7

Human Impacts on Marine Biodiversity: Macrobenthos in Bahrain, Arabian Gulf

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1. Introduction

In recent decades, biological diversity has received increased interest. However, most studies are related to terrestrial systems, and knowledge of marine biodiversity lags behind that of land systems (Ellingsen, 2002). Oceans cover about 70% of the earth, and soft-sediment habitats cover most of the bottom of marine environments (Snelgrove, 1998). These habitats support a diverse array of macrobenthic communities that play important roles in ecosystem processes such as recycling nutrients, detoxifying pollutants, dispersion and burial, and secondary production (Gray, 1997; Snelgrove, 1997). Additionally, these organisms provide food for humans and are considered an important source of food for fishes and birds (Snelgrove, 1999; Thrush & Dayton, 2002). Human activities are the primary cause of recent changes to marine biological diversity in coastal and subtidal areas. It is therefore important to improve our understanding of both biodiversity in marine sediments and anthropogenic impacts affecting these habitats in order to effectively incorporate conservation measures.

The Arabian Gulf is a semi-enclosed sea situated in the subtropical zone and characterized by low precipitation and high aridity. It is a shallow sedimentary basin dominated by soft substrate benthos. The average depth of the Arabian Gulf is 35 m, and whole of its substrate lies within the photic zone. The Kingdom of Bahrain is an archipelago composed of 37 islands located in the Arabian Gulf between latitude 25° 32′ and 26° 20′ north and longitude 50° 20′ and 50° 50′ east (Fig. 1). The total land area of Bahrain is about 762 km^2. The length of the coastlines of Bahrain is approximately 126 km and the marine area is estimated to be around 8000 km^2. Despite the limited land area of Bahrain, waters around its islands support a range of coastal and marine habitats such as seagrass beds, coral reefs, mangrove swamps, offshore islands, and mud and sand flats.

High levels of salinity and surface temperature are the main natural stresses in the Arabian Gulf. Salinities around Bahrain are generally high due to the effects of high temperatures associated with high evaporation rates. Salinities on the west coast are higher than those on the east coast, with average means of 50-57 psu for the west coast and 43-45 psu for the east coast (Price et al., 1985). This variation in the salinity gradients may be attributed to a complex system of water circulation around Bahrain enforced by reduced water exchange, particularly in south of Bahrain, where salinity could reach 70 - 80 psu in areas with restricted water flow such as tidal pools and lagoons (Al-Zayani, 2003).

