010.0289.
Mardis, E.R., 2008. The impact of next-generation sequencing technology on genetics. Trends Genet. 24, 133–141. https://doi.org/10.1016/j.tig.2007.12.007.
Marques, T.A., Thomas, L., Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J., Harris, D., Tyack, P.L., 2013. Estimating animal population density using passive acoustics. Biol. Rev. 88, 287–309. https://doi.org/10.1111/brv.12001.
Matsumoto, J.K., Martin, K.L.M., 2008. Lethal and sublethal effects of altered sand salinity on embryos of beach-spawning California grunion. Copeia 2008, 484–491. https://doi.org/10.1643/cp-07-097.
McCauley, D.J., Pinsky, M.L., Palumbi, S.R., Estes, J.A., Joyce, F.H., Warner, R.R., 2015. Marine defaunation: animal loss in the global ocean. Science. https://doi.org/10.1126/science.1255641.
McDonald, D., Vázquez-Baeza, Y., Walters, W.A., Caporaso, J.G., Knight, R., 2013. From molecules to dynamic biological communities. Biol. Philos. 28, 241–259. https://doi.org/10.1007/s10539-013-9364-4.
McGenity, T.J., Folwell, B.D., McKew, B.A., Sanni, G.O., 2012. Marine crude-oil biodegradation: a central role for interspecies interactions. Aquat. Biosyst.. https://doi.org/10.1186/2046-9063-8-10.
Mendes, R.S., Evangelista, L.R., Thomaz, S.M., Agostinho, A.A., Gomes, L.C., 2008. A unified index to measure ecological diversity and species rarity. Ecography 31, 450–456. https://doi.org/10.1111/j.0906-7590.2008.05469.x.
Meshkati, N., Tabibzadeh, M., Farshid, A., Rahimi, M., Alhanaee, G., 2016. People-technology-ecosystem integration: a framework to ensure regional interoperability for safety, sustainability, and resilience of interdependent energy, water, and seafood sources in the (Persian) gulf. Hum. Factors 58, 43–57. https://doi.org/10.1177/0018720815623143.
Miller, S., Shemer, H., Semiat, R., 2015. Energy and environmental issues in desalination. Desalination 366, 2–8. https://doi.org/10.1016/j.desal.2014.11.034.
Missimer, T.M., Maliva, R.G., 2018. Environmental issues in seawater reverse osmosis desalination: intakes and outfalls. Desalination. https://doi.org/10.1016/j.desal.2017.07.012.
Missimer, T.M., Ghaffour, N., Dehwah, A.H.A., Rachman, R., Maliva, R.G., Amy, G., 2013. Subsurface intakes for seawater reverse osmosis facilities: capacity limitation, water quality improvement, and economics. Desalination 322, 37–51. https://doi.org/10.1016/j.desal.2013.04.021.
Modarress, B., Ansari, A., Thies, E., 2016. Outsourcing in the Persian Gulf petroleum supply chain. Strategic Outsourcing 9, 2–21. https://doi.org/10.1108/SO-08-2015-0019.
Moore, M.N., Depledge, M.H., Readman, J.W., Leonard, D.P., 2004. An integrated biomarker-based strategy for ecotoxicological evaluation of risk in environmental management. Mutat. Res. Fundam. Mol. Mech. Mutagen. https://doi.org/10.1016/j.mrfmmm.2004.06.028.
de Mora, S., Tolosa, I., Fowler, S.W., Villeneuve, J.P., Cassi, R., Cattini, C., 2010. Distribution of petroleum hydrocarbons and organochlorinated contaminants in marine biota and coastal sediments from the ROPME Sea Area during 2005. Mar. Pollut. Bull. 60, 2323–2349. https://doi.org/10.1016/j.marpolbul.2010.09.021.

Naser, H.A., 2014. Marine ecosystem diversity in the Arabian Gulf: threats and conservation. In: Biodiversity - The Dynamic Balance of the Planet. https://doi.org/10.5772/57425.
Naser, H.A., 2015. The role of environmental impact assessment in protecting coastal and marine environments in rapidly developing islands: the case of Bahrain, Arabian Gulf. Ocean Coast. Manag. 104, 159–169. https://doi.org/10.1016/j.ocecoaman.2014.12.009.
Naser, H.A., 2017. Variability of marine macrofouling assemblages in a marina and a mariculture centre in Bahrain, Arabian Gulf. Reg. Stud. Mar. Sci. 16, 162–170. https://doi.org/10.1016/j.rsma.2017.09.005.
Nasr, H., Yousef, M., Madkour, H., 2019. Impacts of discharge of desalination plants on marine environment at the southern part of the Egyptian Red Sea coast (case study). Int. J. Ecotoxicol. Ecobiol. 4, 66. https://doi.org/10.11648/j.ijee.20190403.12.
