Desalination 365 (2015) 416–433

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Understanding the role of ecological indicator use in assessing the effects of desalination plants

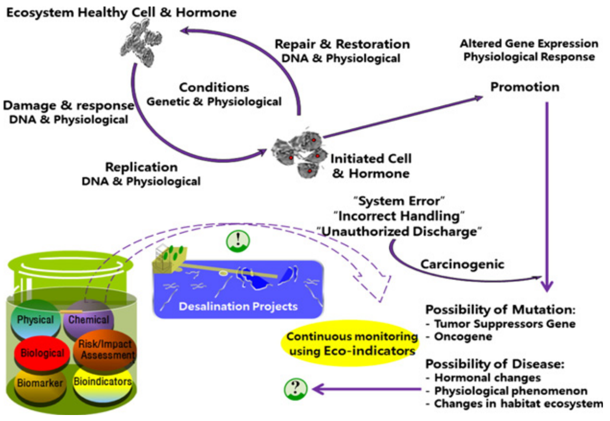
Jin-Soo Chang

Molecular Biogeochemistry Laboratory, Biological & Genetic Resources Institute (BGRI), Jeonming-dong, 505 Inno-Biz Park, 1646 Yuseong-daero, Yeseong-gu, Daejeon 305-811, Republic of Korea

HIGHLIGHTS

- This is a first assessment in desalination application with a potential ecological indicator.
- Ecological indicator studies of desalination project are reviewed.
- Sustainability management of ecological indicators' major characteristics is important in risk and/or impact assessment.
- This study aims to propose a future research model in desalination project using an ecological indicator.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 December 2014
Received in revised form 6 March 2015
Accepted 11 March 2015
Available online 3 April 2015

Keywords:
Seawater desalination
Ecological indicators
Environmental impact assessment
Environmental risk assessment
Ecosystem health assessment

ABSTRACT

Understanding the role of a global seawater desalination plant project using potential ecological indicators is important in assessing ecological risk and/or impact evaluations from observations at a molecular level. A marine health assessment of ecological indicators (e.g., as an early-warning system) can provide information about an area of ecosystem disturbance, the disappearance of symbiosis, organism mortality, instability of fertility and breeding species, the emergence of single species, the bioaccumulation of test bed operation pollutants discharged, and changes in the communities. Here, we provide a comprehensive review of ecosystem health assessments using potential ecological indicators in a seawater desalination test bed. We review some empirical analyses and compare desalination concentrate treatments, the impact of reverse osmosis and multistage flash, chemicals used in the plant, the impact pathway, the brine outfall pipe, an operational assessment, salinity tolerances, and the eco-toxicological effect of brine in a marine ecosystem. Based on literature research results and data illustrating the degraded ecosystem and/or the original ecosystem, stress caused by a desalination project on the marine ecosystem damage can provide information about the marine ecosystem disturbance, the disappearance of symbiosis relationship, which may be as important as sustainable management using living ecological indicators.

E-mail address: jinsoosu@daum.net.

http://dx.doi.org/10.1016/j.desal.2015.03.013
0011-9164/© 2015 Elsevier B.V. All rights reserved.

Contents

1. Introduction

Understanding the ecological damage of desalination in the plant environment is of great interest to comparative biologists and ecologists. It is becoming increasingly important, as the effects of single port outfall or multiport diffuser sea outfall of brine discharge through the biosphere are a marine eco-risk [1–7]. Ecological indicators of metabolic activity are key components of monitoring, evaluating, and biological assessment that are directly or indirectly linked to desalination processes that are important for organism survival. The steady desalination process started contaminating the marine ecosystem and ecological damage has been a risk, so impact assessments must be conducted. Rombouts et al. [8] and Culhane et al. [9] investigated different biological indicators and evaluated a coral reef ecosystem, ecosystem degradation, marine ecosystem health and conducted quality assessment. The combination of ecological attributes should be used to manage conservation in the future, and oligotrophic coastal ecosystem for routine monitoring [10–13]. Chang [8,14] stated that a good ecological indicator is characterized by ease of handling and identification, sensitivity to small variations in environmental stress, independence of reference states, applicability in extensive geographical areas and in the greatest possible number of communities or ecological environments, its ability to be quantified, its key role in the marine ecosystem, being present in a wide range of marine ecosystem, and existence in large and dominant populations. It is not easy to fulfill all of these requirements, but good ecological indicators will be the basis of desalination companies because the marine ecosystem stress can be the basis for evaluation as well as biochemistry, molecular biology, morphology, physiology, and genetic research.

There is growing worldwide need for this study, with the increasing water desalination plants exceeding $17 billion [15]. In this study, we focus on potential ecological indicators, but they can clearly be integrated into the broader issues of desalination ecosystem damage and can be used as important ecological indicators in future policy decisions. Consequently, many studies investigated the monitoring bar, ecological impact and/or risk assessment of seawater desalination plants, the effects of alkalinity changes, entrainment, increased salinity, impingement, temperature increase, and thermal pollution and become available biocide, antiscaling additives, antiforming additives, coagulants, chemical cleaning, other physical factors of marine ecosystem have is led to the development of potential ecological indicators to biochemical metabolic condition, heavy metal pollution, and biological stress [16–21]. Scientists have also applied these potential eco-indicator species and/or ecotoxicological effects to plant organism of seawater desalination plant procedure, new eco-problems of desalting, and ecosystem quality assessment on marine community [9,22,23]. On the other hand, their potential impact on desalination of harmful algae provides some general guidelines on how early detection may help prevent or minimize the impact of HABs on a facility's production capacity or its water quality [24]. Most life cycle assessment studies did not quantify the aquatic eco-toxic potential of seawater reverse osmosis (SWRO) desalination system due to integrated coastal management, and complex brine discharge produced [19,21]. It also provides a more comprehensive coverage, not only considering the impact of organic chemical and metals, but also including the contribution of inorganic chemical or boron contamination. Also, Lattemann and El-Hab [25] evaluate the potential environmental impact of desalination projects, adverse effects mitigated as fast as possible, changes in biological species, due to human and ecosystem health consequences species diversity [26–28].

As seawater desalination methods become more widespread, they draw the attention of desalination ecologists and eco-engineers, who should study eco-risk and/or impact assessments using environmental engineering, ecological engineering, and civil engineering. Through studies of the possibility of desalination process damage, it may be possible in the future to use DNA, RNA, protein, and cell research as potential ecological indicators. These potential ecological indicators demand a systematic scientific literature examination related to risk and/or impact assessment. In this context, the purpose of this study is two-fold. First, we aim to provide/suggest effective management strategies for future desalination projects and to present the possibility of various kinds of potential ecological indicators from information obtained from laboratory experiments, field experiments, desalination project reports, and government policy reports in each country. We explore, through a literature review, the various desalination project approaches using living indicator species that provide information about ecosystem disturbance, the disappearance of symbiosis, disposal options, impact/risk effluents, chemicals used, eco-toxicological effects, experimental tolerances of various ecosystem damages, changes in living groups, and potential eco-monitoring.

2. Results and discussion

2.1. Comparative characteristics of various handling methods of desalination

Desalination brine disposal "marine pollution" has increased because changes in salt concentrations can be harmful and even lethal to the marine ecosystem and can cause habitat damage. As shown in Table 1 the treatment methods for seawater desalination concentrated effluent include surface water discharge, sewer disposal, deep well disposal, terrestrial application, evaporation ponds, evaporation concentration, zero liquid discharge, mixing with cooling water discharge, and mixing with sewage treatment effluent [29–31]. Table 1 shows the desalination treatment, discharge, and disposal methods involved in membranes and chemicals. Management of consumption is important to control economic costs; fresh water production costs directly affect a plant, so the optimum method of treating an effluent needs to be considered [31,32]. Desalination plants with installed ocean surface water discharge are considered to be the most economical. However, such emissions can cause contamination of the marine environment, including high concentrations of salt. Sewer disposal, deep well disposal, evaporation ponds, and evaporation concentration are direct discharges that may be expected to cause secondary pollution (Table 1). Further, for desalination concentrated effluents, the reverse osmosis treatment method should be selected in terms of managing costs, and technical, environmental, and other legal matters. Usually, direct ocean discharge, mixed with an effluent discharge plant, is released to the coast or through a pipe using a distributed mechanism with water to drain away the emissions. Marine concentrated effluent from a desalination plant is classified according to the position of the coastal exhaust and a single or multiport diffuser.

By appropriate construction of desalination plants, salt water disposal, and countermeasure, it is known that the risk to marine ecosystems can be reduced. Various seawater desalination plant effluent discharge methods are known, as follows. Marine surface water discharge has great advantage in that it can be processed; however, it interferes with the ocean ecosystem, as affected by natural ocean circulations [33]. On realistic alternative method provides marine ecosystem surface water discharge and deep well disposal of effluent. Additionally, evaporation pond methods can lead to soil and groundwater contamination, and thus are only used when small capacities are discharged. The discharge of the concentrated water pollution should be avoided to minimize risks between the intake and drainage. Further, in the marine environment design to reduce the risk of potential side effects, the distance between the water intake and drainage should be more than 2 km. Bleninger and Jirka [30] reported an effluent diffusion model regarding installation of a multi-port to the outlet to reduce marine environment damage, such as that due to the brine, concentrated chemicals, and seawater temperature. Zero liquid discharge at a large commercial desalination plant is difficult, with the high salt concentration due to desalination. A high salt concentrated effluent can be introduced into a distillation process, and concentrations of 180 g/L can be dealt with. In addition, zero liquid discharge, reverse osmosis process, and heat extracted from the distillation process of 600 m^3/day combined with 528 m^3/day were recovered. Zero liquid discharge is a relatively secure system for marine systems, eliminating the need for added chemicals, and does not require terrestrial help or desalination plant capacity. However, the deep well disposal method may cause a risk of nearby terrestrial and marine ecosystem disturbances, as well as potential groundwater pollution (Table 1). Mickley [34] reported 45% of plants in the U.S.A. used surface water discharge, 27% used sewer disposal, and 13%, deep well disposal. However, in 25,000 m^3/day capacity desalination plants, more than 40% used surface water discharge and deep well disposal are up to 40%.

Combinations of various methods are used to formally examine the potential effects of marine ecosystems, a proposed government-policy, surveillance-program, or next-desalination project plan. They had begun in the 1590s when a steady desalination process started the contamination of the marine ecosystem and the ecological damage has been such a risk, so impact assessment must be appreciated. The international ecologically damaging mechanism of marine ecosystem and checking to determine its risk or impact on assessment are difficult to prove for confirmation with other methods. Various damages on marine ecosystems have been reported near desalination plants located in shoreline area. The effects of these plants' operations, however, have not been clearly evaluated due to the immediate dilution of the concentrated seawater effluents in huge ocean body and other factors. The reason for this is that the initial stage of research uses the level of the sample number to report the degree of contamination, and although desalination process is obviously damaging the marine ecosystem, simple numbers do not represent environment risk and impact assessment that can be caused in the living organisms. Seawater desalination assessment using various indicators can overcome these limitations and can be expanded to the gene level. In many developed countries, the government supervises the basic and applied research, continuously monitoring the ecological indicators species and application on marine ecosystem restoration. We present the various operation modes for seawater desalination. The chemical emissions in the marine ecosystem and pipeline around the concentrated pollution can be expected by looking at the approximate number of ecological indicators species. The seawater desalination poses environmental risk and/or the impact assessment by ecological indicator species providing information about the marine ecosystem disturbance, disappearance of symbiosis, and change of living groups.

2.2. Eco-toxic and effluent characterization of chemical used in the desalination plant

2.2.1. Antiscalants

Tables 2 and 3 show the antiscalants used for reverse osmosis of desalination through scale formation within the facility to prevent contamination via the generally used sulfuric acid, poly acrylic acid (PAA), poly methacrylic acid (PMAA), poly maleic acid (PMA), sodium hexametaphosphate (SHMP), polyphosphates, polymeric acid, aqua feed AF-650 (mainly sulfate-based), permatreat-91 (mainly sulfate-based), PTP-100 (mainly sulfate-based), flocon-100 (mainly sulfate-based), and belgard-BRD [5,35–37]. Such antiscalant chemical is mainly carbonate scale formation suppressing the function of holding a certain pH [36,38]. Generally, 2 ppm is used as antiscalants included in exhaust discharged even though the marine ecosystem risk is relatively low [38]. Lattermann and Höpner [18] reported polyphosphate used in the operation of desalination eutrophication problem areas, but this is the first where the major producers of orthophosphate nutrients are easily hydrolyzed. On the other hand, policarbonic acids and phosphonates are stable substances that have low biodegradation rate in the long run since they remain in the beach area. These substances in desalination plants are mixed to disperse the calcium and magnesium ions by reducing scale formation in the marine environmental since the divalent metal can affect natural processes. Thus, using antiscalants using the desalination projects, which may play an important role as ecological indicators of the marine ecosystem, should be monitored. Antiscalants that may be affected include: bioaccumulation, ecotoxicological effect and subsequent changes to the local ecology and biodiversity. Ecological indicators selected anticipate the use of biological accumulation and an unknown side-effect on chronic effects should continue to be monitored (see Fig. 1).

Table 1
Comparison of general handling, advantages, and disadvantages of the desalination concentrate treatment system.

Disposal method	General handling	Advantages	Disadvantages
Surface water discharge	– Using distributed mechanism rivers, marshes, ocean surface water discharge, etc.,	– Can handle large volumes – By dilution and natural resolution – In expensive emissions – Natural processes promote degradation – Water body promotes dilution – Often least expensive option – Possible dilution and blending with power plant discharge	– Marine ecosystem disturbances – Limited effect on aquatic ecosystems ability to midnight and hydraulic dilution – Depends on natural circulation patterns and hydrographic currents in the area – Environmental impacts need to be monitored – Good knowledge and monitoring of receiving waters required – Limited natural assimilation capacities causing adverse impacts on marine environment if exceeded
Sewer disposal	– Existing sewer discharge is less applicable if the amount of concentrated	– Dilution throughout waste stream – Using the existing sewer system – Lower the BOD of the resulting effluent – Dilutes the brine concentrate – Uses existing infrastructure – Possible beneficial treatment	– Limited sewage treatment capacity – Sewage water quality standards meet statutory – Restricted capacity depending on sewage plant – Must meet sewer quality standards – Final disposal generally still to surface water – Can inhibit bacterial growth – Can hamper the use of the treated sewage for irrigation due to the increase in TDS and salinity of the effluent – Overload the existing capacity of the sewage treatment plant
Deep well disposal	– Number concentration of 330–2600 m in depth how to handle injected into underground aquifers	– As the lack of impact on the marine ecosystems – Available in low volume plants – Viable for inland plants with small volumes of brine – No marine impact – Good option for smaller inland plants	– Marine ecosystem disturbances – For underground injection has limitations in separate aquifers – Danger of groundwater pollution – Expensive cost and need a structurally isolated aquifer – Increase the salinity of groundwater – Only cost efficient for larger volumes – Maximum capacity hard to assess – Dependant on suitable, isolated aquifer structure
Land application	– Concentrated water treating the soil dispersing	– A source of water supply substitute for the kind of resistance – No marine impacts – Alterative water source for irrigation of tolerant species	– Only for smaller discharge flows – Risk soil and groundwater pollution – Storage and distribution system required – Species conversion of soil and groundwater ecosystems – Possible adverse impact of chemical and pollutants on plants – Storage and distribution system needed
Evaporation ponds	– Using the solar energy can be concentrated by evaporating bulk is reduced	– Do not have the technical management – No marine impact expected – Possible commercial salt exploitation – Low technological and managing efforts – A viable option for inland plants in highly arid regions – Can commerically exploit the concentrate	– Only a small capacity when discharged – Soil and groundwater contamination – Storage and distribution system required – Strongly restricted capacity and needs regular monitoring – Large areas of land necessary and expensive option – Only in dry climate with high evaporation – Risk of soil and groundwater pollution – Disposal of unusable salts needed – Can increased salinity of groundwater and underlying soil – Needs dry climates with high evaporation rates – Requires large parcels of land with a level terrain
Evaporation concentration	– Thermal evaporator, crystallizer, spray dryer using methods such as sludge treatment or buried in a way to make the solids	– Liquid waste treatment unnecessary – Salt and minerals can be recovered	– Requires high-energy and high-cost – Requires further treatment of sludge and solids
Zero liquid discharge	– Normally, the evaporation–crystallization section receives the reject from a reverse osmosis section	– Can produce zero liquid discharge – Can exploit concentrate commerically – Reduced impact on marine – No liquid waste disposal – Recovery of salt and minerals	– Expensive and consumes high energy – Production of dry solid waste – Still not feasible on industrial scale – Solid residuals
Mixing with the cooling water discharge	– Cooling the concentrated mixing with the water discharge	– Achieves dilution of both effluents prior to discharge – Combined outfall reduces the cost and environmental impacts of building two outfalls – Necessary to reduce salinity if disposing in fresh water bodies	– Dependent on the presence of a nearby thermal power plant
Mixing with the sewage treatment effluent	– Wastewater treatment using the apparatus release	– Achieves dilution of brine effluent prior to discharge – Does not overload the operational capacity of sewage treatment plant – Necessary to reduce salinity if disposing in fresh water bodies	– The brine could enhance the aggregation and sedimentation of sewage particulates that can impact benthic organisms and interfere with the passage of light in the reviving water body

Note: based on [3,31,32,169,177–181].