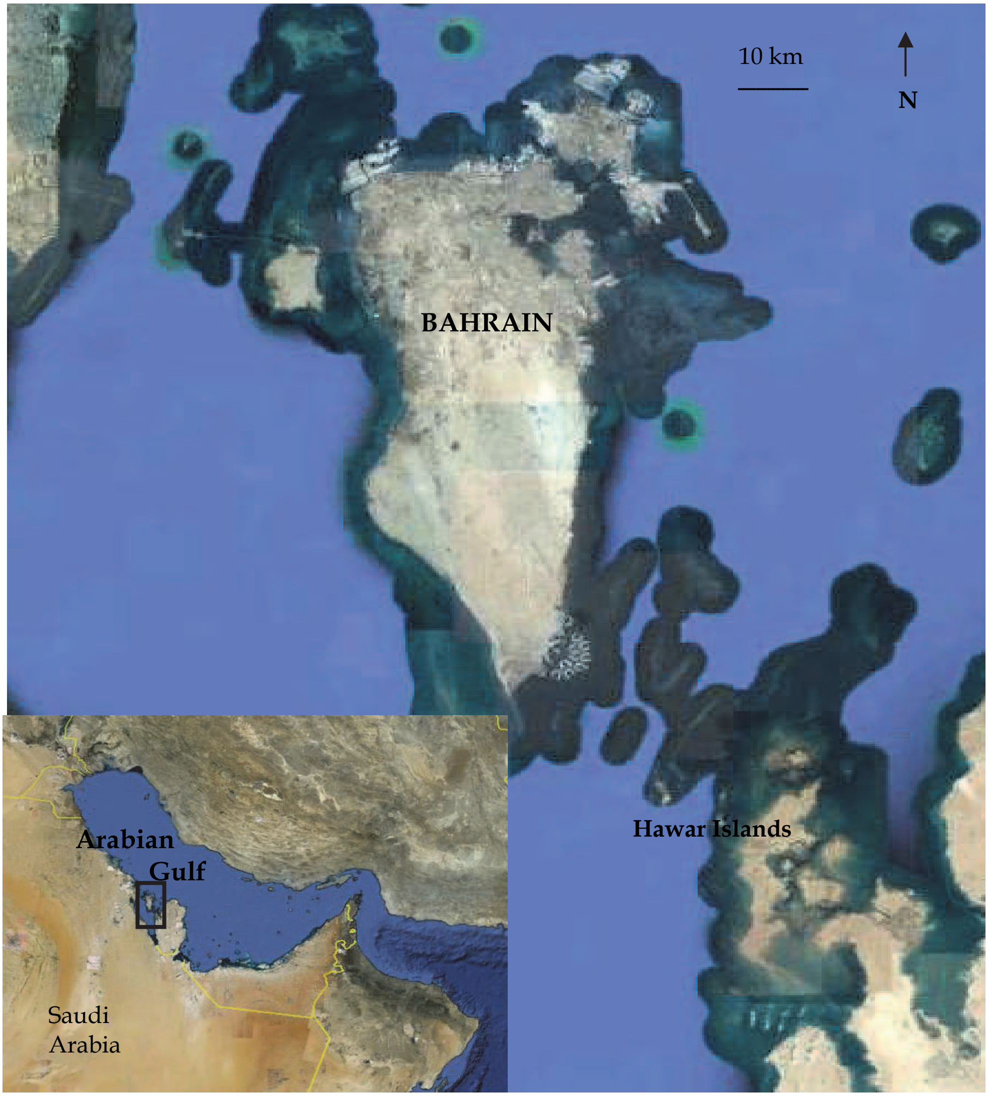

Fig. 1. Maps showing the Arabian Gulf and Bahrain (Google-Earth).

Although macrobenthos in the Arabian Gulf are characterized by high levels of biodiversity, they are distinguished by low species richness due to harsh environmental conditions such as high levels of salinity and temperature (Al-Yamani et al., 2009; Basson et al., 1977; Price, 2002; Sheppard et al., 2010). Additional anthropogenic effects could arguably be critical for biodiversity and abundance of macrobenthos inhabiting the naturally stressed marine environment of the Arabian Gulf, which is considered among the highest anthropogenically impacted regions in the world (Halpern et al., 2008). Such impacts include reclamation and dredging, industrial and sewage effluents, hypersaline water discharge from desalination plants, and oil pollution (Hamza & Munawar, 2009; Sheppard et al., 2010). This chapter explores the biodiversity of macrobenthos and anthropogenic impacts affecting these assemblages. Additionally, measures that may contribute to conservation of macrobenthos are discussed.

2. Macrobenthos biodiversity in the Arabian Gulf

Macrobenthos are a species-rich group of invertebrates that are defined as animals retained on a 300 μm sieve (Snelgrove, 1998). Macrobenthos are mainly composed of polychaetes, crustaceans, molluscs, and many other taxonomic groups. Polychaetes occur in almost all benthic marine sediments, and are typically the dominant component of macrobenthos in terms of number of species and abundance (Hutchings, 1998). Similarly, crustaceans and molluscs constitute diverse taxonomic groups that inhabit all major marine habitats (Feulner & Hornby, 2006; Snelgrove, 1998). Biodiversity and distribution of marine macrobenthos are influenced by sediment type, temperature, salinity, primary productivity, depth and physical disturbance (Basson et al., 1977; Coles & McCain, 1990).

Study	Area	Biodiversity of major groups
Basson et al. (1977)	Eastern coastline of Saudi Arabia	530 species were associated with seagrass, 638 species were recorded in subtidal sand, and 610 species were recorded in subtidal mud
MCain (1984)	Eastern coastline of Saudi Arabia	A total of 624 species of benthic organisms were identified, 452 from sand biotope and 369 from seagrass biotope samples
Coles and McCain (1990)	Eastern coastline of Saudi Arabia	834 species were found associated with seagrasses and sand/silt substrata
Zainal et al. (2007)	Baseline ecological survey for Hawar Islands, Bahrain	119 species were identified (47 Crustacea, 40 Mollusca, 30 Polychaeta)
Al-Yamani et al. (2009)	Kuwait coastal and subtidal areas	270 species were identified (103 Mollusca, 83 Polychaeta, 38 Crustacea)
Naser (2010a)	Subtidal areas influenced by organic and industrial effluents off the eastern coastline of Bahrain	97 species were identified (46 Polychaeta, 25 Mollusca, 18 Crustacea)

Table 1. Examples of studies conducted on macrobenthos in the Arabian Gulf.