National Research Council, 2008. Desalination: A National Perspective. National Academies Press. https://doi.org/10.17226/12184.
Odhiambo, G.O., 2017. Water scarcity in the Arabian Peninsula and socio-economic implications. Appl Water Sci 7, 2479–2492. https://doi.org/10.1007/s13201-016-0440-1.
Oliver, M.J., Glenn, S., Kohut, J.T., Irwin, A.J., Schofield, O.M., Moline, M.A., Bissett, W.P., 2004. Bioinformatic approaches for objective detection of water masses on continental shelves. J. Geophys. Res. C Oceans 109. https://doi.org/10.1029/2003JC002072.
Pagola-Carte, S., Saiz-Salinas, J.I., 2001. Changes in the sublittoral faunal biomass induced by the discharge of a polluted river along the adjacent rocky coast (N. Spain). Mar. Ecol. Prog. Ser. 212, 13–27. https://doi.org/10.3354/meps212013.
Palenzuela, P., Alarcón-Padilla, D.C., Zaragoza, G., 2015. Large-scale solar desalination by combination with CSP: techno-economic analysis of different options for the Mediterranean Sea and the Arabian Gulf. Desalination 366, 130–138. https://doi.org/10.1016/j.desal.2014.12.037.
Panagopoulos, A., Haralambous, K.J., Loizidou, M., 2019. Desalination brine disposal methods and treatment technologies - a review. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2019.07.351.
Parks, S.E., Miksis-Olds, J.L., Denes, S.L., 2014. Assessing marine ecosystem acoustic diversity across ocean basins. Ecol. Inform. 21, 81–88. https://doi.org/10.1016/j.ecoinf.2013.11.003.
Parmar, T.K., Rawtani, D., Agrawal, Y.K., 2016. Bioindicators: the natural indicator of environmental pollution. Front. Life Sci. 9, 110–118. https://doi.org/10.1080/21553769.2016.1162753.
Pashaei, R., Gholizadeh, M., Iran, K.J., Hanifi, A., 2015. The effects of oil spills on ecosystem at the Persian Gulf. Int. J. Rev. Life Sci. 5, 82–89. https://doi.org/10.13140/RG.2.1.2239.3684.
Peters, S., Brockmann, C., Eleveld, M., Pasterkamp, R., Van DerWoerd, H., Ruddick, K., Park, Y., Block, T., Doerffer, R., Krasemann, H., Roettgers, R., Schoenfeld, W., Joergensen, P., Tilstone, G., Martinez-Vicente, V., Moore, G., Soerensen, K., Hokedal, J., Aas, E., 2005. Regional Chlorophyll Retrieval Algorithms for North Sea Waters: Intercomparison and Validation. European Space Agency, (Special Publication) ESA SP, pp. 347–356.
Petersen, K.L., Paytan, A., Rahav, E., Levy, O., Silverman, J., Barzel, O., Potts, D., Bar-Zeev, E., 2018. Impact of brine and antiscalants on reef-building corals in the Gulf of Aqaba – potential effects from desalination plants. Water Res. 144, 183–191. https://doi.org/10.1016/j.watres.2018.07.009.
Pettorelli, N., Safi, K., Turner, W., 2014. Satellite remote sensing, biodiversity research and conservation of the future. Philos. Trans. R. Soc. B Biol. Sci. 369 https://doi.org/10.1098/rstb.2013.0190.
Philpot, W., 2007. Estimating atmospheric transmission and surface reflectance from a glint-contaminated spectral image. IEEE Trans. Geosci. Remote Sens. 45, 448–457. https://doi.org/10.1109/TGRS.2006.887161.
Ranjan, R., Rani, A., Metwally, A., McGee, H.S., Perkins, D.L., 2016. Analysis of the microbiome: advantages of whole genome shotgun versus 16S amplicon sequencing. Biochem. Biophys. Res. Commun. 469, 967–977. https://doi.org/10.1016/j.bbrc.2015.12.083.
Rivas, A.L., Dogliotti, A.I., Gagliardini, D.A., 2006. Seasonal variability in satellite-measured surface chlorophyll in the Patagonian Shelf. Cont. Shelf Res. 26, 703–720. https://doi.org/10.1016/j.csr.2006.01.013.
Roberts, D.A., Johnston, E.L., Knott, N.A., 2010. Impacts of desalination plant discharges on the marine environment: a critical review of published studies. Water Res. https://doi.org/10.1016/j.watres.2010.04.036.
Sandoval-Gil, J.M., Marín-Guirao, L., Ruiz, J.M., 2012. The effect of salinity increase on the photosynthesis, growth and survival of the Mediterranean seagrass Cymodocea nodosa. Estuar. Coast. Shelf Sci. 115, 260–271. https://doi.org/10.1016/j.ecss.2012.09.008.