2.2.2. Antifoulants

Desalination system use of foulant control agents (antiscalant/dispersants) is key to the successful long-term performance, and its performance in system design should not be underestimated. Table 3 shows the antifoulant agents that are commonly used as foulant control agents and they are categorized as follows: polyphosphate, phosphonates, proprietary, formulated blends and synthetic polymers (e.g., acrylic acid, PAA, methacrylic acid, PMAA, and maleic acid, PMM) [39]. Polyphosphates have many advantages in terms of cost-effectiveness and toxicity. However, the main disadvantage of polyphosphates is that the phosphorus–oxygen (PO) bond in the orthophosphate is subject to hydrolysis. An orthophosphate ion can react with calcium to

Table 2
Environmental impact of reverse osmosis (RO) and multistage flash (MSF) effluents.

Effluent characteristic	Concentrations	Environmental impact
Salinity	– RO (≈70 mg/L) – MSF (<50 mg/L)	– Can be harmful; reduces vitality and biodiversity at higher – Values; harmless after good dilution
Temperature	– MSF (+10–15 °C)	– Can be harmful; can have local impact on biodiversity
Chlorine	– MSF (≈2 mg/L)	– Very toxic for many organisms in the mixing zone, but rapidly degraded,
THM	– RO – MSF	– Carcinogenic effects; possible chronic effects, more persistent, dispersal with current, main route of loss is thorough evaporation
Antiscalants	– RO (≈2 mg/L) – MSF (≈2 mg/L)	– Poor or moderate degradability + high total loads ➔ accumulation, chronic effects, unknown side-effects
Coagulants	– RO (1–30 mg/L)	– Non-toxic; increased local turbidity ➔ may disturb – Photosynthesis; possible accumulation in sediments
Antiforaming	– MSF (0.1 mg/L)	– Non-toxic in concentration levels; good degradability
Copper	– MSF (15–100 μg/L)	– Low acute toxicity for most species; high danger of accumulation and long term effects; bioaccumulation
Other metals (Fe, Cr, Ni, Mb)	– RO – MSF	– Only traces metals; partly natural seawater components; no toxic or long term effects (except maybe for Ni in MSF)
RO cleaning solution	– Low or high pH, disinfectants, detergents, complexing agents	– Highly acidic or alkaline cleaning solutions that may cause toxicity without neutralization, disinfectants highly toxic at very low concentrations, detergents moderate toxicity; complexing agents very poorly degradable
MSF cleaning solutions	– Low pH, corrosion inhibitor	– Highly acidic cleaning solutions that cause toxicity without neutralization low toxicity; poor degradability

Note: based on [30].

form calcium phosphate scale, and after discharge, nutrients, it is a potential cause of eutrophication [39,40]. Polyphosphates and reverse osmosis desalination processes are used in many industries with lower concentrations to avoid precipitation of calcium carbonate, and mainly, 1–5 mg/L concentrations of sodium hexametaphosphate (SHMP). Various other polyphosphates are used in the 2–10 mg/L concentration range, and heavy metal particles caused by diffusion effect have been reported in corrosion control. However, synthetic polymers also react with the calcium ions to form calcium–polymer salt, which can be a problem in desalination treatment. Now, to prevent problems related to this calcium, proprietary products (organic polyelectrolytes) are under development [39]. Antifoulants in marine ecosystems should be

Table 3
Comparison of chemicals used in the desalination plant.

Reference	Category	Chemical used	
		Acronym	Structure
[39]	Antiscalants	Sodium tripolyphosphate (STPP)	$Na_5P_30_{10}$
[38]		Sodium hexametaphosphate (SHMP)	$(NaPO_3)_6$
		Amino tri (methylene phosphonic acid) (AMP)	$N(CH_2PO_3H_2)_3$
		1-Hydroxyethylidene-1,1-diphosphonic acid (HEDP)	$CH_3C(PO_3H_2)OH$
		Ethylenediaminaetetra (methylene phosphoric acid) (EDTMP)	$CH_3C(PO_3H_2)_2OH$
		Hexamethylenediaminetetra (methylene phosphonic acid) (HMTMP)	$(CH_2PO_3H_2CH_2)_2N(CH_2)_6N(CH_2PO_3H_2)_2$
		Diethylenetriaminepenta (methylene phosphonic acid) (DETMP)	$N(CH_2)PO_3H_2[(CH_2)_2N(PO_3H_2)]_2$
		2-Phosphonobutane 1,2,4-tricarboxylic acid (PBTC)	$CH_2COOH(PO_3H_2)COOH(CH_2)_2COOH$
		Poly (acrylic acid) (PAA)	$(CH_2CHCOOH)n$
		Poly (methacrylic acid) (PMAA)	$(CH_2C(CH_3)COOH)n$
		Poly (maleic acid) (PMA)	$(CHCOOHCHCOOH)n$
[36]		Sulfuric acid	H_2SO_4
		Sodium hexametaphosphate (SHMP)	$(NaPO_3)_6$
		Aqua Feed AF-650 (mainly sulfate-based)	$CuSo_4$-based
		Permatreat-191 (mainly sulfate-based)	$CuSo_4$-based
		PTP-100 (mainly sulfate-based)	$CuSo_4$-based
		Flocon-100 (mainly sulfate-based)	$CaSo_4$-based
		Belgard-BRO	
[182]	Antifoulants (antoscalants/dispersants)	Polyphosphates (mainly phosphate-based)	HPO_4-based
		Orthophosphates (mainly phosphate-based)	HPO_4-based
		Synthetic polymers: Poly (acrylic acid) (PAA)	$(CH_2CHCOOH)n$
		Synthetic polymers: Poly (methacrylic acid) (PMAA)	$(CH_2C(CH_3)COOH)n$
		Synthetic polymers: Poly (maleic acid) (PMA)	$(CHCOOHCHCOOH)n$
		Organic polyelectrolyte	
[38]	Coagulants	Ferric chloride	Fe_2O_3
[37]		Aluminum sulfate	$Al_2(SO_4)_3$
[36]	Biocides	Chlorine	Cl
[38]		Sodium hypochlorite	NaClO
[18]		Calsium hypochlorite	$Ca(ClO)_2$
[36]	Cleaning chemicals	Citric acid	$C_6H_8O_7$
[38]		Oxalic acid	$C_2H_2O_4$
[18]		Sulfuric acid	H_2SO_4
[61]		Sodium hydroxide	NaOH
		Sodium perborate	$NaBO_3.nH_2O$
[38]		Sodium hypochlorite	NaClO
[183]		Ethylenediaminetetraacetic acid (EDTA)	$C_{10}H_{16}N_2O_8$
[14–185]		Dodecyl sulfate	$C_{12}H_{25}SO_4$

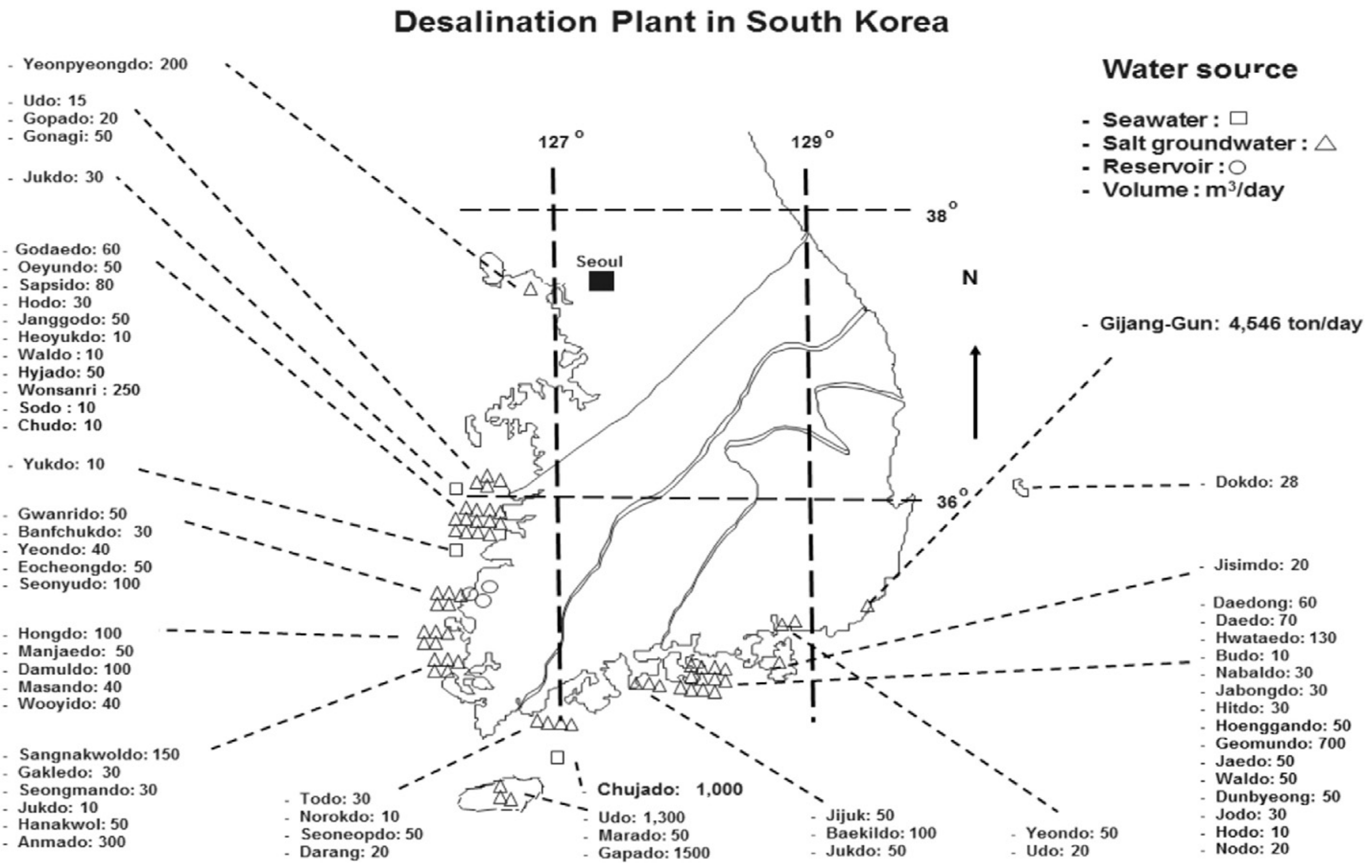


Fig. 1. Regional construction operation of desalination plants in the Republic of Korea.

subject to risk or impact assessments and should be monitored at all times. Antifouling using ecological indicators can be selected to minimize danger to marine life; those with the lowest acute toxicity and least danger of accumulation (see Fig. 1).

2.2.3. Biocides

As shown in Table 3 the biocides are important in the process of reverse osmosis; organic chemicals contained in the water react with halogenated organic compound by-products to create compounds that are harmful to organisms [23,38]. Chlorine residue and disinfection by-products can cause environmental problems and there are concerns caused by conventional preparation methods of sodium bisulfite [41], monochloramine [42], copper sulfate [43], and ozone [41]. In many applications, the use of chlorine is not allowed, so chlorine dioxide is used in many areas of the Arabian Gulf as an alternative to chlorine injection. Chlorine dioxide is a strong oxidant. Thus, its environmental impact is lower than that of chlorine [44]. However, chlorine dioxide and other biocides in surface water discharges can still influence biological impact/risk [38]. Chlorine is highly biocidal, and its toxicity has been confirmed in many toxicological studies. In the case of evaporation processes, 10–20% concentration of 200–500 μg/L of the FRC level has been reported [16]. After discharge, FRC level is reduced by 90%, at which point 20–25 μg/L is the expected concentration [45]. The process of evaporative discharge points to 30–100 μg/L as representing matches [46]. Chlorine is toxic and a highly effective disinfectant, as confirmed through many toxicology studies.

In an environmental risk assessment for hypochlorite in the EU, the 'predicted no effect concentration' (PNEC) based on free available chlorine in the water was determined as 0.04 μg/L. It can affect the ecosystem seriously in effluent at 200–500 μg/L concentration and at a point discharge of 100 μg/L. The EU environmental risk assessment report also suggested that the thermal stress and discharge of chlorine may produce a synergistic effect. Various chemical reactions in seawater were caused by organic substances, hypochlorite, hypobromite, and the generation of by-product like trihalomethanes (THMs) and haloacetic acid [47]. In addition, near an evaporative process plant, levels of 9.5 μg/L and 83 μg/L of THMs have been reported [47]. The EU risk assessment reported that regarding the toxicity of total THMs and chloroform, the PNEC in freshwater was 146 μg/L. Desalination concentrates by-product of chlorine residues in the aquatic ecosystem and can cause serious ecological toxicity. However, organisms react to acid concentrations and THMs, which can act as carcinogens in the marine ecosystem. Professional exposure to PT18 biocides may occur in both adults and children (inhalation, skin contact) and infants (inhalation, fumigation). This issue has been raised again regarding biocides. Further studies evaluating these bio-indicators should be conducted to confirm effective methods of assessing biocides (see Fig. 1).

2.2.4. Boron

Boron (B) has been and will continue to be an important plant project hazard for desalination to discharge. For a long time, boron has been known to cause important physiological response in drinking water and marine ecosystem damage, so it is possible for boron biology to contribute to low pH condition not only in terms of operational problems but also in terms of being removed in desalination. Chemically uncombined boron, which is classed as a metalloid, is found in small amounts in meteoroids, but it is not found naturally on earth. Several desalination studies of boron removal have been reported over the effect of membrane fouling [48], ultrafiltration–reverse osmosis (UF–RO) processes in pilot-scale tests [49], polyvinylidene fluoride (PVDF) flat-sheet membranes [50], reverse osmosis (RO) system [51], complexes with polysol [52], tumor-suppressive effect [53], human brain tumors [54], and using constructed wetlands [55]. Frequently, the high boron concentration in the injection seawater for a desalination process can exceed the standards for drinking water. Studies on boron, its mechanism, and heath effects show that 112 mg/kg body weight is an acute poisoning hazard; it is a main cause of gastrointestinal tract abnormalities [56,57]. Animal experiment have revealed the risk and/or impact and/or toxicity results from food boron intake that exceeds the standards set by law. According to a U.S. Environmental Protection Agency [58] report, similar effects were shown for rats after oral examination, and boron level in mice exceeded 4000 mg/kg [59] and a blood boron level of ~2020 ng/g affected normal development [60]. For this reason, seawater desalination projects need to deal with boron contamination of the marine ecosystem.

A seawater reverse osmosis desalination plant is characterized by treatment of dissolved ionic materials through exclusion. Due to the characteristics of reverse osmosis, the exclusion ratio of divalent ion would be higher than that of univalent ion; thus, water generated by desalination would be expected to have a different composition from that of surface or ground water. Also, the membranes used in reverse osmosis would have lower efficiency in removing dissolved gases such as CO_2, so this would lower the pH of the water. In particular, the concentration of boron in processed water would likely exceed the water quality standard if the original sea water contains a high concentration of boron. If the concentration of boron in discharged water exceeds the water quality standard of drinking water, then symptoms such as gastric disorder, anorexia, vomiting, nausea, and astigmatism may occur.

However, carcinogenicity studies have been reported to be negative. The standards for boron in the world drinking water are Korea 0.3 mg/L, World Health Organization (WHO) 0.3 mg/L, Japan 0.2 mg/L, England 1.0 mg/L, Australia 3.0 mg/L, Canada 5.0 mg/L, and Germany is 1.0 mg/L. Currently, many researchers who are interested in desalination projects have concentrated on treatment with risk assessment related to unauthorized discharges. In desalination, using boron can be an important early warning ecological indicator for the assessment of contaminated marine ecosystem due to the propensity to accumulate pollutants. These findings are contained in the water of the various materials for the desalination plant orders, and operational risk and/or impact in the future is a problem since they have enough potential. Fig. 1 shows that the boron contamination from desalination projects can be monitored using ecological indicator species, and in this monitoring, the damages can be estimated in terms of the levels of DNA, RNA, proteins, and cells [3].