Giving that more than 97% of the bottom substrate of the Arabian Gulf is dominated by sand and mud (Al-Ghadban, 2002), macrobenthos form the largest and most diverse marine ecosystem. Indeed, mudflats are among the most productive marine habitats on the southern shore of the Arabian Gulf (Basson et al., 1977; Sheppard et al., 2010). Mudflats and coastal wetlands in Bahrain support high levels of biodiversity and primary productivity, and contribute significantly into fisheries productivity (Abdulqader, 1999) and provide feeding and roosting grounds for important numbers of shorebirds (Mohamed, 1993).

It can be argued that biodiversity of macrobenthos in the Arabian Gulf is underestimated. Generally, studies of soft-sediment macrobenthic assemblages in tropical coastal and marine environment, including the Arabian Gulf, lag behind that of equivalent environments in temperate zones (Mackie et al., 2005). These studies require the identification of organisms, which is typically constrained by time, costs and the shortages of trained taxonomists. Nonetheless, studies investigating macrobenthic communities in coastal and subtidal areas of the Arabian Gulf revealed considerable levels of biodiversity (Table 1). Even though these studies were conducted using different sampling and processing methods, a general trend of reduction in diversity and abundance of macrobenthos could be detected. For instance, higher numbers of species were recorded in the earlier studies (Basson et al., 1977; Coles & McCain, 1990; MCain, 1984) in comparison with the most recent studies (Al-Yamani et al., 2009; Naser, 2010a; Zainal et al., 2007;). This reduction in both species number and abundance could be primarily attributed to the environmental degradation due to escalated anthropogenic activities in the Arabian Gulf (Sheppard et al., 2010).

3. Human impacts on macrobenthos

3.1 Dredging and reclamation

Bahraini coastal and marine environments are the prime target for most of the major housing, recreational, and economic projects, which typically associated with intensive dredging and reclamation activities (Naser et al., 2008). Presently, reclamation activities have resulted in adding 91 km^2 representing an increase of 11% of the total land area. Bahrain National Land Use Strategy 2030 recognizes reclamation as the major option for securing the future needs for land, indicating that coastal environment will continue to be the major focus for developmental projects in the coming future (Naser, 2011). Coastal reclamation is regularly carried out in Bahrain to meet the demand of rapid coastal developments (Fig. 2). Generally, sand and mud characterized by lower levels of biodiversity and abundance are extracted from designated borrow areas within the territorial waters of Bahrain, and then dumped into coastal and subtidal areas characterized by high levels of biodiversity and productivity (Naser, 2010a).

Dredging and reclamation involve the direct removal of macrobenthos and results in physically smothering the coastal and subtidal habitats and deoxygenating the underlying sediments (Allan et al., 2008; Newell et al., 1998). These physical and chemical alterations may reduce biodiversity, richness, abundance and biomass of macrobenthos (Smith & Rule, 2001).

Naser (2011) conducted a microcosm experiment to examine the effects of mud burial on selected macrobenthic species collected from a proposed reclaimed coastal area in the north-east of Bahrain. The study found significant difference in numbers of survived organisms between control and experimental treatments, with a survival percentage of 41.8% for all of the selected species. Dredging and reclamation in Bahrain are major activities causing the direct removal and burial of macrobenthic assemblages in the coastal and marine environments. Therefore, biodiversity and abundance of macrobenthos are severely affected by mortality and smothering associated with dredging and reclamation activities.

Fig. 2. Reclamation of sandy and muddy coasts of Tubli Bay.

