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The cumulative impacts of reclamation and dredging on the marine ecology and land-use in the Kingdom of Bahrain

Khadija Zainal [a,*], Ismail Al-Madany [b], Hashim Al-Sayed [a], Abdelqader Khamis [b], Suhad Al Shuhaby [b], Ali Al Hisaby [b], Wisam Elhoussiny [b], Ebtisam Khalaf [b]

[a] University of Bahrain, College of Science, Department of Biology, P.O. Box 32038, Sakhir, Bahrain
[b] The Public Commission for the Protection of the Marine Resources, Environment and Wildlife, Bahrain

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ABSTRACT

This article assesses the ecological and economic impacts of land reclamation and dredging through consulting recent environmental impact assessment reports. Geographic features of Bahrain during 1963–2008 are produced using Geographical Information System. Extensive but inexpensive shallow coastal areas and tidal flats have been reclaimed particularly from 1997 to 2007 at a high rate of 21 km^2/year. Formal records show the increase in the original land mass by the year 2008 to be 91 km^2. An estimated total cumulative loss of major habitats resulting from 10 reclamation projects was around 153.58 km^2. Also much larger scale impacts should be considered resulting from the borrow areas used for the extraction of sand or infill materials. A number of key habitats and species are affected in the vicinity of these projects. The study attempts to assign a monetary value to the marine ecosystem functions. There is a need for efficient coastal zone management to regulate a sustainable use of the marine resources.

1. Introduction

The Kingdom of Bahrain is an archipelago of around 40 islands, the largest is the main island of Bahrain, all of which are low-lying islands between latitudes 27°10′ and 25°22′ North and longitudes 51°07′ and 50°16′ East. The water around Bahrain is shallow ranging between <0.5 and 30 m. The islands are located in the subtropical region east of Saudi Arabia and Qatar. The salinity is high reaching up to 50‰. The total area of Bahrain islands is currently 755.8 km^2 and the territorial waters area is about 7151 km^2 according to the Geographical Information System (GIS) information (GEOMATEC, Bahrain, 2009). Another smaller archipelago, Hawar is about 20 km off the south east of Bahrain. It consists of six main islands and more than 30 smaller ones, all together cover around 51.5 km^2. The total population of Bahrain according to statistics of 2008 is around 1,400,000. Relative to the size of the land, the country's population density is considered very high.

Bahrain is located in the Arabian Gulf which is a semi-enclosed sea with a limited exchange of water through the open Indian Ocean. The Gulf is situated in a semi-arid area within the Middle East bordering eight countries forming the GCC (Gulf Cooperation Council). The Arabian Gulf has a number of unique natural productive coastal ecosystems. However, discovery of oil and the subsequent socio-economic developments have subjected these ecosystems to various types of stressors (Ahmed et al., 1998; Linden et al., 1990; Madany et al., 1987; Zainal et al., 2008). The coastal environment has been subjected to a variety of factors that resulted in a sharp decline of the mangrove and coral ecosystems, as well as seagrass habitats which accommodate a wide variety of marine biota (Linden et al., 1990; Sheppard et al., 1992).

During the last two decades, the coastal and marine areas in most of the GCC countries has also witnessed massive dredging and land reclamation activities (Sheppard and Price, 1991; IUCN, 1987), particularly, along the northern and eastern coastal areas of Bahrain. Due to the shallowness of the sea large areas of the intertidal zone is exposed to the sun during low tide forming tidal flats. Such topographical feature is prevalent in northern and eastern parts of Bahrain, especially in Muharraq and Sitra. Flat and shallow features of some shoreline therefore, make infilling relatively easy and inexpensive (Al-Madany and Al-Sayed, 2001). In recent years, many issues have emerged creating conflicts and clashes between different interests and a need of an appropriate policy for a sustainable and integrated coastal zone management has been recognised. Although fragmented, there are some environmental policies and legislations to avoid damaging sensitive coastal areas during developmental projects (Ministry of works, Bahrain, web page).