Schuster, S.C., 2008. Next-generation sequencing transforms today's biology. Nat. Methods. https://doi.org/10.1038/nmeth1156.
Shah, N., Tang, H., Doak, T.G., Ye, Y., 2011. Comparing bacterial communities inferred from 16S rRNA gene sequencing and shotgun metagenomics. In: Pacific Symposium on Biocomputing 2011, PSB 2011, pp. 165–176. https://doi.org/10.1142/9789814335058_0018.
Sharifinia, M., Afshari Bahmanbeigloo, Z., Smith, W.O., Yap, C.K., Keshavarzifard, M., 2019. Prevention is better than cure: Persian Gulf biodiversity vulnerability to the impacts of desalination plants. Glob. Chang. Biol. https://doi.org/10.1111/gcb.14808.
Siddig, A.A.H., Ellison, A.M., Ochs, A., Villar-Leeman, C., Lau, M.K., 2016. How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in ecological indicators. Ecol. Indic. https://doi.org/10.1016/j.ecolind.2015.06.036.
Simboura, N., Zenetos, A., 2002. Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new Biotic Index. Mediterr. Mar. Sci. 3, 77–111. https://doi.org/10.12681/mms.249.
Sims, D., Sudbery, I., Ilott, N.E., Heger, A., Ponting, C.P., 2014. Sequencing depth and coverage: key considerations in genomic analyses. Nat. Rev. Genet. https://doi.org/10.1038/nrg3642.
Singh, U.B., Ahluwalia, A.S., Sharma, C., Jindal, R., Thakur, R.K., 2013. Planktonic indicators: a promising tool for monitoring water quality (early-warning signals). Ecol. Environ. Conserv. 19, 793–800.
Širović, A., Hildebrand, J.A., Wiggins, S.M., Thiele, D., 2009. Blue and fin whale acoustic presence around Antarctica during 2003 and 2004. Mar. Mammal Sci. 25, 125–136. https://doi.org/10.1111/j.1748-7692.2008.00239.x.
Smith, C.J., Osborn, A.M., 2009. Advantages and limitations of quantitative PCR (Q-PCR)-based approaches in microbial ecology. FEMS Microbiol. Ecol. https://doi.org/10.1111/j.1574-6941.2008.00629.x.
Soldevilla, M.S., Wiggins, S.M., Hildebrand, J.A., 2010. Spatial and temporal patterns of Risso's dolphin echolocation in the Southern California Bight. J. Acoust. Soc. Am. 127, 124–132. https://doi.org/10.1121/1.3257586.
Soliman, Y.S., Al Ansari, E.M.S., Wade, T.L., 2014. Concentration, composition and sources of PAHs in the coastal sediments of the exclusive economic zone (EEZ) of Qatar, Arabian Gulf. Mar. Pollut. Bull. 85, 542–548. https://doi.org/10.1016/j.marpolbul.2014.04.027.
Sousa-Lima, R.S., Norris, T.F., Oswald, J.N., Fernandes, D.P., 2013. A review and inventory of fixed autonomous recorders for passive acoustic monitoring of marine mammals. Aquat. Mamm. https://doi.org/10.1578/AM.39.2.2013.205.
Steinacher, M., Joos, F., Frölicher, T.L., Bopp, L., Cadule, P., Cocco, V., Doney, S.C., Gehlen, M., Lindsay, K., Moore, J.K., Schneider, B., Segschneider, J., 2010. Projected 21st century decrease in marine productivity: a multi-model analysis. Biogeosciences 7, 979–1005. https://doi.org/10.5194/bg-7-979-2010.
Strong, J.A., Andonegi, E., Bizsel, K.C., Danovaro, R., Elliott, M., Franco, A., Garces, E., Little, S., Mazik, K., Moncheva, S., Papadopoulou, N., Patrício, J., Queirós, A.M., Smith, C., Stefanova, K., Solaun, O., 2015. Marine biodiversity and ecosystem function relationships: the potential for practical monitoring applications. Estuar. Coast. Shelf Sci. https://doi.org/10.1016/j.ecss.2015.04.008.
Sueur, J., Pavoine, S., Hamerlynck, O., Duvail, S., 2008. Rapid acoustic survey for biodiversity appraisal. PLoS One 3. https://doi.org/10.1371/journal.pone.0004065.
Swiston, K.A., Mennill, D.J., 2009. Comparison of manual and automated methods for identifying target sounds in audio recordings of pileated, pale-billed, and putative ivory-billed woodpeckers. J. Field Ornithol. 80, 42–50. https://doi.org/10.1111/j.1557-9263.2009.00204.x.