3.2 Industrial effluents

Bahrain has witnessed a rapid industrial growth, mainly in the sectors of oil refining, aluminum and petrochemical industries. Several companies and industrial factories are producing effluents that may contain hydrocarbons, ammonia, phenols, phosphorous and heavy metals. In Bahrain, most of the industrial activities are located along the eastern coastal areas. It is estimated that around 1, 793, 294 m^3 day^{-1} of industrial effluents characterized by high inputs of heavy metals and hydrocarbons are discharged to the shallow subtidal areas off the eastern coastline of Bahrain (Naser, 2010a). The eastern coastline of Bahrain is considered a hotspot for high concentrations of hydrocarbons (De Mora et al., 2010) and heavy metals (De Mora et al, 2004). Effects of industrial effluents on macrobenthic assemblages involve changing the composition of the community structure, increasing the numbers of opportunistic species, and reducing the general biodiversity and abundance (Bigot et al., 2006; Frouin, 2000).

Naser (2010a) investigated the community structure of macrobenthos inhabiting a subtidal area subject to effluents containing hydrocarbons and heavy metals from the main oil refinery in Bahrain. The study recorded 44 species of which polychaetes, molluscs, crustaceans and remaining groups accounted for 66.0%, 22.7%, 6.8% and 4.5% respectively. Crustaceans are considered sensitive bioindicators for marine environmental pollution

(Gesteira & Dauvin, 2000, Ugolini et al, 2004). This is reflected in the limited number of species and abundance of crustaceans in the area influenced by the industrial effluents in Bahrain.

3.3 Sewage discharges

Sewage effluents are major sources of coastal pollution in Bahrain. Several sewage treatment plants varying in size and degree of treatment are discharging effluents to the coastal and subtidal areas in Bahrain. The main one is Tubli Water Pollution Control Centre (TWPCC), which discharges around 160,000 m^3 day^{-1} of treated effluents into the shallow water of Tubli Bay (Fig. 3). These effluents are characterized by high-suspended solid reaching up to 290 FTU. Seawaters adjacent the TWPCC are distinguished by high load of nutrients such as ammonia, nitrate and phosphate with concentrations reaching 1.40, 0.90, and 3.60 mg l^{-1} respectively. In particular, phosphate largely exceeded the maximum value of 2.0 mg l^{-1} recommended in the Bahraini effluent standards (Naser, 2010a).

Fig. 3. The outfall of Tubli Water Pollution Control Centre, the main sewage treatment plant in Bahrain.

Changes in macrobenthic community structure associated with moderate organic enrichment are represented by an increase in species richness, abundance and biomass. However, excessive organic enrichment reduces species richness, and increases densities and numbers of few opportunistic species and their associated biomass (Grall & Chauvaud, 2002; Savage et al., 2002). Naser (2010b) investigated the effects of sewage discharge on macrobenthic assemblages inhabiting subtidal areas surrounding the major treatment plant in Bahrain. The study showed a reduction in biodiversity, richness and evenness of macrobenthos due to the increase in organic enrichment mainly ammonia and phosphate. Indeed, some areas adjacent to the outfall that were characterized by high levels of organic content (> 60%) were devoid of macrobenthic assemblages reflecting severe sewage pollution.

3.4 Desalination plants

Bahrain, like most of the Arabian Gulf countries, depends mainly on desalination seawater as a source of potable water. In Bahrain, there are currently four major desalination plants producing fresh water and energy (Zainal et al., 2008). Sitra Power and Water Station (SPWS) is the largest plant in Bahrain (Fig. 4) with a capacity of 125 megawatts of electrical power and around 100 x 10^6 L day^{-1} of desalinated water using multi-stage flash technology (Khalaf & Redha, 2001).

Fig. 4. Sitra Power and Water Station.

SPWS produces around 66,000 m^3 day^{-1} of effluent to the marine environment of which 12,000 m^3 are brine water. This brine water causes an average increase in temperature of 7.5 ^oC above the natural water temperatures of summer and winter (Altayaran & Madany, 1992).

Reduced levels of biodiversity and abundance were recorded in stations adjacent to SPWS outlet reflecting severe impacts on macrobenthic assemblages caused by brine wastewater discharges, which are associated with high temperatures, salinities, and a range of chemical and heavy metal pollutants (Naser, 2010a). Generally, a decline in populations of all macrobenthic species is expected in the mixing zone of an effluent discharge potentially associated with toxic wastes. Survival of species in the adjacent areas of a mixing zone depends on their tolerance and adaptation. This is demonstrated by the dominance of tube anemones (*Cerianthus* sp.) in the areas adjacent to the outlet of SPWS, which suggests that these species might be resistant or adaptable to pollutants and changes in water quality.