Geographically, Bahrain suffers from land limitation relative to the increasing population density and economic development. In order to accommodate the vast and diverse developmental programmes, unplanned land reclamation through dredging the seabed has been one of the 'problem solving' processes. Few quantitative studies on the effect of dredging and coastal infilling

* Corresponding author. Tel.: +973 3412332; fax: +973 449158.
E-mail address: kzainal@uob.bh (K. Zainal).

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have been undertaken in Bahrain, although, qualitatively, a number of environmental issues have been investigated. For example Madany et al. (1987), Al-Madany et al. (1991), Al-Madany and Al-Sayed (2001), IUCN (1987), IUCN/UNEP (1985), Sheppard and Price (1991) and Vousden and Price (1985) predict loss of habitats and smothering of communities and species due to land reclamation. Zainal (1993) uses remote sensing to assess changes in the size and nature of the habitats over time and attributes such changes to the sedimentation associated with dredging activity. Al-Ghadban and Price (2002) give a comprehensive review on environmental problems associated with land reclamation and dredging in the Arabian Gulf. In some Gulf States, as much as 40% of the coastline has been developed eliminating critical habitats for wildlife and biodiversity (Ahmed et al., 1998; Al-Duaij and Maber, 2008; Linden et al., 1990).

Limited amount of information is available on the impact of reclamation and dredging on the Gulf marine ecosystem for example, in Saudi Arabia, 46.5 km^2 of coastal habitats have been dredged during the land-filling operation for the Jubail city and more than 200 Mm^3 of sediment was removed (IUCN, 1987). The present investigation assesses environmental, economic, land-use issues relating to the cumulative impacts on the marine environment with reference to the geo-morphological feature of the islands.

2. Materials and methods

Environmental impact assessment (EIA) reports conducted during 2002–2008 have been studied and their reported total reclaimed areas used to estimate a cumulative size of the reclamation around the coastal areas of Bahrain. Data was also obtained through creating Geographic Information System (GIS) maps and from the literature. Ecologically important areas were further depicted from the literature.

The geographic features of Bahrain during 1963, 1977, 1982, 1989, 1997 and 2004 were produced using all purposes topographic maps with a scale of 1:50,000. The maps of 1963 and 1977 were historically produced by the British Military Surveying Department. Additional maps were produced and printed by the National Surveying Authority in the Kingdom of Bahrain. Thematic map for marine habitats developed by the Environmental Protection Committee in 1986 as a part of Bahrain Marine Habitat Survey developed using field surveys. Another thematic map developed by the Ministry of Housing describing the land-use in Bahrain was adopted. This land-use map illustrates the locations (coordinates) of borrow areas using Global Positioning System (GPS). The GIS data on the shore line for Bahrain during the years 2006 and 2007 provided by Geographical Information System for Marine Technology (GEOMATEC). Digital data were produced by scanning processes. The digital copy of the maps was then geo-referenced to a standard projection and datum to produce a rectified digital copy maps. These were further digitized to convert them to vector forms and were stored in a geo-database. GPS data of the borrow areas were re-projected and converted into GIS data format. MARGIS data (Sims and Zainal, 2000) was re-calibrated prior to storing into the geo-database.

Geo-referencing is a process of resetting the pixel coordinates to meet the real coordinates on the earth scale. This process includes scaling, rotating, translating and skewing the image to match a particular size and position using sophisticated calculations based on ground control points. The shoreline of 2006 and 2007 were also imported from MARGIS dataset. MARGIS dataset however, uses different projections. These data were re-projected to the standard projection defined by the Universal Transverse Mercator, UTM Zone 39 North Hemisphere – World Geodetic System WGS 1984 projected coordinate system. A set of six points were extracted from the modified MARGIS dataset and compared to the dataset developed by the present study. The location error was found to be 0.45 m. GPS data describing the borrow areas were presented in the form of tables attached to routine reporting system developed by the General Directorate for Protection of the Marine Resources. These data were not projected to the same datum/projection system. In addition, some data were described geographically (using longitude and latitude) and some others were described using the UTM/WGS. All GPS data were re-projected to the standard projection. Finally, data was converted to ESRI shape-file GIS format. Coastal changes were identified using 'Union Overlay' which calculates the geometric intersection of any number of feature classes and feature layers within the system. Using this system of intersections, lost marine habitats and current land use on the reclaimed areas were defined. The present study focuses on three case studied locations namely, Tubli bay, Muharraq and the Northern coast of Bahrain. A number of species including keystone species were identified.