2.2.5. Cleaning chemicals

The desalination reverse osmosis membrane is cleaned regularly to maintain the necessary efficiency [36]. Cleaning chemicals used include sodium perborate and citric acid [61], sodium hypochlorite and oxalic acid [62], ethylenediamine tetra acetic acid, sulfuric acid [63] and sodium hydroxide [183]. These cleaning chemicals need to be changed depending on the type [64]. These cleaning chemicals will be released in the wash one to several times per year; in addition, marine organisms can potentially be damaged by extremely high or low pH without neutralization [18,37]. The washing procedure varies depending on the type of fouling. In the case of a reverse osmosis process plant, to remove biofilm contamination, an alkaline solution (pH 11–12) is used, while to remove scale, acid (pH 2–3) is used to oxidize the dissolved metal and acid solution. To increase the cleaning efficiency of such solutions, additional compounds are used as detergents (e.g. dodecylsulfate, dodecybenzene sulfonate) or oxidizing agents (e.g. sodium perborate, sodium hypochlorite) (Table 3). These cleaning chemical agents even when used in accordance with the intended effects, can adversely affect the marine ecosystem (Table 2). Desalination projects should continue to monitor the marine ecosystem, and monitor for cleaning chemicals contained in effluent. Cleaning chemicals introduced into the discharge would be expected to be contaminate the marine ecosystem. Cleaning chemicals in the marine ecosystem and plants around a concentrated pollution source can be assessed by looking at the approximate numbers of ecological indicators species (see Fig. 1). These potential ecological indicators are used primarily to assess to condition of the desalination plant: as an early-warning system.

2.2.6. Coagulants

The coagulants through the backwash can be easily removed so that it turns into large particles; the suspended particulate matter will coagulate and precipitate [18,37]. Desalination concentrated waste will be created during the backwash; products include ferric chloride, aluminum sulfate, and polyacrylamide [36,37]. Ferric chloride is a red-brown substance in the effluent discharged during backwash; if it is not removed effectively, it can lead to marine pollution [18]. However, the coagulant is injected in the seawater desalination plants; ferric chloride at 1–30 mg/L or polyacrylamide at 1–4 mg/L levels, showed no toxicity due to increased turbidity. According to a report by Lattermann and Höpner [18], if the iron salt is used, the occurrence of red high turbidity due to the concentrated water penetration or light is reduced, and fixative discharge area may be buried in undersea creatures (Tables 2, 3). The use of desalination coagulants for drinking water clarification has importance in marine ecosystems and plants.

2.2.7. Heavy metal

For successful treatment in a desalination plant, it is essential to secure materials with excellent resistance to the aggressively corrosive saltwater [38,65]. Stainless steel use has advantages because of its exceptional durability and minimum maintenance costs. Moreover, the use of stainless steel in a seawater desalination plant, will reduce concentrations of other materials as follows: lower levels of copper, iron, chromium, lead, nickel, molybdenum, and zinc, as heavy metals [38,65]. Generally, there are no heavy metals detected in natural fresh water [36]. However, heavy metals may be detected in the preprocessing step after a concentration step. Desalination discharges can include chemicals used at tens to thousands of kg per day into coastal water. Höpner and Lattermann [38] reported that in 21 desalination plants assessed, the daily chemical discharge amounts into the marine ecosystem were 2708 kg chlorine, 36 kg copper, and 9478 kg antiscalants, when their effluent concentrations were 0.25 ppm, 0.015 ppm, and 2 ppm, respectively (Table 4). Also, Saeed et al. [47] detected high concentration of hydrocarbons near the outlet of a desalination plant in Kuwait. In particular, the Key West, FL, USA, the 5–10-fold higher concentrations of copper were detected around a seawater desalination plant and the anticipated amount of discharge was 45 kg/day [66]. Heavy metals were detected in Saudi Arabia at a desalination plant: high concentrations of Cd, Cu, Hg, Ni, P, and Zn. The copper concentration was expected to be 15–100 μg/L. However, the presence of copper necessarily affects the environment. Reported natural coastal copper concentrations are in the range of 0.1–100 μg/L [67]. In addition, Bou-Hamdashad et al. [68], reported copper concentrations in the Arabian Gulf region: <1 μg (Qatar) to 25 μg/L (Kuwait). The copper concentration criteria of the USEPA and European criteria for short-time exposure are up to 4.8 μg/L and for long-term exposure, to 3.1 μg/L [69]. Heavy metal accumulation, especially mercury, by commercially important fish and shrimp species should be evaluated for potential human health impacts [70]. These observations suggest that the plant effluent increases heavy metal concentrations in the sediment from a desalination plant effluent outfall over a 6×6 km^2 area. Because heavy metals produced by desalination projects endanger marine biota, proper selection of organism groups from various parts of the ecosystem can have vital importance in the biological impact and/or risk assessment. Potential ecological indicators of heavy metal assessments should not to be used as the only evidence in a desalination plant region, and the contamination risk assessment with biota and toxicity evaluations should be integrated. The assessment of heavy metal contamination by living ecological indicators species can provide valuable information regarding marine ecosystem disturbance, as well as the disappearance of relationships.

Table 4
Ecological and toxicological effects of desalinating brine in a marine ecosystem.

Reference	Location	Matrix/species/community	Summary of findings	Available on the potential impact of biological and damage [b]
Biological monitoring and Contaminant monitoring [a]				
[101]	Red Sea, Egypt	Red Sea water and Plant reject water	– pH decreased from 8.3 ± 0.3 to 5.8 ± 0.3 – Total alkalinity decreased from 120 to 65 – Temperature increase from 23.0 °C to 27.0 °C ± – Chloride increased from 24,000 ppm to 32,000 ppm – Free carbon dioxide appear Nil to 8 – Total hardness increased from 10,000 to 27,000 – TDS increased from 42,300 to 60,000 – Partial alkalinity disappeared 20 to Nil	– Most of the coral has disappeared from the coastal areas – Many planktonic organisms have disappeared from the area around the plant – Populations of many fish species have declined and even disappeared – Marine forms from other areas have not been able to become established in the Hurgada area – Marine sediment stress from the anthropogenic activities in Red Sea, Egypt. [188].
[38]	Red Sea (21 plants), Egypt Qatar	Discharge	– Amounts to 2.7 ton of Cl – Amounts to 36 kg of Cu – Amounts to 9478 kg of anti-foulants	– Vulnerable marine ecosystems and risk of damage to ecosystems – Deterioration (not good) for human health; air and noise pollution, and biotic environments [189].
[124]		Desalted water	– Amounts at outlet 3.05 ton per day of Cl – Halogenated (chlorinated and brominated)	– depicts toxic chlorine concentrations for a range of species by means of the LC_{50} indicators [31]. – MSF effluents and in the mixing zone are acutely toxic for many of the examined marine organisms. – Chlorine toxicity levels for a range 440 μg/L: LC_{50} Bluegill (96 h). – Chlorine toxicity levels for a range 208 μg/L: LC_{50} Coho salmon (1 h) [190].
[16]	Arabian Gulf	Brine water	– Temperature increase to 40°C – Amounts to 1350 ppm of Ca and 29,000 ppm of Cl – Amounts to 52,000 ppm of TDS – Emission of NO_X, SO_2, and CO_2 – Construction and operation of the desalination plants would result in an increase in noise levels surrounding the location – Produce chlorite effluents [26]	– Seawater desalination plants around the surrounding ecosystem of damage – Potential damage is very dangerous for ecosystem of desalination plant surrounding areas – Heavy metals contamination in coastal and marine environments is becoming an increasingly serious threat to both the naturally stressed marine ecosystems and humans that rely on marine resources for food, industry and recreation [20]. – Chlorites have human and ecosystem health implications [26]. – Biological effects of reef scallpos found on the rock piles around an inspection valve [30].
[66]	Key West, Florida	Seawater	– Estimate that up to 45 kg of Cu the plant for each day of normal operation – Around 10 vol the concentration of Cu near the desalination plant	– Echinoderms showed the greatest sensitivity and died within days of exposure to as little as 3% brine in seawater. – Whereby echinoderms ascidians, gorgonian corals and stone crabes were transplanted [88].
[186]	McMurdo, Antarctica	Sediments	– Max level increase to 3700 ppm of Cu – Max level increase to 3,00 ppm of Pb	– Bioindicator organisms for the biomonitoring of Cu and Pb in the environment and the related toxicity mechanisms and ecological effects of heavy metal pollution [191].
[70]	Ras Tanajib, Saudi Arabia	Sediments	– Plant outlets in the area within 100–250 m concentration increased Cu, Hg, Ni, Cd, Zn, and P	– Benthic macroalgae as biological indicators of heavy metal pollution in marine environments thus can be used as a very good biomonitor [192].
[168]	Jersey, England	Epibiota	– Accumulates high concentrations of Cu – Copper increased from 3.51 to 32.20 $mg\ kg^{-1}$ dry sediment	– Clams and shellfish accumulate high concentrations of Cu in the greater ecosystem impacts. – Biomonitoring studies have found accumulation of metals in macroalgae, mussels and benthic sediments [70].
[187]	USA (28 plants)	Discharge	– 28 plants, up to 60% of samples exceeded water quality criteria for Cu. However, current does not exceed a legal standard.	– Copper levels for a range 2900 μg/L: LC_{50} Rangia cuneata (96 h) – Copper toxicity levels for a range 222 μg/L: LC_{50} *Crassostrea gigas* (96 h) – Copper toxicity levels for a range 13 μg/L: LC_{50} *Nitaschia closterium* (96 h) – Copper toxicity levels for a range 1.4 μg/L: LC_{50} Daphnia magna (21 days) [31,38].
[116]	Southern California Bight (USA)	Coastal surface	– Risk of occurrence of harmful algae in coastal waters – Marine ecosystem effects	– Microalgae, domoic acid (DA), and amnesic shellfish poisoning [193]. – Human effects, marine mammal mortalities, and bird mortalities [194,195].
[170]	Gijang-Gun, Republic of Korea	Discharge	– Intake or/and effluent excessive salinity at the intake (effluent) increases to 800 ppm in summer.	– Larger, mobile animals such as adult fish are likely to be able to avoid the plume in the immediate vicinity of the discharge, but smaller invertebrates (and some species of fish) living in or near reefs and at the bottom sediments would be unable to escape its influence [4].
[82]	Sado estuary, Portugal	Salinity biological testing	– Four-week reduction in the life-span, lower life expectancy, shorter generation time, faster individual growth, anticipation of age at maturity and higher population growth rate.	– Effect of temperature and salinity on life history of the marine Amphipod *Gammarus locusta*.

[a] Reported in prior: Biological monitoring studies are limited to studies incorporating multiple reference locations.
[b] Predictable study: Damage the operation of desalination are marine exosystems using available on the potential impact of biological and chemicals for general ecological damage.

2.2.8. Salt concentrates

In the construction of a desalination plant or pilot testing, the effects on the marine ecosystem, the discharge of salt concentrates and physical and chemical additives have been investigated for effects – positive or negative – in animals and plant in Table 1 [3,30,71–73]. Salt concentrates at an appropriate level with appropriate dilution, are an eco-friendly non-toxic discharge, with no long-term effects on marine ecosystems. The discharge of salt concentrates over 40 psu salinity is limited to around drains into the original seawater. The effects of the discharge of salt concentrates in the outfall pipelines area and the ecosystems of fish, marine farm, and fishery have been reported as ecological indicators for ecosystem monitoring [30,71–77]. In sea grasses, *Thalassia testudinum*, optimal growth was examined at the level of 30–40 ppt salt concentrates; however, at 50 ppt, the survival rate decreased, and at 70 ppt, 100% mortality resulted [78,79]. In the Australian sea grass, *Zostera muelleri*, at low salt concentrate levels there was a decreased rate of photosynthesis. Data indicate that live *Sargassum filipendula* and *Sargassum pteropleuron* can tolerate temperature and salt concentrates in the ranges seen in desalination plant areas, and sedimentation resulting from disruption of the tidal flow [80].

Salt concentrates can be discharged from desalination plants into the marine environment and cab affect species distribution; the damage can show a decisive effect on the growth of macrobenthic communities [81]. Neuparath et al. [82], reported changes in the salt concentration (35–70 ppt range), and the following changes were observed in the marine ecosystem: species development, degradation of reproductive performance, survival challenges of marine biological larvae, and individual density symptoms of marine ecosystems. This was caused by the construction of a desalination plant, changing the seawater salinity. Plankton organisms are most sensitive to salt concentrations affected by discharges [83]. The effects of changes in salinity depend on the species observed [84]. The size of the fish species that influences the concentration of the salt is increased to 50 ppt [84]. The sea grass *Posidonia oceanica* (L.) and *T. testudinum* were negatively influenced by increased salinity in the Mediterranean [78,79,85]. It is known that *P. oceanica* is one of the most sensitive sea grasses to salinity increments; it is more tolerant to salinity reductions (25.0–36.4 psu), perhaps due to the terrestrial origin of the sea grass. *Posidonia* sea grass species are known to be very sensitive to salinity, with 38 ppt salinity causing growth reduction, 45 ppt causing mortality, and 50 ppt causing 100% mortality [86]. These results suggest that the impact of the marine ecosystem salt concentrations can be based on research results and should be managed systematically. Salt concentrations in terms of impact/risk and/or the footprint of the desalination plant in the surrounding ecosystem results have practical implications for government policy and management strategies for the sustainability of much biological damage in the local ecosystem [3,87]. Also, although the salinity water have impacts to marine ecosystem, there is another reason such as COD pollution. At present, the discharge of salt concentrates should be monitored continuously [3]. Thus, to assess damage to ecosystems by salt concentrate discharges, future research is needed to understand the role of ecological indicator communities in these marine ecosystems.

2.2.9. Tempersture rise, heating effluent, stress, and noise

Table 4 shows that the desalination projects can be accompanied by discharges affecting the marine ecosystem caused by temperature rise, heated effluent, stress, and noise [77]. In addition, a plant operating at high temperatures also increases the temperature of the salt concentrates. Generally, thermal pollution occurs because of the desalination of high salt and higher alkalinity with two-fold increases versus that in the seawater. Desalination plant outfall areas can tolerate the temperature rises, where sea grasses have been investigated [77]. *Zoetera marina* species with increasing temperature had high resistivity. Sea grass was able to tolerate 30 °C and also 42 °C significantly. In addition, Australian sea grass shows an increased rate of photosynthesis up to 30 °C, and then sharply decreased to 42 °C. Thus, such salinity, seawater temperature, and alkalinity changes can induce effects in marine ecosystems [61]. Gijang-Gun at a desalination plant capacity of 45 tons/day does not have a lot of effect on the level of geography; the outlet is not far from where the background levels are likely to be recovered in Fig. 1 [3,88]. However, continuous monitoring of concentrated discharges must be managed and observed in marine ecosystems. Desalination plants installed worldwide and at Gijang-Gun can discharge heavy metals, in the case of corrosion, directly to the shoreline due to the potential long-term factors, which may be contaminated. In addition, heavy metals released into seawater can be adsorbed on suspended matter and accumulate in marine sediments so continuous monitoring is needed. Buros [89] reported that the discharge of salt concentrate and the temperature rise of seawater caused changes in the distribution of marine species in the ecosystem. These results show that the temperature rise of the seawater and the marine species have a direct relationship. Thus, the temperature of seawater in marine ecosystems, sea grasses, and animals are important factors that should be monitored continuously. A desalination plant, due to physical and chemical factor (temperature rise, heating effluent, stress, and generating noise), can affect the surrounding ecosystem and biological habitat movement. Long-term health assessments can include ecological indicators species in impact and/or risk assessments [17]. As such for a variety of assessments and pollution caused, can be compared with future desalination policies by the government. In many developed countries with desalination processes, the governments supervise basic and applied research, continuous monitoring of ecological indicators, and application in marine ecosystem restoration.