3.5 Oil pollution

The Arabian Gulf is considered the largest reserve of oil in the world. Consequently, Bahrain is under a permanent threat from oil related pollution. The sources of oil spills are offshore oil wells, underwater pipelines, oil tanker incidents, oil terminals, loading and handling operations, weathered oil and tar balls, and illegal dumping of ballast water (Literathy et al., 2002). Generally, Bahraini ports and oil terminals are at high risk of major oil spill incidents. Similarly, minor oil spills are frequent in the territorial waters of Bahrain. For instance, six minor oil spills, including leakages in pipelines, over flooding of containers, weathered oil and tar balls, and incidents during loading of tankers in the terminals, were recorded in 2000.

Benthic assemblages are sensitive to oil spills. However, the effects of oil pollution primarily depend on the proportion of hydrocarbon-sensitive species, particularly crustaceans, in the affected community (Gesteira et al., 2003). Suchanek (1993) reviewed in details the impacts of oil on marine invertebrates. This study indicated that macrobenthic invertebrate assemblages respond to severe oil pollution with initial massive mortality and lowered community diversity followed by fluctuations in population of opportunistic species. Studies in the Arabian Gulf reported a reduction in macrobenthos diversity (Jones et al., 1998) and a decline in the abundance of major faunal groups after a major oil spill (Price, 1998).

4. Macrobenthos conservation

4.1 Marine Protected Areas

A marine protected area (MPA) is defined by the World Conservation Union (IUCN) as any area of the marine environment that has been reserved by law or other effective means. Marine protected areas may contribute significantly to both preservation and conservation of genetic characteristics, species, habitats and cultural biodiversity in marine environments (Agardy, 1994; Kelleher & Phillips, 1999; Krupp, 2002).

Coastal and marine protected areas have been established in Bahrain (Table 2). Marine protected areas in Bahrain are considered an affective mean of protecting macrobenthos diversity. For example, Hawar Islands, the largest protected area in Bahrain, support high levels of macrobenthos diversity. Zainal et al. (2007) recorded 119 species in the shallow subtidal habitats of Hawar Islands. Likewise, the sheltered mudflats in Ras-Sand are characterized by high levels of macrobenthos diversity and abundance (Naser, 2010a). It is recognized that mudflats provide several ecosystem services (Zedler & Kercher, 2005), and higher levels of benthos diversity and abundance in these habitats are important to bird populations (Zou et al., 2008). Several nationally and internationally important birds use mudflats in Ras-Sand as feeding and roosting grounds (Evans, 1994). Similarly, Al-Sayed et al. (2008) indicated that the protected mudflat of Duwhat Arad is a productive ecosystem, and macrobenthic assemblages inhabiting this area provide food resources for bird populations.

However, the lack of management plans for the Bahraini protected areas may restrict the achievement of the conservational objectives of these areas. The Convention on Biological

Diversity requires that each of the contracting parties prepares a National Biodiversity Strategy and Action Plan. Toward this, Bahrain is preparing the Bahraini National Biodiversity Strategy and Action Plan (BNBSAP) with support from United Nations Development Programme (UNEDP). The BNBSAP will address the current lack of management plans for the protected areas and suggest measures to protect biodiversity in Bahrain (Naser et al., 2008).

Protected area	Ecological importance
Hawar Islands	Extensive growth of seagrass beds and algal mats that support vulnerable species such as dugongs, turtles and dolphins. These islands host one of the largest breeding colonies of the endemic Socotra Cormorants with a winter population of 200,000 individuals.
Ras-Sanad area in Tubli Bay	A sheltered lagoon hosting the last remaining mangrove ecosystems in Bahrain. Foraging and roosting ground for migratory and breeding birds.
Mashtan Island	Offshore island characterized by extensive growth of seagrass and algal mats for the feeding of dugongs and turtles.
Duwhat Arad	Tidal mudflat used as a feeding and roosting ground for important shorebird populations.
Fasht bulthama	Small reef characterized by relatively high levels of diversity and cover (> 50%)

Table 2. Marine protected areas in Bahrain and their ecological importance.

4.2 Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a systematic process of identifying, predicting, evaluating and mitigating the environmental consequences of a proposed project on the biological and physical environments (Glasson et al., 1999). EIA aims at integrating environmental considerations in the decision-making system, minimizing or avoiding adverse impacts, protecting natural systems and their ecological processes, and implementing principles of sustainable development (IAIA, 1999).