The average global annual ecosystem services based on Costanza et al. (1989, 1997) has been utilized in the estimation for the opportunity cost associated with the damage to the marine and coastal resources. The estimated figures were adjusted to Purchasing Power Parity (PPP), and other factors such as time value of money and inflation. Some assumptions and adjustments had to be made prior to the estimation of the value of the lost habitats.

The calculation was based on the requirement of the adjusted benefit value approach which has been selected to estimate the resource damage associated with land reclamation in Bahrain. The figures given in Costanza et al. (1997) were for the year 1994 prices. To extract the present value for the dollar today, the time value and the inflation over the past 14 years were accounted for. This value should be added to the Purchasing Power Parity (PPP) between Bahrain and the US.

It has been assumed that the commodities and services index rise annually by average of 3% and the inflation rate by 2%. Therefore, a 5% adjustment rate could be applied in order to obtain the present value for one dollar of 1994:

$$\$ = 1(1 + 0.05)^{14} = 1.98$$

Therefore, the ecosystem service value was multiplied by 1.98 to obtain today's values as per market price in the US. The theory of (PPP) and an equilibrium equation between the exchange rate for the US \$ and Bahrain Dinnars (B.D) were applied. The basis of PPP is the "law of one price" in the absence of transportation and other transaction costs, competitive markets will equalize the price of an identical good in two countries when the prices are expressed in the same currency hence:

$$\mathrm{PPP} = (\mathrm{PPP\ GNP}_y/\mathrm{PPP}_x)^E$$

where PPP GNP is the Purchasing Power Parity to Gross National Product for country y, and y in this case is Bahrain and x is the US; E denotes to the elasticity factor. According to World Bank statistics in 2004, the PPP GNP for Bahrain was about $ 19,670 and for US was 29,240. Therefore, by applying elasticity factor equal to 1, we can obtain the PPP for Bahrain which was used in the calculation.

3. Results

The original land mass of the Kingdom of Bahrain was increased from 667.88 km^2 in 1963 to 759 km^2 in 2007/08. The land mass was 711 km^2 in 1998 which was a 7% increase but it increased by 13.6% in the year 2009, to around 759 km^2. The calculated reclaimed coastal areas during the last few decades reached up to 91 km^2 (Table 1). The period from 1997 to 2007 has particularly,

Table 1
The increase in the land mass and the annual rate of increase during (1963–2008).

Period	Added area (km^2)	Increase in the land mass (km^2)	Annual rate of increase (km^2/year)
1963–1977	13.14	667.88	0.94
1977–1982	1.46	681.02	0.29
1982–1989	20.10	682.48	2.87
1989–1997	8.60	702.58	1.07
1997–2004	15.68	711.18	2.24
2004–2006	10.12	726.86	5.06
2006–2007/08	21.99	736.98	21.99
Total	91.09	758.97	

witnessed a higher rate (21 km^2/year). This increase was attributed to the increasing demand for land. The main land-use of the reclaimed land has been for roads (23.2%), agriculture (21.4%), industrial areas (14%), parks and green areas (17%). Fig. 1a and 1b show the change in the land mass over the last decade (1998–2008) and Table 1 shows the accumulation of land areas gained by reclamation since 1963 until 2007/08.