2.3. Potential ecological indicators of desalination to field ecosystem

2.3.1. Amphipod, bivalve, and copedod

Potential ecological indicators of desalination to marine ecosystem investigation were conducted to describe biological damage to amphipod, bivalve, copepod, infauna, or the number of organisms which can be used for future report [90–93]. Previous studies have shown that the amphipod species *Ampelisca brevicornis* survival is a sensitive organism to assess the toxicity of contaminated sediment [94–96]. This study demonstrates that the sediments pollutant by fish farm effluents may lead to an alteration of the biodiversity of the exposed organisms, and bivalves do not represent an appropriate tool for reducing the environmental impact of fin fish aquaculture in open water [97]. These results were reported in desalination research and physiological status of *Gammarus fossarum* (Crustacea; Amphipoda) exposed to secondary treatment wastewater [98]. Neuparth et al. [82] also suggest that a multiple-response approach, including the effects of temperature and salinity on life history of the marine Amphipod *Gammarus locusta*., should be applied in chronic ecotoxicological tests. Also, very high arsenic concentration of up to 156 $\mu g\ g^{-1}$ from Gulf of Oman and copper bioaccumulation from Limski Kanal of North Adriatic Sea was reported in bivalve species from the region, despite anthropogenic contamination [92]. Desalination plant project which can be used in the potential ecological indicators may serve as a basis for implementation of life-table analysis in long-term tests with amphipod (*Allorchestes compressa*), bivalve (*Mytilus eduli*), and copepod (*Gladioferens imparipes*, Mysidopsis (*mysid shrimp*)) marine ecosystem to assess truly population-level responses to toxicants [3,99]. Likewise, certain species of the amphipod, bivalve, and copepod group are considered capable of accumulating toxic substances, as well as species of the polychaetes group like *Nereis diversicolor*, *Neanthes arenaceodentata*, *Glycera alba*, *Tharyx marioni*, *Nephtys hombergii*. On the other hand, Echinoderms are osmoconformer organisms and are expected to be very sensitive to brine discharges, and this species in desalination projects can be used as ecological indicators [100]. Marine ecosystem due to the impact and/or risk of desalination projects has been reported such as Amphipoda, Bivalve, and Copepod, and previously reported results closely make use of genetics.

2.3.2. Coral reef

The desalination plant outlet point at a reef is an issue and will most affect survival in the reef bottom sediment-dwelling organisms. Mabrook [101] and Heimeier et al. [102], reported the changed chemical parameters resulting from the environmental impact of waste brine disposal from a desalination plant as follows: most of the coral has disappeared, many planktonic organisms have disappeared, and many fish species have declined and even disappeared from the coastal areas. This result in the pH factor of the marine ecosystem is already a topic of much research on the impact of small changes in the biota, which is known to be a major influence. In Egypt, in the case of the Red Sea, the pH was reduced from 8.3 ± 0.3 to 5.8 ± 0.3 [101]. Also, ecological indicator studies of the diversity and distribution of marine plankton larvae have used DNA barcoding and depend on molecular methods in assessing future desalination effects [102]. Specifically, the main changes in the marine ecosystem can be summarized as follows: loss of coral, death of the plant organisms suspended in the surrounding area, a reduction in the populations and species extinctions, and formation of similar coastal ecosystems is impossible. Such results have been reported in Hurghada city [3], the Arabian Gulf [103–107], Hawaii [107,108], Florida [108,109], the Rea Sea [110], and Cape city [111]. In the Gulf of Panama, it was reported that the biological safety of the coral *Pocillopora damicornis* depended on seawater temperature; when it increased from 30 to 32 °C, 5 weeks after, 32 were dead. Salt concentrates in effluent can be discharged from the desalination plant at about 61 ppt (very high). Table 5 shows that the proliferation was reduced to 2% within 50 m. Salinity tolerances of corals ecosystems showed the following: *Montipora verrucosa* (exposure day; 20), *Porites compressa* (exposure day; 20), *Stylophora pistillate* (exposure day; 20), and *Pocillopora damicomis* (exposure day; 20), completely died *M. verrucosa* 45 ppt/100% response, *P. compressa* 49 ppt / 50% response, *S. pistillate* 49 ppt/100% response, *P. damicomis* 45 ppt/100% response [107,108]. These results demonstrate that reduced salinity is detrimental to the coral reef ecosystem, and if salinity is lowered by natural or desalination plant projects, then pale, bleached coral results, followed by death [12,112,113]. Some coral reefs have also been assessed in desalination in various works focusing on the effects of toxic pollution of the marine environment, due to their bioaccumulation capability and existing relationship among pathologies suffered by any benthic coral reef, fish, or various organisms and the presence of polluting substances. A desalination discharge causing visual damage to a coral reef is easy to use as an ecological indicator. After research, coral reef ecosystems and genetic research should be prepared based on academic ecological indicators. Accordingly, physical–chemical problems due to desalination projects must be solved by monitoring the coral reef ecosystem response to potential ecological indicators. (See Table 6.)

2.3.3. Conservation and endangered species

Conservation of commercially valuable species and endangered species plays an important role in the ocean ecosystems in changes in the food chain [4,77]. Reverse osmosis plant discharge effects have been was investigated in terms of the impact on the marine mammals; plants have great impacts with shoreline construction [77]. However, GHD [4] reported sea turtle migration path use was surveyed and a desalination plant did not interfere with the turtles' route. In addition, a desalination plant on the gold coast Australia was subjected to an ecological risk assessment, with plant construction designed so that marine mammals were less likely to be affected. Endangered and protected species habitats are often overlooked, and this is a reason that desalination projects in marine ecosystems may cause various damage. Conservation and endangered species legislation at the national and regional level reduces the possibility of clearing a desalination plant with a problem, while they should strengthen the purity of marine ecosystem. Also, an information and forecast system must be configured to compile and validate the management, as well as to activate the ecological indicator protocols required for desalination ecosystem assessments. It is difficult to draw conclusions about the prior negative research on desalination projects and endangered and protected species, and ecological indicators should continue to be used for monitoring.

2.3.4. Algae, plankton, and microbial ecosystem

Marine red algae have a range of tolerances to salt concentrates of 40 ppt [80] regardless of photosynthesis. Pankratz [114,115] reported the presence of harmful assessment in coastal waters that might be used in desalination plant assessments: algal blooms can cause significant operational issues that result in increased chemical consumption and increased membrane fouling rates [116]. Regarding desalination vegetation, this is a series of genera that appears universally when pollution situations occur. Among them are the green algae *Chaetomorpha*, *Cladophora*, *Enteromorpha*, and *Ulva*, the red algae *Corallina*, *Gracilaria*, and *Porphyra*, and influenced mainly by desalination *Acidovorax* and *Ulothrix*. Other authors, such as Heng et al. [117], have examined permanganate and chlorine fouling, Wilson et al. [80], were concerned with environmental tolerances of free-living coral lines, Latorre [86] assessed the environmental impact of brine disposal, Seubert et al. [118], reported on algal toxins and desalination operations and saxitoxin, Tuzen et al. [119], studied the biosorption of As (III), Seubert et al. [118], assessed algal toxins in field monitoring of brevetoxin and okadaic acid as potential ecological indicators for the presence of heavy metal or ecological damage caused by desalination discharges. Seubert et al. [118], investigated the potential impact of algal toxic and field monitoring of domoic acid, saxitoxin, brevetoxin, okadaic acid by challenging a bench scale RO unit with high concentrations of DA, STX, and PbTx. Even non-toxic algae concentrations can deplete water of oxygen and irritate fish gills, and otherwise affect marine ecosystems, accumulate quickly, and pose a threat to humans. They can also affect fish, mammals, birds, and some commercial species [24]. Harmful algal blooms (HABs) monitoring is the most effective shellfish monitoring and detection system. On the other hand, salination project ecosystems are significantly affected by contributions from phytoplankton, zooplankton, and fish in the energy and discharge outfall areas.

Plankton structural responses in desalination ecosystems to chemical stresses were noticeable in terms of an increase in phytoplankton cell size and phytoplankton and microzooplankton, species diversity, and in the ration (Table 6). The level of plankton organisms in marine ecosystems is the most sensitive to high salt concentrations, but in some species of marine life it also has a positive impact. However, desalination plant marine organisms before and after construction work can tolerate temperature, salinity, alkalinity, as clearly demonstrated by the

Table 5

Experimental salinity tolerances and ecosystem damage to a variety of corals.

Reference	Location	Family	Species	Day exposure	Salinity exposure (ppt)/response (%)				
					Normal	Pale	Bleached	Mortality	Died
[108]	Hawaii	Acroporidae	*Montipora verrucosa*	20	40/50	40/50			45/100
[109]	Florida	Poritidae	*Porites porites*	3	37/100		40/50		40/100
[108]	Hawaii	Poritidae	*Porites compressa*	20		40/70			40/30, 45/100
[108]	Gulf	Poritidae	*Porites compressa*	20	45/100	49/40	49/40		49/50, 51/100
[109]	Hawaii	Poritidae	*Porites compressa*	3	37/100		40/50	45/100	
[108]	Gulf	Pocilloporidae	*Stylophora pistillate*	20	43/100				49/100
[108]	Hawaii	Pocilloporidae	*Pocillopora damicomis*	20	40/10	40/10	40/80		45/100
[110]	Florida	Favidae	Montastrea annularis	1.5	40/100				
[111]	Rea Sea	Pocilloporidae	*Stylophora pistillate*	21					40/100

Table 6
Impact pathway and assessment for operating the reference project desalination plant in a marine environment.

Impact pathway	Impact assessment
– Potential impacts from the discharge of saline concentrate and other diluted chemical wastes	– Salt is the primary stressor in the Reference Project discharge. – Rapid initial dilution of the discharge should result in no acute toxicity at the point of discharge. – Chronic toxicity as a result of exposure to slightly elevated salt concentrations not likely but there is a potential for a community shift in some benthic species within a mixing zone.
– Potential impacts on water quality from the above-mentioned discharges	– No impacts on water quality are expected outside of a declared mixing zone. – Within the mixing zone, it is expected that water quality will not be compromised. – This is evident by the low dilution requirements for most constituents (for most, no dilution is required, and other < 10 fold) in the discharge in relation to trigger levels.
– Entrainment, entrapment and impingement of adult marine organism and marine vertebrates	– Small number of adult marine biota may be removed by the inlet the impact will be minor at the population level.
– Entrainment, entrapment and impingement of eggs, larvae and other plankton.	– A small portion (maximum 1.8%) of eggs, larvae and plankton may be entrained from a given area, but this is unlikely to have an impact at the population level.
– The use of an exclusion zone for marine recreational and commercial activities (located above the marine structures during operation).	– As the inlet and outlet will be located away from the shore, exclusion ones around these structures are unlikely to impact most recreation which is based closer to inshore and as such no further assessment is required

Note: based on [195].

level of the materials. Plankton indicates that a healthy ecosystem can be characterized by the following: small cell size phytoplankton, large body size in zooplankton, high or low zooplankton and macro zooplankton biomass levels, and a high zooplankton is showed in Fig. 2 [120]. Fig. 2 shows the relative to desalination-contaminated ecosystems, a healthy and/or Gulf coastal waters ecosystem will have a higher zooplankton biomass, low phytoplankton biomass, height zooplankton/phytoplankton ratio, and chlorophyll plankton and sustainability of ecosystem [120,121]. With regard to the potential ecological indicators, the conceptual diagram of the model considers the original ecosystem, such as before the operation of desalination plants in terms of ecosystem structure, function, stress, and mortality. Abdul Azis et al. [121], studied the ecological relationship that the phytoplankton and the zooplankton of region possesses with respect to intake and discharge. Plankton ecosystems should be used as ecological indicators for marine ecosystem damage due to desalination projects in management and monitoring.

Microbial communities play important roles in biogeochemical cycles and heavy metal redox biotransformation in adjacent coastal areas, sediments, and/or diverse processes in the outfall area ecosystem [3,10,121–123]. Bacteria production affects the surveys differently, and the effect of the discharges on water quality and microbial community were identified, potentially affecting microbial life in the marine environment [124]. Increased salinity and temperature together affect water quality and the microbial community at the disposal site. Moreover, sediments have several roles; they act as sinks of outfall detritus material through mineralization, sea grasses, and benthic respiration. The microbial community can evaluate the TDC, ATP, and AOC in biofilters and the diagnosis of membrane biofouling [125–128]. A dynamic shift in the bacterial community was observed at the top part

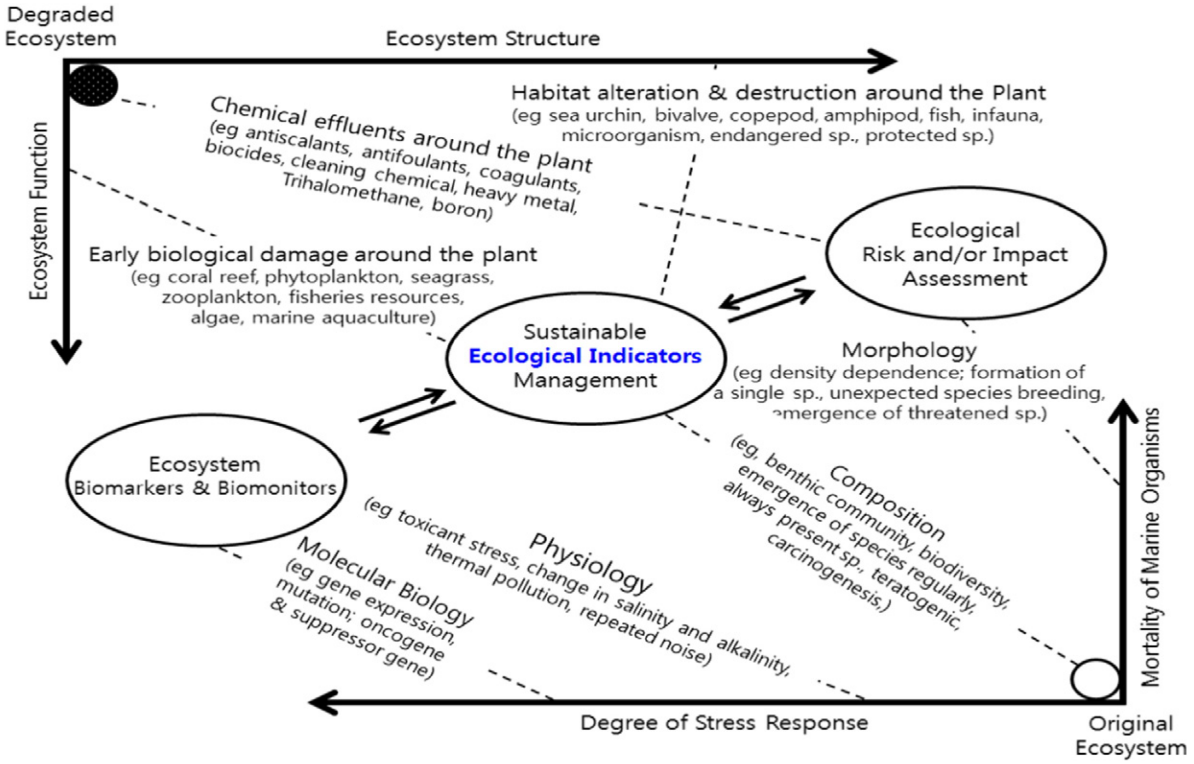


Fig. 2. Proposed ecological indicators and approaches for degraded and/or original ecosystems such as operating a desalination plant ecosystem structure, function, stress, and mortality characterization. Sustainability management of ecological indicators major characteristics is important risk and/or impact assessment.

of a microbial biofilter [123] and microbial assemblages [129] effluents from desalination technologies, which may influence natural bacterial due to changes in salinity, pH, and various by-products. Changes in marine life can be expected in the damaged marine ecosystem with algae, plankton, and microbial ecosystems. The ecological damage changing these species, managing acids or marine resources, underwater, and marine organisms, are described in this review of potential ecological indicators, and they can be assessed at the genetic level.

2.3.5. Impingement and entrainment

Desalination discharges affect the productivity of fish and induce various changes, including habitat appearance and destruction, place interference, impingement, entrainment, and the amount of nutrients. Rate of inflow quantity of a desalination plant during construction affected impingement and entrainment [4]. However, when inlet flow rates are low, and a screen of appropriate mesh size has been installed, the fish community is not affected by impingement and entrainment [18]. Lattemann and Höpner [18] reported impingement to be collisions with the plant screen and entrainment research in the construction of various desalination plants. Dawoud and Al Mulla [16] studies showed more specific effects of desalination plants such as impingement and entrainment of marine organisms due to the intake pipeline type. Desalination plants can be harmful to the marine ecosystem by impingement and entrainment intake, which cause injury or death of organisms. In an injecting desalination plant, the amount of screen impingement and entrainment of marine organisms to be removed from the seawater was heavily dependent on the screen design used. These results suggest that specific information is required to minimize the mortality of marine organism by screen design. Desalination inlet and outlets were observed in various marine ecosystems and were included in the value of protected species and aquatic species. These results influence the degree of impingement and entrainment in operation: factors include intake, outlet, discharge characteristics, discharge point, salinity, and water quality standards in each country. However, damage should be monitored continuously. Impingement and entrainment assessment studies of desalination plants should be a new research field for ecological indicators.