EIA is considered a standard tool for decision-making in most countries throughout the world (Erickson, 1994). It ensures that authorities are provided with necessary knowledge relating to any likely significant effects of a proposed project on the environment prior to the decision-making process. The integration of environmental considerations may result in a rational and structured decision-making process that maintains a balance of interest between the development action and the environment (Glasson et al., 1999). EIA minimizes or avoids the adverse effects of a proposed development on the environment, by addressing effective designs, alternatives, mitigations, cumulative impacts, and monitoring (Cooper & Sheate, 2002). EIA contributes to protect biodiversity, ecosystems and natural resources (Treweek, 1999). Since the early stages of incorporating EIA in The National Environmental Policy Act in 1969 in the USA, ecological considerations have been an integrated part of the EIA process (Gontier et al., 2006). EIA addresses environmental consequences along with economic and social considerations in the planning system, which is widely recognized as a principle of sustainable development (Lee & George, 2000). EIA was formally adopted in

Bahraini environmental system in 1998 to protect the environment and to reduce environmental degradation associated with major developmental projects.

EIA is widely recognized as an important tool for integrating biodiversity considerations into planning and decision-making processes (Slootweg et al., 2003). The Convention on Biological Diversity (CBD) requires the use of EIA to ensure that impacts on biodiversity are taken into account and adverse effects are avoided or minimized. However, there is a recognized need for further enforcement and integration of biodiversity issues into EIA processes (Wegner et al., 2005).

Most of developmental projects in Bahrain are related to the coastal and marine environments. Therefore, macrobenthic assemblages are subject to direct or indirect impacts by associated dredging and reclamation activities. Naser et al. (2008) evaluated the quality of ecological input in 15 Bahraini EIA reports concerning coastal and marine developments produced between 1996 and 2004. The study showed major shortcomings in these reports, including limited new ecological surveys, inadequate evaluation of impacts, neglecting cumulative and long-term impacts, and failing to address adequately mitigation and monitoring measures. Nonetheless, several major developmental projects have been undertaken at a rapid rate in Bahrain in the recent years, and quality of the EIA reports are notably improving.

Macrobenthic assemblages are considered a useful tool for ecological assessment within the framework of EIA. These organisms can facilitate the characterization of existing impacts as well as the prediction of likely impacts due to proposed projects (Naser 2010a). EIA can be used to ensure that necessary measures needed to protect biodiversity and its sustainable use are addressed in the process of development planning (Khera & Kumar, 2010). Therefore, effective EIA can contribute to the protection of macrobenthos biodiversity and the sustainable use of coastal and marine environments in Bahrain.

4.3 Legal instruments and higher environmental policies

The Environmental Protection Committee (EPC), established by Decree No. 7 of 1980 under the Ministry of Health, was the first governmental authority concerned with the protection of the Bahraini environment. The EPC was upgraded by the Legislative Decree No. 21 of 1996, establishing ‘Environmental Affairs’ under the Ministry of Housing, Municipalities, and Environment, which was reorganized under the Ministry of State for the Municipalities Affairs and Environmental Affairs in 2000. For the purpose of integrating efforts and resources to achieve effective protection of the environment, the three main governmental bodies concerned with the environment, namely Environmental Affairs, National Commission for Wildlife Protection, and Directorate of Fisheries were joined under the umbrella of the ‘Public Commission for the Protection of Marine Resources, Environment and Wildlife’ (PCPMREW) in 2002. The PCPMREW was established by the Legislative Decree No. 50 of 2002 and reorganized further by Decrees No. 10 and No. 43 of 2005. The PCPMREW is considered as a positive initiative towards the institutionalization of the authorities concerned with the environment in Bahrain.

Recognizing the escalation of environmental degradation, Bahrain has undertaken several initiatives to prevent the ongoing deterioration of the environmental quality. Towards this, Bahrain launched the National Environmental Strategy (NES), which was approved by the Council of Ministers in 2006. NES indentifies mechanisms by which principles of sustainable development can be implemented, including enforcing the role of EIA during planning, implementation and after commissioning phases of major projects, adopting principles of integrated environmental management for coastal and marine environments, applying valuation systems to estimate the costs of environmental degradation and rehabilitation, strengthening institutional and legal frameworks, and increasing public awareness and participation (GDPEW, 2006).