The geographical distribution of the marine habitats which were affected by the land reclamation from 1989 to 2007 were traced based on mapping of the habitats provided by Vousden (1986) (Tables 2 and 3). The most significantly affected habitat was rock with soft veneer (estimated at 11% lost habitat out of the original size). Marine habitats affected by dredging were mostly mixed sands/seagrass/algae (34%), seagrass 23.5%, deeper water gravels (22%) and medium to fine sands (12%). Tubli bay in particular, has been badly affected during 1963–1977 and again during 1982–1989. The bay major habitats reported as rocks with soft veneer (55%) and mixed sand/seagrass/algae (44%). The reclaimed land was used for landscape (63%), public services (12.5%) and residential (6.7%). Today, Muharraq is larger than its original size by about 400%. An estimate of the most impacted habitats on this island were also rock with veneer (57%) and rock/sand with coral/algae/seagrass (24%). The land use pattern is dominated by residential/park/garden/water front (23%) and industrial areas (18%). Northern coast reclamation activities took place slowly during 1982–1989 but over 59% took place during 2006–2007. Similarly, in this part of Bahrain, the major habitat lost was rocks with soft veneer (53%) and mixed sands/seagrass/algae (29%) and again land-use was mainly for residential/agriculture/park/gardens and water front (53% of the total area).

An estimated total cumulative loss of major habitats (seagrass, algal beds, rocks and corals) resulting from 10 selected reclamation and dredging projects was around 153.58 km^2. Seagrass and rocky substrates including corals and or 'Fashts' (dead corals) and the organisms associated with these habitats such as rabbit fish, dugongs and the green turtles are affected as a result of eliminating their habitats and feeding or breeding grounds.

4. Valuation estimates

For the following calculation, it has been assumed that the commodities and service index rise annually by an average of 3% and inflation rate by 2%. Therefore, a 5% adjustment rate was applied in order to obtain the present value for one US dollar of 1994 because the figures given in Costanza et al. (1997) was those for 1994 prices.

$$\text{The current value according to US market prices per hectare}: = 4052 \times 1.98 = \text{US\$}8023.$$

According to the World Bank Statistics in 2004, the PPP-GNP for Bahrain was \$19,670 and for the US was \$29, 240. Hence, by applying an elasticity factor equal to one, the PPP for Bahrain would be equal to:

$$19,670/29,240^1 = 0.67.$$

$$\text{The current value according to Bahrain market prices per hectare} := 8023 \times 0.67 = \text{US\$}5375.4.$$

Considering the reclaimed coastal areas during the last three decades as 91 km^2 by the end of 2007/08 and to obtain the present value of these services according to the US market prices, the ecological damage can therefore be estimated as:

$$5.38 \times 9100 \text{ ha} = \text{US\$}49 \text{ million}.$$

The total economic value of the goods and services provided by the Gulf marine environment is worth US\$ 1.88 billion per year (Sheppard, 2007). This figure is significant when compared to the estimated GDP of Bahrain in 2006 which was 4.1 BD billion (approximately 10.8 US\$ at a constant 2001 prices (Loughland and Zainal, 2009). The present estimation of costs related to the coastal development and the extent of the ecological impacts helps assigning a monetary value to the marine ecosystem functions. The estimation did not however, include all of the ecosystem goods and services. For instance, it did not include sand and gravel within the raw material value. Some important raw materials are free of charge. As an example, recently, 522 Million Bahraini Dinnars worth of sand has been given away free of charge to two of the mega projects (GDN, 2011 vol xxxiv No. 221). Similar large scale coastal developments are occurring around the coastal areas of the majority of the neighbouring countries and for a multitude of purposes (Sheppard et al., 2010).

The current estimation was based on formal records which have indicated that changes in the land mass accounted for 13% of the original land mass of 1963 (91 km^2 increase). However, if the total areas of only 10 selected reclamation projects were added for the cumulative direct impact, the total area affected was 153 km^2. This figure although does not include the dredging areas (borrow areas) which account for even larger size, it shows the scale of the damage can be exponential. Sedimentation plumes extend to wider areas affecting more habitats and have serious indirect effects.