2.3.6. Climate change

Climate change and desalination project impact/risk and/or ecological indicators are growing concerns for communities, policy-makers, outfall ecosystems, discharges, sea grass, marine organisms, and plant managers around the world [130–132]. These elements are problems with desalination projects: climate change issues may have a close relationship with cleaning chemical, noise, temperature rise, heating effluent, stress, and salt concentrations. At the same time, climate change will be contributing effects on marine ecosystems and causing many problems, including changes of species. McEvoy and Wildr [133] reported the potential negative impact and/or effect of desalination and climate change on the long-term salt balance, large-scale, less path-dependent, incorporating social learning and climate change adaptation interventions [134]. Large-scale marine ecosystem and active desalination environmental research efforts are in progress on ecological quality. The Global Change Research Program provides a common basis for evaluating research in diverse and desalination based projections of local climate change effects in 2030 and 2070 [134]. Nunes-Vaz [134,135] paper has identified an endangered species integration time of ~6 months for the response of salinity to environmental forcing and spatial–temporal dynamics of biotic and abiotic features of temperate ecosystems as revealed by a combination of ecological indicators [136, 137]. Table 5 shows that the climate change and damage to marine ecosystems are more severe problems that are expected to affect desalination operations and the ecosystem [138].

Ecological indicators show the most significant impacts of climate change: coral reef effects apart from coral bleaching, and the effects of ocean acidification resulting from desalination operations. Salinity impacts of climate change can estimated. It is estimated that 884 million people do not have access to clean drinking water around the world [131]. Desalination causing rising water salinity is a further potential challenge with climate change and other public health problems among large sectors of the global population. The use of ecological indicators in desalination management is growing, especially in response to climate change and plant projects and/or marine ecosystem impacts on communities and their surrounding environments [131]. Ecological indicator managers also want to understand more about how to manage marine ecosystem resilience in the face of climate change and desalination use changes. Markus et al. [139] reported multi-model ensemble simulations using three coupled physical–biogeochemical fluxes that were performed to calculate the combined impact of climate change on ecological quality indicators and combined projected into the future. The Intergovernmental Panel on Climate Change (IPCC) was expected to limit greenhouse gas emissions according to the CO_2 concentration in the atmosphere between 2040 and 2050 to a level of two times the natural concentration of 550 ppm. England's MarClim project on climate change biodiversity used ecological indicators and the main intertidal species. Also, rapid climate change indicated by ecological indicator richness will provide information about population structure, as well as the distribution and range of environmental changes. Thus, desalination project selection and management is important to ecological indicators, climate change, ecosystem change, and effective countermeasures. Climate change has the potential to impact the marine ecosystem, habitats for biological diversity, and desalination plant management operation decisions. A management challenge is future research and understanding the potential impact/risk and/or ecological indicators of climate change on desalination management and adapting to those changes as required.

3. Research needs in ecological indicators of potential biochemical relationships

Research findings in ecological indicators to push the known boundaries of biochemical ecosystem into seemingly impossible depths, temperature rise, salt concentrations, heating, effluent, habitat escape, noise, stress, and physiological changes in these environments will influence desalination projects significantly and form the basis of significant biogeochemical phenomena.

Whether in marine ecosystem organisms or not, the biochemistry attributes that allow growth under these discharge conditions are fundamentally intriguing. Biomarkers can be confirmed through genetic potential ecological indicator, such as breeding, abnormal behavior, habitat avoidance due to hormonal change and desalination project fish genetic characteristics [140]. Furthermore, as suggested, many of these findings have important biochemistry indicators for broader scientific thought about the desalination plant ecology and evolutionary changes of ecological indicators strategies. Danlhoff [1] investigates the effects of temperature, food availability, metabolic activity (enzymes, DNA/RNA/Protein), marine physiological ecology, heat stress (heat shock protein, or Hsps) damage due to climate change, or other physical factors on the physiological of marine ecosystem. Risk and/or impact assessing the physiological condition of ecological damage to important marine organism is understanding the desalination ecosystem and using biochemical indicators for ecological indicators from marine ecosystem studies. Ecological indicators are used for marine habitats from fronds to fish, and benthic ecosystems, with case studies from temperate change [141]. Biochemical research is needed in ecological problems of other enzyme indicators that are used in marine ecosystem studies, including DNA/RNA/Protein, and Hsp expression, and those studies focus on the balance of desalination plant project and discharge.

Along these lines, molecular analyses should go beyond gene expression and reach an understanding of monitoring of desalination plant cues; they should identify potential physiological phenomena. Biochemistry, genomics, proteomics, and physical, chemical, biological, biomarker, and bioindicators in risk and impact assessment studies will become more prominent in desalination plant studies facilitated by past, present, and future methods using ecological indicators (graphical abstract). Gong et al. [142], reported that a stress-responsive gene *Fortunella crassifolia* FcSISP was encoded as a putative protein of 47 amino acids; it is induced appreciably by salt, leading to enhanced tolerance. In this study, extra work was required to investigate whether overexpression of *Fortunellla crassifolia* FcSISP could affect heavy metal accumulation in transgenic lines to understand the role of salt stress resistance [142]. Marine ecosystems show important physiological responses of the sea urchin *Paracentrotus lividus* fed with the sea grass *P. oceanica* and the alien algae *Caulerpa racemosa* and *Lophoxladia lallemandii*, in addition to tropical freshwater on a global scale in cyanobacterial harmful algal blooms (cyanoHABs) where secondary metabolite gene expression appeared to be dangerous for drinking and recreation [143,144]. These results suggest that biochemical studies of sea grass ecosystem damage by a desalination project as a result of ecological indicators can be used in same way as a coral reef ecosystem in the future. To investigate the influence of sewage on the differential gene expression of Pacific oysters, *Crassostrea gigas*, suppression subtractive hybridization method was used [145]. This research examined a desalination indicator gene; also, the genes identified were associated with different metabolic functions, like biotransformation, membrane transport, and aerobic metabolism. Suppression subtractive hybridization suggests the applicability of these genes as potential ecological indicators and/or biomarkers, which is being investigated through field experiments and may be useful for desalination plants. Various biochemicals have been reported [146] to accumulate in higher plants under salinity stress, and amino acids including alanine, arginine, glycine, leucine, serine, and valine which may be indicators of salt tolerance [147]. This use of biochemistry information in salt tolerance needs to be applied with future genetic approaches with molecular, biochemical, and physiological results. Fluoroquinolone resistance *qur*B, *qur*S, and *qur*D genes were detected in sediment, water, soil, and fecal flora in an environment polluted by discharges, as was a response relationship [148]. Also, the *qnr*D gene is important to study as an ecological indicator in the desalination discharge in both well water and fecal sample indicators in future.

Climate change thus provides an opportunity for the study of the genetic basis of adaptation in a desalination project ecosystem. The goal of Franks and Hoddiman's [149] research was to investigate the genetics of climate change adaptation to understand the process of evolution in a natural population [150]. Genetic variation can be expected due to potential ecological indicators, such as temperature change expected from climate change and biochemistry damage in fish. Thus, climate change should take into consideration the safety of the marine ecosystem for desalination projects. Although recent research has increased the understanding of links between biochemistry traits and/or molecular biology responses to ecosystem change, marine ecosystem damage relationship must be monitored continuously and genetically due to climate change and desalination projects. According to the 2007 ICPP report, as a result of global warming, the temperature is expected to increase by 6.4 °C within 100 years with a rise in sea level, and the destruction of the marine ecosystem food chain is expected. This phenomenon, based on the habitat of living coral ecosystems, must be the first to leave zooxanthella coral habitats, and coral bleaching phenomena in up to 90% of coral reefs. In addition, a variety of marine habitats and coral ecosystems are usually destroyed. Thus, based on the marine ecosystem, the coral ecosystem's importance can be used as an ecological indicator for seawater desalination projects.

Genomic insights into marine microalgae with genetic manipulation and regulatory processes will allow direct monitoring of the state of the marine ecosystem [151]. This can be coupled with sensors and ecological indicators, and this biochemistry information may help respond to increased desalination project impacts. Also, metagenomics and metatranscriptomics can help with ecological indicators, monitoring, biomarkers, and bio-indicators, to assess discharge ecosystem changes in the face of increasing marine impact and/or risk assessments. Molecular biology techniques can be used in the marine ecosystem for the rapid, specific, and sensitive detection of target gene damage information and monitoring of microalgae in the marine environment. Polymerase chain reaction and other molecular based techniques can be important tools for assessing the ecological indicators that are to be determined for management. Torres et al. [152], reported that biochemical biomarkers in algae show effects of marine pollutants in terms of cellular damage and potential biochemical mechanisms that algae use. Algae may damage filters, cause clogging problems, and disorders in coagulation sedimentation, resulting in a stench and visual effects [153,154]. Algae breeding caused by long-term high temperature exposure occurs due to desalination projects and microcystins are not removed, but ozone and other strong oxidizing agents can be removed. If discharges do not have controls in desalination projects, microcystins and anatoxin-a toxicity problems may clearly occur. Algae may be useful as potentially important ecological indicators such as indicators of biochemical systems involved in detoxification of chemical compounds in the marine ecosystem. Cuif et al. [155], reported biochemical markers of zooxanthellate (13 sp. or 11 sp. non-zooxanthellate) that show symbiosis in the mineralizing matrices of living corals; with their metabolism, it is possible to discriminate between symbiotic and non-symbiotic amino acids and monosaccharides. In addition, the possible biochemical effects of marine ecosystems, such as bleaching, and the biochemical composition of coral tissue show reductions in proteins, lipids, amino acids, and carotenoid concentrations [165,166] and ecological phenomena in coral reefs (Table 5). Some reef corals do not bleach, resisting stress; this resilience implies that the coral of the Gulf and their algae symbionts have been capable of acclimatization and genetic plasticity [77,156,157]. Coral bleaching has been documented, as has mortality in response to a variety of environmental or desalination projects and stress conditions [156,158]. Degraded reefs due to desalination projects may recede due to climate change or discharges. Thus, it is important that data be gathered for future coral reef conservation and understanding the dispersal potential of coral and other coral reef organisms' resilience for restoration projects [77,159–162]. These results may show the potential genetic or physiological damage and it is necessary to continue research on this. Coral damage due to desalination effluents include damage to the food chain, loss of coral ecosystems, floating organism death, bacterial disappearance, fish population changes, and reduced causes of apoptosis. As such, these coral biochemistry changes and/or genetic restoration data can be estimated from the effects of desalination projects. Biochemistry, phylogenetics, and population genetics are useful as ecological indicators of coral reefs ecosystem desalination discharges and for guiding restoration for coral reef conservation for the future plant projects [159]. These research efforts suggest that corals may be able to alter their biochemistry and/or gene damage in response to changes in the desalination ecosystem by marine chemistry. Expanded studies of reproductive processes, coral ecosystem symbiosis, molecular genetics, biochemistry, connectivity, eco-modeling, calcification, physiological replication, and/or repair may help ecological indicator researchers to better understand how coral reef ecosystems function and the variety of stressors and early-warning indicators of desalination project discharges.

4. Desalination: future model of potential ecological indicators

Seawater desalination poses environmental risks and impact assessments including ecological indicator species can provide information about marine ecosystem disturbances, the disappearance of symbiosis, and changes in living group. The living group of ecological indicators indicate risk or impact assessment checks in determining the status of the health damage in marine ecosystems. In addition, ecological indicators can explain the phenomena of physical degradation, damage, response, function, stress, and mortality, as outlined in Fig. 2 following the graphical abstract. Recent research has demonstrated the accuracy of genetics-based methods as ecological indicator tools, such as PCR, qPCR, AFLP, RFLP, T-RFLP, VNTR, LOH, SSCP, mitochondrial, chromosome, and various gene technologies, which have been used to assess desalination-related marine ecosystems. The activity and induction of genetic/physiological conditions may induce healthy cells in the ecosystems and hormones in the desalination discharge may enhance the various damaging effects of the desalination plant. The ecological indicators used in desalination plant studies were chosen due to the possibility of genetic damage and the possibility of physiological phenomena, because altered gene expression plays a key role in physiological response pathways (graphical abstract). By the 1990s, Castellini and Margaret Castellini [163] examined models of the interplay between the hormones and biochemistry in marine mammals.

Local contents of chlorites in the sediments have been reported to accumulate up to 6% by desalination effluents. However, because chlorites have health implication for humans and the marine ecosystem, this research has shown the need for potential ecological indicators [26,141]. Also, Barrett et al. [150], suggested that cold tolerance was due to the changes in desalination projects; that marine sticklebacks carry sufficient genetic variation to adapt to seawater temperature changes [164]. Multiple biomarkers of pollution effects in caged mussels resulted in useful parameters in the assessment including neurotoxicity (AchE), biotransformation of glutathione S-transferase (GST), metal exposure (Mts), and protein synthesis (RNA:DNA ratio) in the effects of environmental pollution (1). Genetic monitoring should continue these results in desalination projects. Changes in marine life can be expected in the damaged marine ecosystem: changes in fish, coral reefs, shellfish, sea urchin species, algae, and seaweed. Seawater desalination assessment using various indicators can overcome these limitations and can be expanded to the gene level.

Lirman et al. [165], reported that low-stress environment conditions in coral reef communities can be determined based on data from >50,000 colonies from 11 coral species, with <5% prevalence of mortality. This use of ecological indicators can provide early-warning management because similar desalination discharge conditions can be assessed in terms of the status of coral reef population as a matter of ongoing management, an important step towards ecosystem-based fishery assessment [166]. Table 5 shows the advantage of these coral ecosystems is using ecological indicators, so it can be managed from a desalination project [12,156]. Thus, coral ecosystem health assessment desalination can be used as ecological indicators. Forms a symbiotic relationship between zooxanthellae-algae and coral ecosystem, It absorbs CO_2 and photosynthesis, the group most sensitive to marine desalination projects. Therefore, the coral ecosystems from destructive desalination projects around the food chain damage specific objects like starfish species proliferation, create the phenomenon of avoidance of marine habitats, and biological–genetic–biochemical–morphology development should be made based on the coral ecosystem indicators species for using ecological indicators. Many desalination plants are disinfected by periodic treatment with sodium metabisulphite, sodium perborate, sodium hydrochloride, and use various chemicals that have potentially toxic effects on marine ecosystem, even though no empirical study or experimental evidence for this is yet available [167]. Also, Portille et al. [167], evaluated the abiotic and biotic effects of sodium metabisulphite pulses discharged from desalination plant, physico-chemical variables hypersaline, pH, and DOsat on what might be a potential cause of *Cymodocea nodosa* and other sea grass characteristics of benthic community. Various damages on marine ecosystems have been reported near desalination plants located in the shoreline area. Effects of these plants' operations, however, have not been exactly evaluated due to immediate dilution of the concentrated seawater effluents in huge ocean body and other factors as well. Environment-friendly desalination technology is being introduced, such as electrosorption. Electrosorption is defined as potential-induced adsorption of ions onto the surface of charged electrode. When an electrical potential was applied to the electrode, charged ions migrated to the electrode and are held in the electric double layer. This process is environmentally attractive because it requires no chemicals for regeneration [169]. The reason for this is that in the initial stage of research will use the level of sample number to report the degrees of contamination, and although desalination process is obviously damaging the marine ecosystem, simple numbers do not represent environment risk and impact assessment that can be caused in the living organisms.