Environmental legislations related to biodiversity in Bahrain are based on a range of national laws as well as regional and international agreements. Nationally, there are several laws with respect to environment, regulation of fishing and exploitation of marine resources, protection of wildlife, environmental quality standards for wastewater effluents, declarations of protected areas, and banning of catching endangered species. Similarly, Bahrain ratified several regional and international agreements and conventions that could contribute to the protection of biodiversity, including Convention on Biological Diversity, Ramsar convention, UN Framework Convention on Climate Change, and Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution (PCPMREW, 2010). Such legislations and agreements, which protect the biodiversity and promote the sustainable use of environmental resources, can directly or indirectly contribute to the protection of macrobenthos habitats and associated ecosystems.

4.4 Conservation of associated ecosystems

Conducting ecological studies that investigate other ecosystems such as seagrass, mangroves and coral reefs are essential parts of any effort to conserve macrobenthos in Bahrain. As a result of the shallowness of the Arabian Gulf, a wide range of its bottom is covered with seagrass beds (Phillips, 2003). Seagrass beds are highly productive ecosystems that provide important ecological and economical functions (Duffy, 2006). They contribute to the productivity of local fisheries (Price et al., 1993), and provide food sources and nursery grounds for turtles, dugongs, shrimps and a variety of economically important marine organisms (Preen, 2004). It is widely recognized that seagrass habitats support greater macrofauna species diversity, abundance and biomass than adjacent unvegetated habitats (Al-Khayat, 2007; Ansari et al., 1991; Coles & McCain, 1990). Indeed, about 9% of the Arabian Gulf's faunal taxa have been estimated to occur in its seagrass meadows, about half of which are molluscs (Sheppard et al., 2010).

Coral reefs are characterized by both biological diversity and high levels of productivity. They provide a variety of ecological services such as renewable sources of seafood, maintenance of genetic, biological and habitat diversity, and recreational values (Moberg & Folke, 1999). Coral reefs in the Arabian Gulf have traditionally been important habitats for fisheries (Sheppard et al., 1992). Due to the higher levels of productivity in coral reef ecosystems, macrobenthos associated with these habitats are distinguished by higher levels of biodiversity (Moberg & Ronnback, 2003).

Mangrove swamps are ecologically important coastal ecosystems that provide food, shelter and nursery areas for a variety of terrestrial and marine fauna (Saenger, 2002). Mangrove ecosystems maintain species diversity, including macrobenthos (Ellison, 2008; Lee, 2008). Further, many macrobenthos species utilize mangrove habitats as nursery or feeding grounds during some life stage (Moberg & Ronnback, 2003).

4.5 Environmental monitoring and scientific research

Monitoring is an integral part of any effort to reduce the loss of biodiversity (Dallmeier, 1996). Monitoring could provide decision makers with information on the state of biodiversity, and consequently, assist in identifying management goals and assessing priorities for conservation (Niemela, 2000). Monitoring can be described as systemic observations and measurements of ecosystems to detect changes over time (Treweek, 1999).

Soft-sediment macrobenthic assemblages are useful and sensitive indicators of the quality of the environment. They are widely used in biodiversity assessment and monitoring programmes in coastal and marine environments (Gray et al., 1992). This is mainly attributed to their characteristics that make them a useful target for assessment and monitoring purposes. These organisms consist of different species that show different levels of tolerance to stresses and pollution. They can exhibit detectable changes in their community structure in response to stresses and pollution such as changes in biodiversity, abundance, biomass, and numerical dominance of opportunistic species (Gray, 1989). Additionally, macrobenthic assemblages may be utilized to characterize the 'health' of coastal and marine ecosystems represented by their structures (the species and populations involved) and functions (the flow of energy, growth and productivity) (Boesch & Paul, 2001). Indeed, responses of macrobenthic assemblages to environmental variations have been adopted as a tool for evaluating the success of conservation efforts (Winberg et al., 2007), and managing marine environments (Desroy & Retiere, 2004).