5. Discussion

Large-scale projects are usually reclaimed with marine sand excavated by dredgers. The dominant type of dredging intended to supply marine sand for reclamation and construction purposes is called Capital Dredging during which, marine sediment is removed to create a greater depth than had previously existed. Maintenance Dredging is another type used to restore a depth by removing fine sediment settled within an area that had been subjected to previous capital dredging activities. Cutter Suction Dredger is the third type used for excavating cohesive materials. Dredged material is pumped via pipeline to a barge or to an

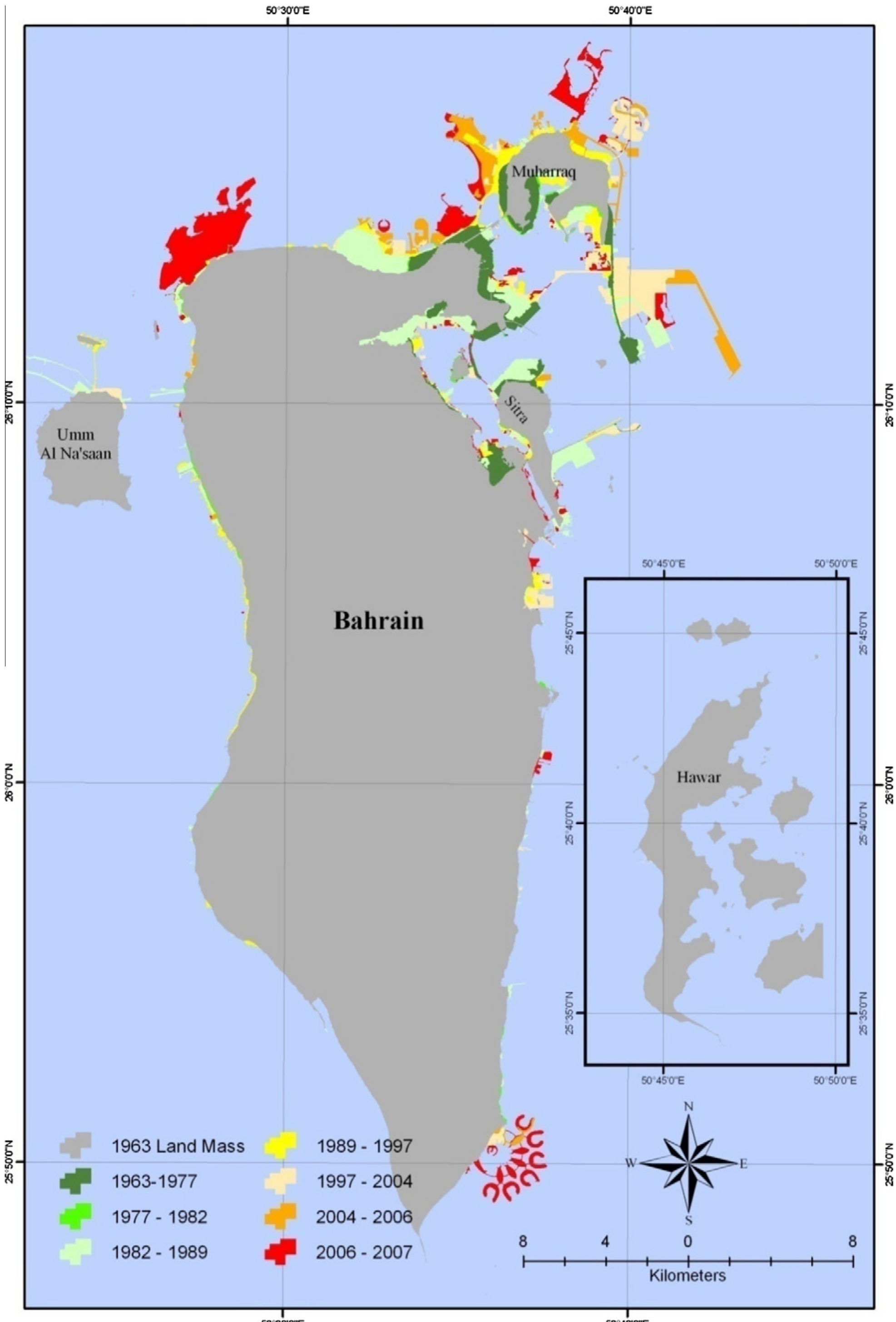

Fig. 1a. Reclaimed sea land around the coastal areas of Bahrain during 1963–2007.