Molecular indicators provide the earliest possible evidence of marine ecosystem and sea grass mortality and the development of ecological indicators for desalination project damage to a variety of stress responses is important. Sea grasses illustrate the importance of potential applications, including the onset of stress, and changes in molecular biology, morphology, physiology, biochemistry, as an effective early warning of mortality due to effects of desalination projects. Worldwide, there are reported contributions from desalination plant discharge to toxic pollutants. In California, a coastal desalination plant reported the discharge of 45 kg/day of copper in effluent and threat is a 10 vol accumulation increase from 3.51 to 32.20 mg/kg/day in Table 4 [88,168]. It is reported that these concentrations in the marine ecosystem cause physiological–genetic damage mortality and/or morphology change. Woo et al. [170], reported the Test Bed for a desalination plant located in Gijang-Gun, South Korea (Table 1) having a capacity of 4546 tons/day. On the other hand, desalination plant Test Bed investigated the damage for 3 years due to construction work, and fishing on the damage between suspended solid (SS) problem of terrestrial ecosystems and construction noise vibration of terrestrial ecosystem and marine ecosystem [3]. Among Asian countries, the Republic of Korea has reported a small capacity (Sodo; 10 tons/day to Geomundo; 700 tons/day) regional construction operation of desalination plants (see Fig. 1). More than 70 small plants are mainly located on the coast, and also for the purpose of industrial water is over 134,540 m^3/day operation. The production of fresh water and a scale of 250,000 tons of these desalination plants since 2008 is associated with a number of countries with hydrological marine emissions, and requires global interest and management. The capacity can threaten the ocean and/or ecosystem of this construction.

Seawater desalination construction companies worldwide should target global marine ecosystem monitoring and management. The items that are not in accordance with the regional desalination project must be measured. However, the need to manage marine ecosystems is also changing due to climate change. Thus, global climate change should be monitored and needs teratogenic, carcinogenesis, suppressor gene, oncogene, and hormonal changes, based on food chain changes in the ocean ecosystem targeting coral ecosystems, algae ecosystems, sea grasses, and desalination outfall and discharges. To build a desalination company, government officials from around the world must respond responsibly to monitor and manage the marine ecosystem. In order to avoid ecological risks induced by the current desalination technology, the followings should be kept such as no system error in operation, no operational method without any international standard, and comprehensive management of the effluent by government. The ecological risks that could be caused by the desalination technology can be alleviated by considering ecological standpoint rather than desalination plant operation. Desalination management and monitoring using ecological indicators is a powerful weapon that will be a topic for academic study, research, and policy tools. Global seawater desalination plant projects depend on intact marine ecosystems, which provide a good habitat environment, and marine environmental protection is also in the inherent interest of the industry. Ecological indicator monitoring of contamination from desalination projects is important in the seawater ecosystem. Moreover, we performed a series of studies to assess the utility of incorporating a molecular genetic diversity indicator into ecological indicator assessments and monitoring efforts. Molecular genetics measures of desalination discharge will ultimately provide highly useful ecological indicators.

5. Conclusion and future directions

The aim of the use of ecological indicators is to increase our understanding of the mechanisms of discharge to identify ecosystem structures and functions as well as the relationship of stress responses and mortality of marine organism pathways that underlie important degraded ecosystem responses and original ecosystem interactions. It is also to determine the risk/impact assessment pathways and exhibit functional variation in desalination plant projects in Fig. 2 [3,61,171]. Ecological indicator studies can be used in terrestrial and marine ecosystems to assess habitat change, destroyed food chains, and species ranges are changing substantially as a result of widespread appeal to desalination scientists. The marine ecosystem is constantly threatened and will eventually be destroyed. Thus, it is necessary to continue to manage and monitor the use of ecological indicators. This is possible through the use of mutations and diseases, tumor suppressor gene, oncogenes, hormonal changes, and physiological responses in the Graphical abstract [172,173].

However from a more desalination project scientific point view, the characteristics defining a potential ecological indicator are:

1. Must be easy to handle and identify.
2. Must play a key role in the marine ecosystem.
3. Must be efficient and/or discharge-sensitive to small variations of marine ecosystem.
4. Must be present in a wide range of marine ecosystems.
5. Must be sensitive to a variety of stresses caused by desalination plant operations.
6. Must be testable under natural conditions or simulated laboratory conditions.
7. Must be efficient, non-laborious methods for extraction of organisms from marine environment and population assessment.
8. Gene database must be managed by means of ecological indicators.
9. Must require strong policy from other countries.

The information gathered from studying these ecological indicators can be used to forecast future changes in the marine ecosystem. It will focus on the aspects of the marine ecosystem which are believed to be important for risk and/or impact assessment and biomarkers and/or biomonitors (see Fig. 2). A marine ecosystem, therefore, has four major attributes: structure, function, response, and mortality, each of which is made up of different elements. Continuous management of ecological indicators should include monitoring between risk/impact assessment and biomonitors/biomarkers. Fig. 2 shows the function of the marine ecosystem and degradation is to see the early biological damage around the plant, it can be confirmed using the following: reefs, phytoplankton, sea grasses, fisheries, algae, and marine aquaculture [152,173]. This study and determining the structure of the original ecosystem allows management through ecological indicators, such as benthic community, biodiversity, and emergent species. Also, the marine ecosystem may be degraded from chemical effluents around the plant, such as antiscalant, antifoulant, coagulant, biocides, cleaning chemical, heavy metal, trihalomethane, and boron. Physiological stress responses can be evaluated in the original ecosystem including toxicant stress, changes in salinity and alkalinity, thermal pollution, and repeated noise. The management of the stress response can be estimated by assessing damage in molecular biology assays, such as gene expression, potential mutations, potential oncogenes, and suppressor gene expression [174]. Furthermore, recent studies have demonstrated the efficiency of molecular techniques in enhancing environmental health indicators, detecting the genetic diversity in biomonitoring [175–177]. There are a number of reasons to believe that monitoring in risk/impact/biomarkers/biomonitors assessment will ultimately provide useful ecological indicators [3,152,170,171,174,177]. In the 21st century, our drinking water solutions should be placed within a reasonable solution by understanding the relationship between desalination and marine ecosystems.

Understanding ecological indicators can be suitable for monitoring the overall management of desalination projects. Thus, a positive approach to ecological indicators will provide healthy marine ecosystem benefits in the future. This research suggests that there is a need for clearly limited and clearly reported data in accordance with the construction of a desalination plant; marine ecosystems could prove positive or negative data. When the effluent is discharged directly into the sea or released after treatment step (s), it is necessary to strengthen the institutional and legal regulations regarding how the risks may affect the ecosystem affected by the effluent. Ecological indicator studies of desalination projects need to include ecotoxicity and monitoring gross indicators of marine organism as well as gene level work. In the initial stages of desalination projects, the degree of contamination was reported using the level of s simple number, but a simple number may not represent the risk/impact itself that can be caused in living marine organisms. Thus, using ecological indicators for marine ecosystem assessments can overcome these disadvantages and gross changes in the index; it can also widen the evaluation by detecting changes even at the gene level. At the national level, the government must supervise research on ecological indicators for monitoring, and managing and evaluating their application to the marine ecosystem. Ocean ecosystem pollution data from desalination project risk/impact assessments that can be appropriate for the development of ecological indicators and database of sustainable monitoring techniques. Drinking water resources of 7 billion people around the world need to be secure; however, desalination plant technology should not ignore ecological rule. In addition, solution to genuine concerns about drinking water security of each country should not destroy the ecosystem. Conservation and maintenance for ecological balance need to be honored.

Acknowledgments

We thank Dr. Choi Mi-Jin, Dr. Lee Eun-Kyeong, Dr. Lee Ji-Ho, Dr. Lee Yun-Seok, Dr. Liw An-Na, Dr. Kim Jun-Yeol, Dr. Kim Hyun-Young, Dr. Yu Hye-Weon, Lee Ji-Hoon, and Dr. Hwang Moon-Hyun for technical assistance for helpful advice. This work was supported by a grant (Y1005E-MPS-E012) from the “Marine Ecological Impact Assessment of Brine Discharge Produced by the Seawater Reverse Osmosis (SWRO) Desalination Test Bed” funded by Doosan Heavy Industries & Construction.

References

[1] E.P. Danlhoff, Biochemical indicators of stress and metabolism: applications for marine ecological studies, Annu. Rev. Physiol. 66 (2004) 183–207.

[2] F. Salas, C. Maarcos, J.M. Neto, J. Patricio, A. Perez-Ruzafa, J.C. Marques, User-friendly guide for benthic ecological indicators in coastal and marine quality assessment, Ocean Coast. Manag. 49 (2006) 308–331.

[3] J.S. Chang, E.K. Lee, H.W. Yu, M.J. Choi, Marine ecological impact assessment of brine discharge produced by the seawater reverse osmosis (SWRO) desalination test bed, Final Report, Biological & Genetic Resources Institute (BGRI), 2013.

[4] GHD Report, Planning for desalination: marine ecological assessment. Preliminary site inspections for an inlet and outlet and possible pipeline route for water distribution, The Ecology Lab Pty Ltd., November 18 2005. (Report number 340405F, Final).

[5] EIC (Environmental International Consultants), Environmental impact assessment for Jebel Ali power and desalination station M, Dubai Electricity & Water Authority, 2009. (Prepared for DooSan, Available at: http://www.eicon.ae, Fisia Italimpianti gruppo Impregilo).

[6] E. Esen, E. Sayin, O. Uslu, C. Eronat, Modeling wastewater discharge at the planning stage of a marine outfall system, Environ. Monit. Assess. 183 (2012) 3165–3184.

[7] U.S. EPA, Evaluation Guidelines for Ecological Indicators, EPA-620-R-99-0052000.

[8] I. Rombots, G. Beaugrand, L.F. Artigas, J.C. Dauvin, F. Gevaert, E. Goberville, D. Kopp, S. Lefebvre, C. Luczak, N. Spilmont, M. Travers-Trolet, M.C. Villanueva, Evaluating marine ecosystem health: case studies of indicators using direct observations and modelling methods, Ecol. Indic. 24 (2013) 353–365.

[9] F.E. Culhane, R.A. Briers, P. Tett, T.F. Fernandes, Structural and functional indices show similar performance in marine ecosystem quality assessment, Ecol. Indic. 43 (2014) 271–280.

[10] C. Desrosiers, J. Leflaive, A. Eulin, L. Ten-Hage, Bioindicators in marine water: benthic diatoms as a tool to assess water quality from eutrophic to oligotrophic coastal ecosystems, Ecol. Indic. 32 (2013) 25–34.

[11] A. Borja, D.A. Dauer, A. Gremare, The importance of setting targets and reference conditions in assessing marine ecosystem quality, Ecol. Indic. 12 (2012) 1–7.

[12] N. Guillemot, P. Chabanet, M. Kulbicki, L. Vigliola, M. Leopid, I. Jollit, O.L. Pape, Effect of fishing on fish assemblages in a coral reef ecosystem: from functional response to potential indicators, Ecol. Indic. 43 (2014) 227–235.
[13] S. Henriques, M.P. Pais, M.I. Batista, C.M. Teixeira, M.J. Costa, H. Cabral, Can different biological indicators detect similar trends of marine ecosystem degradation? Ecol. Indic. 37 (2014) 105–118.
[14] J.S. Chang, Ecological Indicators for Assessment of Arsenic Contamination in Soils, Gwangju Institute of Science and Technology (GIST), Republic of Korea, 2008. 1–28 (PhD. Degree).
[15] G.W.I. (Global Water Intelligence), Desalination Markers, 2010.
[16] M.A. Dawoud, M.M. Mulla, Environmental impacts of seawater desalination: Arabian Gulf case study, Int. J. Environ. Sustain. 1 (2012) 22–37.
[17] R. Einav, K. Harussi, D. Perry, The footprint of the desalination processes on the environment, Desalination 152 (2002) 141–154.
[18] S. Lattemann, T. Höpner, Environmental impact and impact assessment of seawater desalination, Desalination 220 (2008) 1–15.
[19] T.K. Liu, H.Y. Sheu, C.N. Tseng, Environmental impact assessment of seawater desalination plant under the framework of integrated coastal management, Desalination 326 (2013) 10–18.
[20] H.A. Naser, Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: a review, Mar. Pollut. Bull. 72 (2013) 6–13.
[21] J. Zhou, J. Chang, W.C. Victor, A.G. Fane, An improved life cycle impact assessment (LCIA) approach for assessing aquatic eco-toxic impact of brine disposal from seawater desalination plant, Desalination 308 (2013) 233–241.
[22] T. Höepner, A procedure for environmental impact assessments (EIA) for seawater desalination plants, Desalination 124 (1999) 1–12.
[23] V.D. Grebenyuk, A.A. Mazo, V.M. Linkov, New ecological problems of desalting and water re-use, Desalination 105 (1996) 175–183.
[24] HABs reported each year, Keeping Tabs on HABs. New tools for detecting, monitoring, and preventing harmful algal blooms, Environ. Health Perspect. 122 (2014) A206–A213.
[25] S. Lattemann, H.N. El-Hab, UNEP resource and guidance manual for environmental impact assessment of desalination projects, Desalin. Water Treat. 3 (2009) 217–228.
[26] O.A. Alharbi, M.R. Philips, A.T. Williams, A.M. Gheith, R.A. Bantan, N.M. Rasul, Desalination impacts on the coastal environment: Ash Shuqyq, Sauso Arabia, Sci. Total Environ. 421–422 (2012) 163–172.
[27] A. Areiqat, K.A. Mohamed, Optization of the negative impact of power and desalination plants on the ecosystem, Desalination 185 (2005) 95–103.
[28] R. Miri, A. Chouikhi, Ecotoxicological marine impacts from seawater desalination plants, Desalination 182 (2005) 403–410.
[29] WHO (World Health Organization), Desalination for Safe Water Supply: Guidance for the Health and Environmental Aspects Applicable to Desalination, World Health Organization, Geneva, 2007.
[30] T. Bleninger, G.H. Jirka, Environmental planning, prediction and management of brine discharges from desalination plants, MEDRC Series of R & D Reports, Project 07-AS-003December 2010.
[31] W.I. Frank Münk, Ecological and economic analysis of seawater desalination plants(Diploma Thesis) University of Karlsruhe Institute for Hydromechanics, 2008. 54–85.
[32] I. Alameddine, M. El-Fadel, Brine discharge from desalination plants: a modeling approach to an optimized outfall design, Desalination 214 (2007) 241–260.
[33] S. Lattemann, G. Amy, Marine monitoring surveys for desalination plants — a critical review, Desalin. Water Treat. 51 (2013) 233–245.
[34] M. Mickley, Reclamation managing water in the west, Desalination and Water Purification Research and Development Program Report No. 155. Treatment of Concentrate, U.S. Department of the Interior Bureau of Reclamation Press, 2009.
[35] R. Morton, A. Chouikhi, N. Wade, Environmental impacts of seawater distillation and reverse osmosis processes, Desalination 108 (1997) 1–10.
[36] A. Hashim, M. Hajjaj, Impact of desalination plants fluid effluents on the integrity of seawater, with the Arabian Gulf in perspective, Desalination 182 (2005) 373–393.
[37] J.J. Sadhwani, J.M. Veza, C. Santana, Case studies on environmental impact of seawater desalination, Desalination 185 (2005) 1–8.
[38] T. Höepner, S. Lattemann, Chemical impacts from seawater desalination plants — a case study of the northern Red Sea, Desalination 152 (2002) 133–140.
[39] Z. Amkad, Scale inhibition in desalination applications: an overview, The NACE International Annual Conference and Exposition. NACE-96-230, 1996.
[40] C. Fritzmann, J. Löwengberg, T. Wintgens, T. Melin, State-of-the-art of reverse osmosis desalination, Desalination 216 (2007) 1–76.
[41] J.A. Redonodo, I. Momax, Experience with the pretreatment of raw water with high fouling potential for reverse osmosis plant using FILMTEC membranes, Desalination 110 (1997) 167–182.
[42] J.L. Dupavillon, B.M. Gillanders, Impact of seawater desalination on the giant Australian cuttlefish *Sepia apama* in the upper Spencer Gulf, South Australia, Mar. Environ. Res. 67 (2009) 207–218.
[43] E.R. Cornelissen, A. Berteloot, D. Harmsen, E. Beerendonk, Dick van der Kooij, the influence of particles on biofouling behavior in spiral wound membrane elements, Desalin. Water Treat. 34 (2011) 112–116.
[44] H.K. Khordagui, A conceptual approach to selection of a control measure for residual chlorine discharge in Kuwait Bay, Environ. Manag. 16 (1992) 309–316.
[45] A.M. Shams El Din, R.A. Arain, A.A. Hammoud, On the chlorination of seawater, Desalination 129 (2000) 53–62.
[46] M.Y. Ali, J.P. Riley, The distribution of halomethanes in the coastal waters of Kuwait, Mar. Pollut. Bull. 17 (1986) 409–414.
[47] T. Saeed, H. Khordagui, H. Al-Hashash, Contribution of power and desalination plants to the levels of volatile liquid hydrocarbons in the nearby coastal areas of Kuwait, Environ. Int. 25 (1999) 553–562.
[48] P.K. Park, S. Lee, J.S. Cho, J.H. Kim, Full-scale simulation of seawater reverses osmosis desalination processes for boron removal: effect of membrane fouling, Water Res. 46 (2012) 3796–3804.
[49] B. Tomaszeewska, M. Bodzek, Desalination of geothermal water using a hybrid UF–RO process. Part 1: boron removal in pilot-scale tests, Desalination 319 (2013) 99–106.
[50] D. Hou, G. Dai, J. Wang, H. Fan, Z. Luan, C. Fu, Boron removal and desalination from seawater by PVDF flat-sheet membrane through direct contact membrane distillation, Desalination 326 (2013) 115–124.
[51] E. Yavuz, E. Güler, G. Sert, Ö. Arar, M. Yüksel, Ü. Yüksel, M. Kitis, N. Kabay, Removal of boron from geothermal water by RO system effect of membrane configuration and applied pressure, Desalination 310 (2013) 130–134.
[52] P. Dydo, M. Turek, A. Milewski, Removal of boric acid, monoborate and boron complexes with polyols by reverse osmosis membranes, Desalination 334 (2014) 39–45.
[53] N. Morita, J. Hiratsuka, H. Kondoh, M. Uno, T. Assno, Y. Niki, Y. Sakurai, K. Ono, T. Harada, Y. Imajo, Improvement of the tumor-suppressive effect of boron neutron capture therapy for amelanotic melanoma by intermural injection of the *Tyrosinase* gene, Cancer Res. 66 (2006) 3747–3753.
[54] A. Detta, G.S. Cruickshank, L-Amio acid transporter-1 and boronophenylanine-based boron neutron capture therapy of human brain tumors, Cancer Res. 69 (2009) 2126–2132.
[55] O.C. Türkr, J. Vymazal, C. Türe, Constructed wetlands for boron removal: a review, Ecol. Eng. 64 (2014) 350–359.
[56] S. Bakirdere, S. Orenay, M. Korkmaz, Effect of boron on human health, Open Miner. Process. J. 3 (2010) 54–59.
[57] S. Meacham, S. Karakas, A. Wallace, F. Altum, Boron in human health: evidence for dietary recommendations and public policies, Open Miner. Process. J. 3 (2010) 36–53.
[58] U.S. EPA, Health effects support document for boron, EPA Document Number EPA-822-R-08-002January, 2008.
[59] F.H. Nielsen, Boron in human and animal nutrition, Plant Soil 193 (1997) 199–208.
[60] A.R. Scialli, J.P. Bondeb, B. Irene Brüske-Hohlfeldc, D. Culvered, Y. Li, F.M. Sullivabf, An over-view of male reproductive studies of boron with an emphasis on studies of highly exposed Chinese worker, Reprod. Toxicol. (2010) 10–24.
[61] R. Danoun, The Ocean Technology Group, Desalination Plants: Potential Impacts of Brine Discharge on Marine Life, University of Sydney, 2007. (Final Project 05/06/2007. Available at: http://ses.library.usyd.edu.au/bitstream/2123/1897/1/Desalination%20Plants.pdf).
[62] V. Gaeci'a-Molina, R. Chang, M. Busch, First year performance review of Magong UR/RO seawater desalination plant, Desalin. Water Treat. 13 (2010) 203–212.
[63] S.C.J.M. van Hoof, J.G. Minnery, B. Mack, Dead-end ultrafiltration as alternative pretreatment to reverse osmosis in seawater desalination: a case study, Desalination 139 (2001) 161–168.
[64] T. Younos, Environmental issues of desalination, J. Contemp. Water Res. Educ. 132 (2005) 11–18.
[65] J.W. Oldfield, B. Todd, Environmental aspects of corrosion in MSF and RO desalination plants, Desalination 108 (1996) 27–36.
[66] R. Chesher, Biological impact of a large-scale desalination plant at Key West, Florida, Elsevier Oceanography Series, vol. 2, 1971, pp. 99–164.
[67] M.J. Kennish, Practical Handbook of Estuarine and Marine Pollution, CRC Press, 1997. 253–298.
[68] S. Bou-Hamad, M. Abdel-Jawas, S. Ebrahim, M. AL-Mansour, A. Al-Hijji, Performance evaluation of three different pretreatment systems for seawater reverse osmosis technique, Desalination 110 (1997) 85–92.
[69] U.S. EPA, Aquatic life ambient water quality criteria for carbonyl-2012, EPA-820-R-12-12-007, 2012. 1–28.
[70] M. Sadiq, Metal contamination in sediments from a desalination plant effluent outfall area, Sci. Total Environ. 287 (2002) 37–44.
[71] P. Glueckstern, M. Priel, A. Thoma, Y. Gelman, Desalination of brackish fish pond effluents — pilot testing and comparative economic evaluation of integrated UF–RO systems vs. conventional systems, Desalination 132 (2000) 55–64.
[72] A. Simon, L. Vandanjon, G. Levesque, P. Boureau, Concentration and desalination of fish gelatin by ultrafiltration and continuous infiltration processes, Desalination 144 (2002) 313–318.
[73] J. Jundee, S. Devahastin, N. Chuewchan, Development and testing of a pilot-scale electrodialyser for desalination of fish sauce, Procedia Eng. 32 (2012) 97–103.
[74] A.S.Y. Al-Zaidan, S.Y. AL-Mohanna, P. George, Status of Kuwait's fishery resources: assessment and perspective, Mar. Policy 38 (2013) 1–7.
[75] E. Mantzavrakos, M. Kornaros, G. Lyberatos, P. Kaspiris, Impact of a marine fish farm in Argolikos Gulf (Greece) on the water column and the sediment, Desalination 210 (2007) 110–124.
[76] J. Cazenzve, C. Bacchetta, A. Rossi, A. Ale, M. Campana, M.J. Parma, Deleterious effects of wastewater on the health status of fish: a field caging study, Ecol. Indic. 38 (2014) 104–112.
[77] RPS, Effects of a desalination plant discharge on the marine environment of barrow Island, RPS Environment and Planning Report No: N09504. Revision 2August 2009.
[78] A.E. Kahn, M.J. Durako, *Thalassia testudinum* seedling responses to changes in salinity and nitrogen levels, J. Exp. Mar. Biol. Ecol. 355 (2006) 1–12.
[79] Y. Fernandez-Torquemada, K.U. Scnchez-Lizaso, Effect of salinity on leaf growth and survival of the Mediterranean seagrass *Posidonia oceanica* (L.) Delile, J. Exp. Mar. Biol. Ecol. 320 (2005) 57–63.