The role of taxonomic research in biological research in general and biodiversity conservation in particular is widely recognized (Ziegler & Krupp, 1996). Effective conservation can only be achieved if the state of the environment is fully documented and understood. Taxonomy has a crucial role in preserving the biological diversity (Mace, 2004). Indeed, identifying and describing species are critically required to assess the biodiversity and to understand the structure and function of macrobenthic assemblages in Bahrain. However, taxonomic research in the Arabian Gulf is constrained by the limitation of taxonomic keys and guidelines. For instance, there are no comprehensive up-to-date taxonomic guides to the polychaetes in the Indian Ocean region (Mackie et al., 2005), including the Arabian Gulf. Identification to the species-level is critically required to assess the biodiversity and to understand the structure and function of macrobenthos in the Arabian Gulf. Consequently, producing identification guides for macrobenthic organisms in the Arabian Gulf may contribute to solve the problem of taxonomy. However, it is widely recognized that the process of identifying and describing species and subsequently producing such taxonomic guides is constrained by time, costs and shortages of trained taxonomists (Kendall et al., 2000). Therefore, logistical and financial cooperation between local and regional institutions and organizations concerned with the marine environment in the Arabian Gulf is required.

5. Conclusions

Globally, coastal and marine environments support a diverse array of macrobenthic communities that play important roles in ecosystem processes and provide several ecological and economic services. The Arabian Gulf is a shallow sedimentary basin dominated by sand and mud substrates. Macrobenthic assemblages form the largest and most diverse marine ecosystem in the Arabian Gulf. However, these assemblages inhabit one of the harshest marine environments due to marked fluctuations in sea temperatures and high salinities. Additional anthropogenic effects could arguably be critical for biodiversity and abundance of macrobenthos inhabiting the naturally stressed marine environment. Studies that investigated macrobenthos in the Arabian Gulf indicated that anthropogenic pollution and habitat degradation and destruction reduced biodiversity, richness, abundance and altered biomass of macrobenthic assemblages.

Preserving and conserving genetic, species, and habitat biodiversity in the marine environments are immediate priorities. Several measures could be applied to protect the biodiversity of macrobenthos in Bahrain. Marine protected areas are widely recognized as an effective mean of protecting biodiversity. Several coastal and marine protected areas have been established in Bahrain. However, the lack of management plans for the Bahraini protected areas may restrict the achievement of the conservational objectives of these areas.

Further integration of biodiversity into environmental impact assessment system in Bahrain is needed. This is of crucial importance as coastal and marine environments are the prime target for most developmental projects in Bahrain. Considering effects of dredging and reclamation on macrobenthos in EIA studies and suggesting measures to avoid or reduce adverse impacts could contribute to conserve the sensitive and productive mudflat habitats in Bahrain.

Legal instruments and higher level environmental policies in Bahrain are contributing to preventing environmental degradation and conserving biodiversity. Incorporating biodiversity assessment into the legal system and implementing the Bahraini National Biodiversity Strategy and Action Plan may contribute significantly into the enforcement of biodiversity conservation.

Seagrass, mangrove, and coral reef ecosystems support higher levels of marine biodiversity, including macrobenthic assemblages. Therefore, conserving and maintaining these ecosystems in a holistic approach would contribute to preserve the whole marine environment of the Arabian Gulf.

Monitoring and scientific research are integral part of any effort to reduce the loss of biodiversity. Macrobenthic assemblages are widely used in biodiversity assessment and monitoring programmes in coastal and marine environments. Developing necessary plans and mechanisms for population and habitat conservation require adequate knowledge and description of species. This could be achieved by promoting taxonomic research in the Arabian Gulf.

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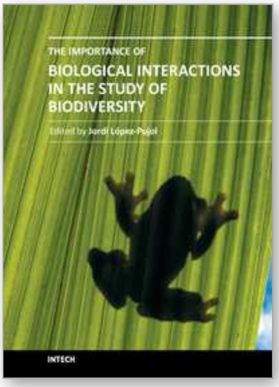

The Importance of Biological Interactions in the Study of Biodiversity

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The term biodiversity defines not only all the variety of life in the Earth but also their complex interactions. Under the current scenario of biodiversity loss, and in order to preserve it, it is essential to achieve a deep understanding on all the aspects related to the biological interactions, including their functioning and significance. This volume contains several contributions (nineteen in total) that illustrate the state of the art of the academic research in the field of biological interactions in its widest sense; that is, not only the interactions between living organisms are considered, but also those between living organisms and abiotic elements of the environment as well as those between living organisms and the humans.