onshore designated area where sediment is allowed to settle. Trailing Suction Hopper Dredger is also used to excavate unconsolidated bed materials. Marine sand, desert sand and construction wastes are used as fill materials for the coastal reclamation. Dredged materials are disposed at the reclamation sites by either contained and/or unconfined placement methods. Discharging into a contained area is one of the environment-friendly methods used to place dredged materials into the reclamation area. Occasionally, dredged materials may also be discharged into open areas. One of the unconfined placement methods used is ‘‘placing by a spray pontoon or fall pipe’’. While dredger is moored in deeper waters, dredged materials are pumped into a floating pipeline. These tools should help reducing the release of fine into the marine environment by discharging dredged materials close to the seabed and, additionally, control the spread of materials in the reclaimed area.

Price (1988) assessed vulnerability of a selected key marine species chosen on the basis of their ecological, commercial or cultural importance by assuming a total of 11 marine habitats. Those found

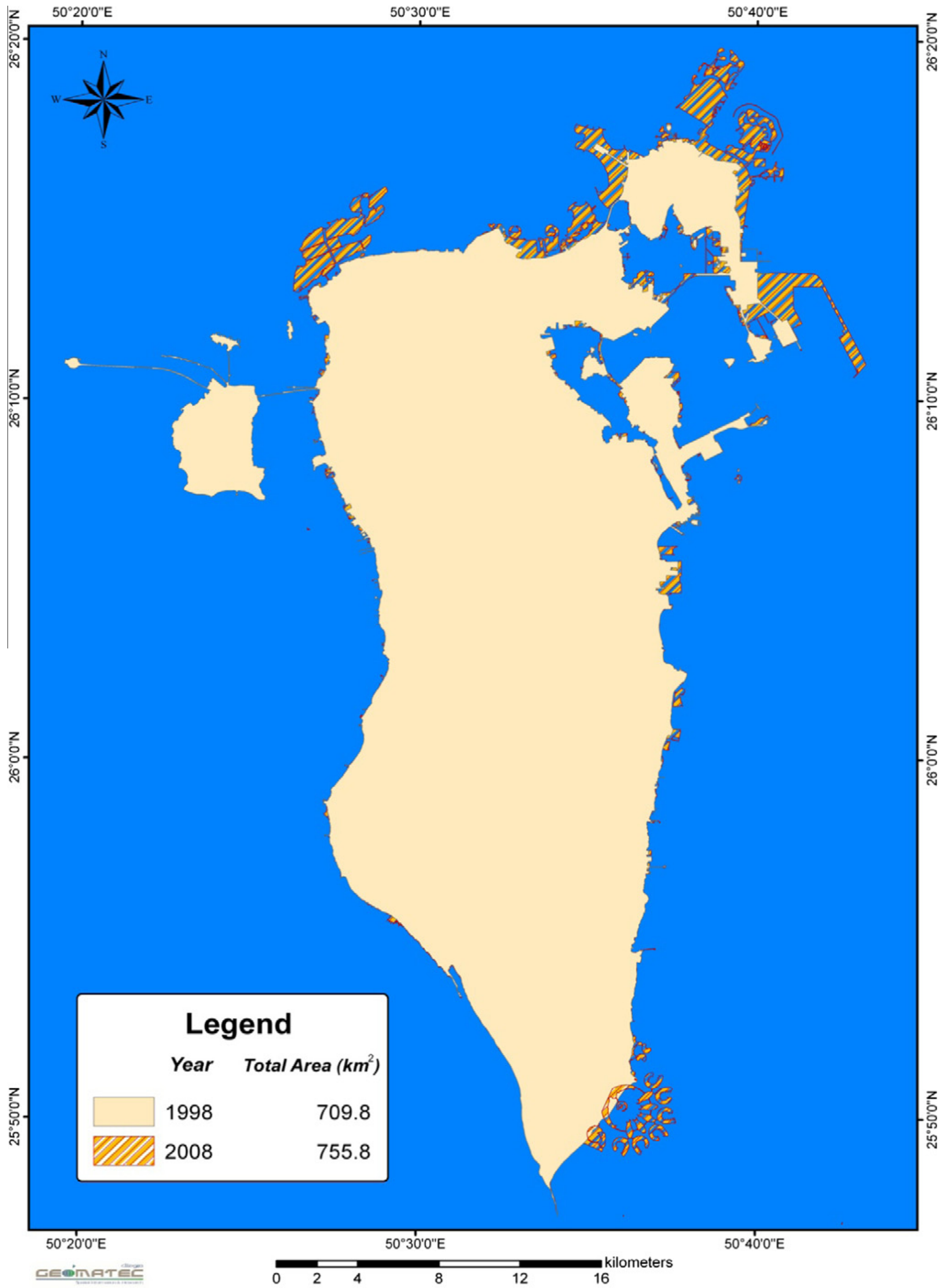

Fig. 1b. Reclaimed sea land around the coastal areas of Bahrain during 1998–2008 (GEOMATEC).

in fewer habitats were considered vulnerable to the consequences of biotope degradation.

Key species have great influence or importance on their community either by being abundant or by their biomass or commercial importance. The presence or absence of a key species could therefore, be used as an indicator of the level of the stress on the environment. For example, the commercial shrimp (Paenidae) is considered a key species in the north of Bahrain. In addition to the indirect losses to the shrimp fisheries during different phases of these projects, the burrowing gobies, goat fish, the commercial sand crab (Portunidae) and the pearl oysters (*Pinctada*), scallops, gastropods, coral and benthic in-fauna all are impacted. Community composition