Taylor, H.R., Harris, W.E., 2012. An emergent science on the brink of irrelevance: a review of the past 8 years of DNA barcoding. Mol. Ecol. Resour. https://doi.org/10.1111/j.1755-0998.2012.03119.x.
Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., Steininger, M., 2003. Remote sensing for biodiversity science and conservation. Trends Ecol. Evol. https://doi.org/10.1016/S0169-5347(03)00070-3.
Uddin, S., 2014. Environmental impacts of desalination activities in the Arabian Gulf. Int. J. Environ. Sci. Develop. 5, 114–117. https://doi.org/10.7763/ijesd.2014.v5.461.
Uddin, S., Al Ghadban, A.N., Khabbaz, A., 2011. Localized hyper saline waters in Arabian Gulf from desalination activity-an example from South Kuwait. Environ. Monit. Assess. 181, 587–594. https://doi.org/10.1007/s10661-010-1853-1.
Valero, F., Arbós, R., 2010. Desalination of brackish river water using Electrodialysis Reversal (EDR). Control of the THMs formation in the Barcelona (NE Spain) area. Desalination 253, 170–174. https://doi.org/10.1016/j.desal.2009.11.011.
Van Lavieren, H., Klaus, R., 2013. An effective regional marine protected area network for the ROPME Sea area: unrealistic vision or realistic possibility? Mar. Pollut. Bull. 72, 389–405. https://doi.org/10.1016/j.marpolbul.2012.09.004.
Vaquer-Sunyer, R., Duarte, C.M., 2008. Thresholds of hypoxia for marine biodiversity. Proc. Natl. Acad. Sci. U. S. A. 105, 15452–15457. https://doi.org/10.1073/pnas.0803833105.
Viarengo, A., Burlando, B., Giordana, A., Bolognesi, C., Gabrielides, G.P., 2000. Networking and expert-system analysis: next frontier in biomonitoring. Mar. Environ. Res. 49, 483–486. https://doi.org/10.1016/S0141-1136(00)00027-1.
Wabnitz, C.C.C., Andréfouët, S., Muller-Karger, F.E., 2010. Measuring progress toward global marine conservation targets. Front. Ecol. Environ. 8, 124–129. https://doi.org/10.1890/080109.
Wabnitz, C.C.C., Lam, V.W.Y., Reygondeau, G., Teh, L.C.L., Al-Abdulrazzak, D., Khalfallah, M., Pauly, D., Deng Palomares, M.L., Zeller, D., Cheung, W.W.L., 2018. Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. PLoS One 13. https://doi.org/10.1371/journal.pone.0194537.
van der Wal, D., Herman, P.M.J., 2007. Regression-based synergy of optical, shortwave infrared and microwave remote sensing for monitoring the grain-size of intertidal sediments. Remote Sens. Environ. 111, 89–106. https://doi.org/10.1016/j.rse.2007.03.019.
Whitfield, A.K., Elliott, M., 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. J. Fish Biol. 61, 229–250. https://doi.org/10.1111/j.1095-8649.2002.tb01773.x.
Wiggins, S.M., McDonald, M.A., Hildebrand, J.A., 2012. Beaked whale and dolphin tracking using a multichannel autonomous acoustic recorder. J. Acoust. Soc. Am. 131, 156–163. https://doi.org/10.1121/1.3662076.
Wiltshire, K.H., Kraberg, A., Bartsch, I., Boersma, M., Franke, H.D., Freund, J., Gebühr, C., Gerdts, G., Stockmann, K., Wichels, A., 2010. Helgoland roads, north sea: 45 years of change. Estuar. Coasts 33, 295–310. https://doi.org/10.1007/s12237-009-9228-y.

Wood, J.E., Silverman, J., Galanti, B., Biton, E., 2020. Modelling the distributions of desalination brines from multiple sources along the Mediterranean coast of Israel. Water Res. 173, 115555. https://doi.org/10.1016/j.watres.2020.115555.
Wowk, K.M., 2013. Paths to sustainable ocean resources. In: Managing Ocean Environments in a Changing Climate: Sustainability and Economic Perspectives, pp. 301–348. https://doi.org/10.1016/B978-0-12-407668-6.00012-4.
Yoccoz, N.G., Nichols, J.D., Boulinier, T., 2001. Monitoring of biological diversity in space and time. Trends Ecol. Evol. 16, 446–453.
Zhang, Y., Pavlovska, M., Stoica, E., Prekrasna, I., Yang, J., Slobodnik, J., Zhang, X., Dykyi, E., 2020. Holistic pelagic biodiversity monitoring of the Black Sea via eDNA metabarcoding approach: from bacteria to marine mammals. Environ. Int. 135, 105307. https://doi.org/10.1016/j.envint.2019.105307.