[80] S. Wilson, C. Blake, J.A. Berges, C.A. Maggs, Environmental tolerances of free-living coralline algae (maerl): implication for European marine conservation, Biol. Conserv. 120 (2004) 283–293.

[81] N. Raventos, E. Macpherson, A. Garcia-Rubies, Effect of brine discharge from a desalination plant on macrobenthic communities in the NW Mediterranean, Mar. Environ. Res. 62 (2006) 1–14.

[82] T. Neuparth, F.O. Costa, M.H. Costa, Effects of temperature and salinity on life history of the maring amphipod *Gammarus locusta*. Implications for ecotoxicological testing, Ecotoxicology 11 (2002) 61–73.

[83] K. Hiscock, A.J. Southward, I. Tittley, S.J. Hawkins, Effect of changing temperature on benthic marine life in Britain and Irelands, Aquat. Conserv. 14 (2004) 333–362.

[84] G. Parry, The development of salinity tolerance in the salmon, *salmon salmo* (*L*), and some related species, J. Exp. Biol. 37 (1960) 425–434.

[85] M.G. Sian, R. Melissa, Salinity indicator plants, Local Government Salinity Initiative (LGSI), Department of Infrastructure Planning and Natural Resources, 2005. (Booklet No. 8).

[86] M. Latorre, Environmental impact of brine disposal on *Posidonia seagrasses*, Desalination 182 (2005) 517–524.

[87] L. Rovira, R. Trobajo, C. Ibanez, The use of diatom assemblages as ecological indicators in highly stratified estuaries and evaluation of existing diatom indices, Mar. Pollut. Bull. 64 (2012) 500–5211.

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

[89] O.K. Buros, Desalting as an environmentally friendly water treatment process, Summary report of a seminar September 1994Water Technology Report No. 13, Water Treatment Engineering and Research Group, 1994.

[90] A. Glavinic, T.M. Ramsdale, S. Dittmann, Adelaide desalination infauna monitoring, Fourth Quarter Report April 2011, School of Biological Sciences, Flinders University, 2011, pp. 18–25.

[91] R. Riera, F. Tuya, A. Sacramento, E. Ramos, O. Monterroso, M. Rodriguez, Influence of the combined disposal of sewage and brine on meiofauna, Cienc. Mar. 39 (2013) 15–27.

[92] D. Martincic, H.W. Nurnberg, M. Branica, Bioaccumulation of heavy metals by bivalves from *Limski kanal* (North Adriatic Sea). II. Copper distribution between oysters, *Ostrea edulis*, and ambient water, Mar. Chem. 18 (1986) 299–319.

[93] M.H. Lin, C.H. Lee, Y.C. Lin, K.H. Yang, Potentially toxic trace elements accumulating in marine sediment and bivalves in the outfall area of a desalination plant, Desalin. Water Treat. 25 (2011) 106–112.

[94] J. Ramos-Gomez, M.L. Martin-Diaz, T.A. Delvalls, Acute toxicity measured in the amphipod *Ampelisca brevicornis* after exposure to contaminated sediments from Spanish littoral, Ecotoxicology 18 (2009) 1068–1076.

[95] I. Riba, T.A. Delvalls, J.M. Forja, A. Gomez-Parra, Comparative toxicity of contaminated sediment from a mining spill using two amphipods species: *Corophium volutator* (Pallas, 1776) and *Ampelisca brevicornis* (A. Costa, 1985), Bull. Environ. Contam. Toxicol. 71 (5) (2003) 1061–1068.

[96] C. Silva, E. Yanez, M.L. Martin-Diaz, I. Riba, T.A. Delvalls, Integrated ecotoxicological assessment of marine sediments affected by land-based marine fish farm effluents: physicochemical, acute toxicity and benthic community analysis, Ecotoxicology 22 (2013) 996–1011.

[97] F. Navarrete-Mier, C. Sanz-Lazaro, A. Marin, Does bivalve mollusk polyculture reduce marine fin fish farming environmental impact? Aquaculture 306 (2010) 101–107.

[98] M. Bundschuh, J.P. Zubrod, R. Schulz, The functional and physiological status of *Gammarus fossarum* (Crustacea; Amphipoda) exposed to secondary treated wastwater, Environ. Pollut. 159 (2011) 244–249.

[99] E. Lundstrom, B. Bjorlenius, M. Brinkmann, H. Hollert, J.O. Persson, M. Breitholtz, Comparison of six sewage effluents treated with different treatment technologies — population level responses in the harpacticoid copepod Nitrocra spininpes, Aquat. Toxicol. 96 (2010) 298–307.

[100] Y. Fernandez-Torquemada, J.M. Gonzalez-Correa, J.U. Scnchez-Lizaso, Echinoderms as indicators of brine discharge impact, Desalin. Water Treat. 51 (2013) 567–573.

[101] B. Mabrook, Environmental impact of waste brine disposal of desalination plants, Red Sea, Egypt, Desalination 97 (1994) 453–465.

[102] D. Heimeier, S. Lavery, M.A. Sewell, Using DNA barcoding and phylogenetic to identify Antarctic invertebrate larvae: lessons from a large scale study, Mar. Genomics 3 (2010) 165–177.

[103] S.L. Coles, Coral species diversity and environmental factors in the Arabian Gulf and the Gulf of Oman: a comparison to the Indo-pacific region, National Museum of Natural History Smithsonian Institute, Washington, D.C., U.S.A. No. 507, 2003, pp. 1–21.

[104] B. Riegl, Corals in a non-reef setting in the southern Arabian Gulf (Dubai, UAE): fauna and community structure in response to recurring mass mortality, Coral Reefs 18 (1999) 63–73.

[105] S.L. Coles, B.M. Riegl, Thermal tolerances of reef corals in the Gulf: a review of the potential for increasing coral survival and adaptation to climate change through assisted translocation, Mar. Pollut. Bull. 72 (2013) 323–332.

[106] G. Rowlands, S. Purkis, B. Riegl, L. Metsamaa, A. Bruckner, P. Renaud, Satellite imaging coral reef resilience at regional scale. A case-study from Saudi Arabia, Mar. Pollut. Bull. 64 (2012) 1222–1237.

[107] S.L. Coles, Experimental comparison of salinity tolerances of reef corals from the Arabian Gulf and Hawaii: evidence for hyperhaline adaptation, Proc 7th International Coral Reef Symposium. Gaum, 1, 1992, pp. 227–234.

[108] J. Marcus, A. Thorhaug, Pacific versus Atlantic responses of the subtropical hermatypic coral *Porites* spp to temperature and salinity effects, Proc 7th International Coral Reef Symposium, Manila, 2, 1981, pp. 15–20.

[109] J.W. Porter, S.K. Lewis, K.G. Porter, The effect of multiple stressors on the Florida Keys coral reef ecosystems: a landscape hypothesis and a physiological test, Limnol. Oceanogr. 44 (1999) 941–949.

[110] C. Ferrier-Pages, J.P. Gattuso, J. Jaubert, Effect of small variations in salinity on the rates of photosynthesis and respiration of the zooxanthellate coral *Stylophora pistillata*, Mar. Ecol. Prog. Ser. 181 (1999) 309–314.

[111] S. Kopko, M. Seamans, J.E. Nemeth, I.C. Wastson, Desalting in cape coral, FL — an operating update, Desalination 102 (1995) 245–253.

[112] W.S. Fisher, L.S. Fore, A. Hutchins, R.L. Quarles, J.G. Gampbell, C. LoBue, W.S. Davis, Evaluation of stony coral indicators for coral reef management, Mar. Pollut. Bull. 56 (2008) 1737–1745.

[113] T.R. McClanhan, N.A.J. Graham, M. Aaron Macneil, N.A. Muthira, J.E. Cinner, J. Henrich Bruggemann, S.K. Wilson, Citical thresholds and tangible targets for ecosystem-based management of coral reef fisheries, Proc. Natl. Acad. Sci. 108 (2011) 17230–17233.

[114] T. Pankratz, Red tides close desal plants, Water Desalination Report, 44, 2008, p. 1.

[115] T. Pankratz, Speaking of red tides, Water Desalination Report, 45, 2009, p. 2.

[116] D.A. Caron, M.-È. Garneau, E. Seubert, M.D.A. Howard, L. Darjany, A. Schnetzer, I. Centinic, G. Filteau, P. Lauri, B. Jones, S. Trussell, Harmful algae and their potential imoacts on desalination operations off southern California, Water Res. 44 (2010) 385–416 (Harmful Algae webpage. Available at: http://www.whoi.edu/redtide/).

[117] L. Heng, Y. Yanling, G. Weijia, L. Xing, L. Guibai, Effect of pretreatment by permanganate/chlorine on algae fouling control for ultrafilation (UF) membrane system, Desalination 222 (2008) 74–80.

[118] F.L. Seubert, S. Trussell, J. Eagleton, A. Schnetzer, I. Cetinic, P. Lauri, B.H. Jones, D.A. Caron, Algal toxic and reverse osmosis desalination operations: laboratory bench testing and field monitoring of domoic acid saxitoxin, brevetoxin and okadaic acid, Water Res. 46 (2012) 6563–6573.

[119] M. Tuzen, A. Sari, D. Mendil, O.D. Uluozlu, M. Soylak, M. Dogan, Characterization of biosorption process of As(III) on green algae *Ulothrix cyindricum*, J. Hazard. Mater. 165 (2009) 566–572.

[120] S.E. JØrgensen, F.L. Xu, R. Costanza, Handbook Ecological Indicators for Assessment of Ecosystem Health, CRC Press Taylor & Francis Grouo, 2010. (Ch.2 pp. 9–76., and Ch.14 pp. 335–356).

[121] P.K. Abdul Azis, I.A. Al-Tisan, M.A. Daili, T.N. Green, A.G.I. Dalvi, M.A. Javeed, Chlorophyll and plankton of the Gulf coastal water of Saudi Arabia bordering a desalination plant, Desalination 154 (2003) 291–302.

[122] J.S. Chang, J.H. Lee, I.S. Kim, Bacterial *aox* genotype from arsenic contaminated mine to adjacent coastal sediment: evidences for potential biogeochemical arsenic oxidation, J. Hazard. Mater. 193 (2011) 233–242.