of infaunal species has been occasionally reported. For example, 105 infaunal species at a reclamation site included 42.5% annelids; 23.8% arthropods, 29.7% molluscs, 1% echinoderms and 3% of the others. *Glycera* spp., *Lumbrineris* spp., *Tellina* spp., Ostracodes, *Glyceridae*, *Oenonidae*, *Magelonidae*, *Eunicidae*, *Orbinii*, *Cardiolucina*, *Laevidentalium* and *Lumbrinereidae*. In addition, Seagrass, *Hermatipic or reef building* corals, Alphus shrimp and its symbiotic fish (goby), bivalves *Pinna* and *Pinctada*, the sponge *Gellius* and *Haliclona* spp., Polychaets and fishes, several species of Nudibranchs and several marine birds were affected.

The ecological effects of dredging and coastal reclamation include both direct and indirect effects (Price et al., 1986), so careful selection of reclamation areas avoiding ecologically sensitive areas is a significant mitigation measure. Even though, mitigation solutions for the direct impacts may be difficult, the impact on socioeconomic issues must be accounted for. In an attempted calculation,

Table 2
Distribution of the Marine Habitats in the Dredging Area of selected projects (areas in km^2).

Projects: habitats	1	2	3	4	5	6	7	8	9	10	Total
Algal dominated	0	0	0	0	0	0	0	0	2.27	0	2.27
Coarse sand	0.64	0	0	0	0.08	0	0	0.03	2.07	0.04	2.86
Deep water gravels	0	2.15	0	0	62.7	0	2.44	0	14.88	0	82.18
Medium to fine sands	0	27.67	0	0	0	0	0	6.74	9.42	1.21	45.05
Mixed sands/seagrass/algae	0	34.97	0.02	0	35.44	0	0.08	24.82	29.84	3.21	128.38
Rock with soft veneer	1.70	0.16	0.09	0	2.02	0.19	0	0	3.05	7.84	15.04
Rock/sand with coral/algae/seagrass	0.93	0.08	0	0.06	4.90	1.20	0.40	1.24	0.99	0	9.79
Seagrass	0	0.05	0	1.92	14.03	0.72	1.34	12.77	49.77	8.33	88.93
Shallow water muds	0	0	0	0.75	0	1.84	0	0	0.11	0	2.71
Total	3.26	65.07	0.11	2.73	119.17	3.96	4.26	45.59	112.41	20.63	377.21

The quoted habitat areas were taken from the 10 accessible environmental statements. Considering the nature of the data in each of those reports, calculation of the actual total impacted area was not possible.