[123] S. Jeong, H. Bae, G. Naidu, D. Jeong, S. Lee, S. Vigneswaran, Bacterial community structure in a biofilter used as a pretreatment for seawater desalination, Ecol. Eng. 60 (2013) 370–381.

[124] D. Drami, Y.Z. Yacobi, N. Stambler, N. Kress, Seawater quality and microbial communities at a desalination plant marine outfall. A filed study at the Israeli Mediterranean coast, Water Res. 45 (2011) 5449–5462.

[125] J.W. Lee, I.S. Kim, Microbial community in seawater reverse osmosis and rapid diagnosis of membrane biofouling, Desalination 273 (2011) 118–126.

[126] G. Naidu, S. Jeong, S. Vignerswaran, S.A. Rice, Microbial activity in biofilter used a pretreatment for seawater desalination, Desalination 309 (2013) 254–260.

[127] Q. Tao, S. Zhou, J. Luo, J.P. Yuan, Nutriet removal and elctricity producion fom wastewater using microbial fule cell technque, Desalination 365 (2015) 92–98.

[128] H.M. Saeed, G.A. Husseini, S. Yousef, J. Saif, S. Al-Asheh, A.A. Fara, S. Azzam, R. Khawaga, A. Aidan, Microbial desalination cell technology: a review and a case study, Desalination 359 (2015) 1–13.

[129] M.T. Montgomery, T.J. Boyd, C.L. Osburn, R.E. Plummer, S.M. Masutani, R.B. Coffin, Desalination technology waste streams: effect of pH and salinity on metabolism of marine microbial assemblages, Desalination 249 (2009) 861–864.

[130] M.D. Spalding, S. Ruffo, C. Lacambra, I. Meliane, L.Z. Hale, C.C. Shepard, M.W. Beck, The role of ecosystems in coastal protection: adapting to climate change and coastal hazards, Ocean Coast. Manag. 90 (2014) 50–57.

[131] P. Vineis, Q. Chan, A. Khan, Climate change impact on water salinity and health, J. Epidemiol. Glob. Health 1 (2011) 5–10.

[132] N. Ahmad, R.E. Baddour, A review of sources, effects, disposal methods, and regulations of brine into marine environments, Ocean Coast. Manag. 87 (2014) 1–7.

[133] J. McEvoy, M. Wildr, Discourse and desalination: potential impact of proposed climate change adaptation interventions in the Arizona-Sonora border region, Glob. Environ. Chang. 22 (2012) 353–363.

[134] R.A. Nunes-Vaz, The salinity response of an inverse estuary to climate change & desalination, Estuar. Coast. Shelf Sci. 98 (2012) 49–59.

[135] R.A. Nunes-Vaz, The effect of desalination and climate change on the long-term salt balance of Northern Spencer Gulf, Appendix H8. Salt balance of Northern Spencer Gulf, 2010. 1–53.

[136] K. Grangere, S. Lefebvre, J.L. Blin, Spatial and temporal dynamics of biotic and abiotic features of temperate coastal ecosystems as revealed by a combination of ecological indicators, Estuar. Coast. Shelf Sci. 108 (2012) 109–118.

[137] J. Yu, C. Wang, J. Wan, S. Han, Q. Wang, S. Nie, A model-based method to evaluate the ability of nature reserves to project endangered tree species in the context of climate change, For. Ecol. Manag. 327 (2014) 48–54.

[138] A.C. Baker, P.W. Glynn, B. Riegl, Climate change and coral reef bleaching: an ecological assessment of long-term impact, recovery trends and future outlook, Estuar. Coast. Shelf Sci. 80 (2008) 435–471.

[139] H.E. Markus Meier, B. Muller-Karulis, H.C. Andersson, C. Dieterich, K. Eiola, G. Anders Hoglund, R. Hordoir, I. Kuznesov, T. Neumann, Z. Ranjbar, O.P. Savchuk, S. Schimanke, Impact of climate change on ecological quality indicators and biogeochemistry glues in the Baltic Sea: a multi-model ensemble study, Ambio 41 (2012) 558–573.

[140] J.C. Avise, A.G. Jones, D. Walker, J. Andrew DeWoody, Genetic mating system and reproductive natural histories of fishes: lessons for ecology and evolution, Annu. Rev. Genet. 36 (2002) 19–45.

[141] D.A. Smale, T.J. Langlois, G.A. Kendrick, J.J. Meeuwing, E.S. Harvey, From fronds to fish: the use of indicators for ecological monitoring in marine benthic ecosystems, with case studies from temperate Western Australia, Rev. Fish Biol. Fish. 21 (2011) 311–337.

[142] X. Gong, J. Zhang, J.H. Liu, A tress responsive gene of *Fortunella crassifolia* FcSISP function in salt stress resistance, Plant Physiol. Biochem. 83 (2014) 10–19.

[143] S. Tejada, S. Deudero, A. Box, A. Sureda, Physiological response of the sea urchin *Paracentrotus lividus* fed with the seagrass *Posidonia oceanica* and the alien *Caulerpa racemosa and Lophocladia lallemandii*, Mar. Environ. Res. 83 (2013) 48–53.

[144] K. Penn, J. Wang, S.C. Ferando, J.R. Thompson, Secondary metabolite gene expression and interplay of bacterial functions in a tropical freshwater cyanobacterial bloom, ISME J. 8 (2013) 1866–1878.

[145] I.D. Medeiros, M.N. Siebert, G.E. Silva, M.O. Moraes, M.R.F. Marques, A.C.D. Bainy, Differential gene expression in oyster exposed to sewage, Mar. Environ. Res. 66 (2008) 156–157.

[146] M.M.F. Mansour, Nitrogen containing compounds and adaptation of plant to salinity stress, Biol. Plant. 43 (2000) 491–500.

[147] M. Ashraf, P.J.C. Harris, Potential biochemical indicators of salinity tolerance in plants, Plant Sci. 166 (2004) 3–16.

[148] C. Rutgersson, J. Fick, N. Marathe, E. Kristansson, A. Janzon, M. Angelin, A. Johansson, Y. Shouche, C.F. Flach, G.J. Larsson, Fluoroquinolones and *qnr* genes in sediment, water, soil, and human fecal flora in an environment polluted by manufacturing discharges, Environ. Sci. Technol. 48 (2014) 7825–7832.

[149] S.J. Franks, A.A. Hoffmann, Genetics of climate change adaptive, Annu. Rev. Genet. 46 (2012) 185–208.

[150] R.D.H. Barrett, A. Paccard, T.M. Heaky, S. Bergek, P.M. Schulte, D. Schulter, S.M. Rogers, Rapid evolution of cold tolerance in stickeback, Proc. Biol. Sci. 278 (2014) 233–238.

[151] M.S. Parker, T. Mock, E. Virginia Armbrust, Genomic insights into marine microalgae, Annu. Rev. Genet. 42 (2008) 619–645.

[152] M.A. Torres, M.P. Barros, S.C.G. Campos, E. Pinto, S. Rajamani, R.T. Sayre, P. Colpicolo, Biochemical biomarkers in algae and marine pollution: a review, Ecotoxicol. Environ. Saf. 71 (2008) 1–15.

[153] E.J. Faassen, L. Harkema, L. Begerman, M. Lurling, First report of (homo) anatoxin and dog neurotoxicosis after ingestion of benthic cyanobacteria in The Netherlands, Toxicon 60 (2012) 378–384.

[154] M.H. Ha, C.J. Valeska, S. Pflugmacher, Uptake of the cyanobacterial neurotoxin, anatoxin-a, and alterations in oxidative stress in the submerged aquatic plant *Ceratophyllum demersum*, Ecotoxicol. Environ. Saf. 101 (2014) 205–212.

[155] J.P. Cuif, Y. Dauphin, A. Freiqald, P. Gautret, H. Zibrowius, Biochemical markers of zooxan-thellae symbiosis in soluble matrices of skeleton of 24 *Scleractinia* species, Comp. Biochem. Physiol. A Mol. Integr. Physiol. 123 (1999) 269–278.

[156] D.O. Obura, Reef corals bleach to resist stress, Mar. Pollut. Bull. 58 (2009) 206–212.

[157] A.F. Budd, J.M. Pandolfi, Evolutionary novelty is concentrated at the edge of coral species distribution, Science 328 (2010) 1558–1561.

[158] S. Coles, B.E. Brown, Coral bleaching — capacity for acclimatization and adaptation, Adv. Mar. Biol. 46 (2003) 183–224.

[159] I. Baums, A restoration genetics guide for coral reef conservation, Mol. Ecol. 17 (2008) 2796–2811.

[160] M.J.H. van Opper, R.D. Gates, Conservation genetics and the resilience of reef-building corals, Mol. Ecol. 15 (2006) 3863–3883.

[161] N.L. Foster, C.B. Paris, J.T. Kool, S.I. Baums, J.R. Stevens, J.A. Sanchez, C. Bastida, C. Agudelo, P. Bush, S.O. Day, R. Ferrari, P. Gonzalez, S. Gore, R. Guppy, M.A. McCartney, S.C. McCoy, S.J. Mendes, A.A. Srinivasan, S. Steiner, M.A. Vermeij, E. Weilsss, P.J. Mumby, Connectivity of Caribbean coral populations: complementary insights from empirical and modelled gene flow, Mol. Ecol. 21 (2012) 1143–1157.

[162] S.M. Coelho, N. Simon, S. Ahmed, J. Mark Cock, F. Partensky, Ecological and evolutionary genomics of marine photosynthetic organisms, Mol. Ecol. 22 (2013) 867–907.

[163] M.A. Castellini, J. Margaret Castellini, Defining the limits of diving biochemistry in marine mammals, Comp. Biochem. Physiol. B 139 (2004) 509–518.

[164] C.P. Cutler, A.S. Martinez, G. Cramb, The role of aquaporin 3 in teleost fish, Comp. Biochem. Physiol. A Mol. Integr. Physiol. 148 (2007) 82–91.

[165] D. Lirman, N. Formel, S. Schopmeyer, S.G. Ault, S.G. Smith, D. Giliam, B. Riegl, Percent recent mortality (PRM) of stony corals as an ecological indicator of coral reef condition, Ecol. Indic. 44 (165) (2014) 120–127.

[166] J.S. Ault, S.G. Smith, J.A. Browder, W. Nuttle, E.C. Franklin, J. Luo, G.T. Dinardo, J.A. Bohansack, Indicators for assessing the ecological dynamics and sustainability of southern Florida's coral reef and coastal fisheries, Ecol. Indic. 44 (2014) 164–172.

[167] E. Portille, M. Ruiz de la Rosa, G. Louzara, J.M. Ruiz, L. Marin-Guirao, J. Quesada, J.C. Gonzalez, F. Roque, N. Gonzalez, H. Mendoza, Assessment of the abiotic and biotic effects of sodium metabisulhite pulses discharge from desalination plant chemical treatment on seagrass (*Cymodocea nodosa*) habitats in the Canary Islands, Mar. Pollut. Bull. 80 (2014) 222–233.

[168] M.G. Romeril, Heavy metal accumulation in the vicinity of a desalination plant, Mar. Pollut. Bull. 8 (1977) 84–87.

[169] Z. Chen, C. Song, X. Sun, H. Guo, G. Zhu, Kinetic and isotherm studies on the electrosorption of NaCl from aqueous solution by activated carbon electrodes, Desalination 267 (2011) 239–243.

[170] S.W. Woo, B.S. Park, W.N. Lee, Y.H. Park, J.H. Min, S.W. Park, S.N. You, G.J. Jun, Y.J. Beak, Desalination intake system in test bed seawater reverse osmosis (SWRO) project, Desalin. Water Treat. 51 (2013) 1–10.

[171] M.C. Ungerer, L.C. Johnson, M.A. Herman, Ecological genomics: understanding gene and genome function in the natural environment, Heredity 100 (2008) 178–183.

[172] F.M. Butterworth, A. Gunatilaka, M.E. Gonsebatt, Biomarkers and biomarkers as indicators of environmental change 2. A handbook, Springer, 2001. 201–238 (pp. 333–360).

[173] J. Seckbach, D.J. Chapman, Red Algae in the Genomic Age, Springer, 2010. 129–344 (and pp. 443–480).

[174] N. Fusetani, W. Kem, Marine Toxins as Research Tools, Springer, 2009. 159–254.

[175] L. Li, B. Zheng, L. Liu, Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends, Procedia Environ. Sci. 2 (2010) 1510–1524.

[176] J. Rice, Environmental health indicators, Ocean Coast. Manag. 46 (2003) 235–259.

[177] K.K. Jain, The handbook of Biomarkers, Humana Press, 2010. 73–86 (and pp. 189–326).

[178] S.A. Abdul-Wahab, B.P. Jupp, Levels of heavy metals in subtidal sediments in the vicinity of thermal power/desalination plants: a case study, Desalination 244 (2009) 261–282.

[179] T. Bleninger, G.H. Jirka, Mixing zone regulation for effluent discharges into EU waters, Proc. Inst. Civ. Eng. Water Manag. 164 (2011) 387–396.

[180] Z. Li, R.V. Linares, M. Abu-Ghdaib, T. Zhan, V. Yangali-Quintanilla, G. Amy, Osmotically driven membrane process for the management of urban runoff in coastal region, Water Res. 48 (2014) 200–209.

[181] I. Moch, Evaluating seawater energy recovery devices, Proceedings of the American Membrane Technology Association Meeting, Las Vegas, New. July 2007, 2007.

[182] T. Peters, D. Pintó, E. Pintó, Improved seawater intake and pro-treatment system based on Neodren technology, Desalination 203 (2007) 134–140.

[183] Z. Amjad, Scale inhibition in desalination applications: an overview, Corrosion96, Int. Annu. Con. Expo. NACE-96-230, 1996 (Paper no. 230).

[184] S.C.J.M. van Hoof, J.G. Minnery, B. Mack, Dead-end ultrafiltration as alternative pretreatment to reverse osmosis in seawater desalination: a case study, Desalination 139 (2001) 161–168.

[185] M.R. Sohrabi, S.S. Madaeni, M. Khosravi, A.M. Ghaedi, Chemical cleaning of reverse osmosis and nanofiltration membranes fouled by licorice aqueous solution, Desalination 267 (2011) 91–100.

[186] A.B. Crockett, Water and wastewater quality monitoring, McMurdo station, Antarctica, Environ. Monit. Assess. 47 (1997) 39–57.

[187] P. Paquin, R. Santore, K.Wu.P. Anid, C. Kavvadas, D. Di Toro, Revisiting the aquatic impacts of copper discharged by water-cooled alloy condensers used power and desalination plants, Environ. Sci. Policy 3 (2000) S165–S174.

[188] A.M. Mansour, M.S. Askalany, H.A. Madkour, B.B. Assran, Assessment and comparison of heavy-metal concentrations in marine sediments in view of tourism activities in Hurghada area, northern Red Sea, Egypt, Egypt, J. Aquat. Res. 39 (2) (2013) 91–103.

[189] LIFE Red Sea Project, Best environmental practices for desalination plants in the South Rea region of Egypt, USAID, EGYPT, 2008. 51–59.

[190] T. Höpner, Information Given in a Presentation at the University of Karlsuhe in 2008, 2008.

[191] A. Valavanidis, T. Vlachogianni, Metal pollution in ecosystems. Ecotoxicology studies and risk assessment in the marine environment, Sci. Adv. Environ. Toxicol. Ecotoxicol. (2010) 1–14 (Issues 17 February, Available at: http://chem-tox-ecotox.org/wp/?p394).

[192] S. Chakraborty, T. Bhatacharya, G. Singh, J.P. Maity, Benthic macroalgae as biological indicators of heavy metal pollution in the marine environments: a biomonitoring approach for pollution assessment, Ecotoxicol. Environ. Saf. 100 (2014) 61–68.

[193] K.R. Buck, L. Uttal-Cooke, C.H. Pilskaln, D.L. Roelke, M.C. Vilac, G.A. Fryxell, L. Cifuentes, F.P. Chavez, Autecology of the diatom Pseudo-nitzschia australis, a domoic acid producer, from Monterey Bay, California, Mar. Ecol. Prog. Ser. 84 (1992) 293–302.

[194] R.A. Horner, D.L. Garrison, F.G. Plumley, Harmful algal blooms and red ride problems on the U.S. west coast, Limnol. Oceanogr. 42 (1997) 1076–1088.

[195] V.L. Trainer, N.G. Adams, B.D. Bill, C.M. Stehr, J.C. Wekell, P. Moeller, M. Busman, D. Woodruff, Domoic acid production near California upwelling zones, June 1998, Limnol. Oceanogr. 45 (2000) 1818–1833.