Table 3
Marine habitats in the national water of Bahrain (from Vousden, 1986).

Habitat type	Area (km^2)
Seagrass	890.72
Mixed sands/seagrass/algae	504.07
Mixed sands/coral	14.19
Medium to fine sands	408.50
Coarse sand	129.71
Rock with soft veneer	263.89
Coral dominated	25.39
Algal dominated	218.20
Rock/sand with coral/algae/seagrass	390.11
Shallow water mud	123.04
Deep water mud	925.15
Deep water gravels	4343.00
Total	8235.98

the value of the loss to the fishermen was thought to be impaired by the lack of data concerning primary and secondary productions. Although compensatory habitats establishment are being frequently proposed to account for the permanent losses of the original habitats, more in depth scientific research would help in any such decision making processes.

Tubli bay has been reduced by 40% by reclamation which destroyed most of the mangroves. During bridge construction over the bay, permanent damage on the sea bed occurred. It has been thought that changes in flushing and tidal hydraulics and increased flushing may improve the water quality. In fact, this may stop macroalgae establish themselves on the rocks. Increased turbidity also reduces the growth of the phytoplankton, benthic vegetation and filter feeders. Fishing finfish is now not permitted in Tubli bay although the bay is important for the shrimp fishery (Al-Madany and Khalaf, 2000). In the past, a variety of marine organisms were recorded in this bay such as seagrass, macroalgae, corals, shrimps, infauna, turtles, dugongs, birds, mangroves and fish, the majority of which do not exist anymore. Sewage outfall in the bay adds to the physical disturbance and causes eutrophication and oxygen depletion. In the south of Bahrain, in addition to the several species of fish, cnidaria, algae, arthropods, molluscs, porifera, ascidians, bryozoans and polychaetes, the land gazelle and some smaller land mammals were reported to be seriously affected. The socioeconomic impacts have also been occasionally considered and mitigation plans put forward. For example, in the northern Bahrain, around 32 Haddrahs (local fish traps) were removed and 380 Gargoors (local fish traps) belonging to 54 licensed fishermen within one project area were badly damaged. The dredging areas were also important grounds for the fisheries. Gargoor fisheries was calculated at 68% of the total finfish landing according to the year 2004 statistics and the northern areas accounted for 60–70% of the total finfish landings. Haddrah fishing in general was reported to be badly affected in the north. On the other hand, Fasht Al-Adhm (coral area) with all its associated fauna and flora is located in the way of Bahrain Qatar causeway project. Rare terrestrial habitats such as sand dunes are also being affected.

Despite the extensive programme of dredging, published data on the recovery of marine community following dredging is limited (Jones et al., 1998). Recovery may be possible but influenced by site-specific features. Jones et al. (2007) provides a compensatory solution for the infill and reclamation impacts. Survival of marine organisms following an impact of infilling has also recently been investigated using a microcosm experimental approach (Naser, 2011).

In general, the amount of the available data is limited to support a non-market valuation for the lost habitats therefore, the adjusted benefit value approach has been adopted. The total ecological value for a coastal ecosystem was $4052 ha/yr according to Costanza et al. (1997). This value was distributed among different sub-ecosystems. For example, nutrient cycling value constitutes the major component with a $3677 per ha/yr, whereas, food production and disturbance regulation comes into the second level and third level with $93 and $88 per ha/yr, respectively. The coastal ecosystems' functions such as storing and cycling nutrients, filtering pollutants from inland discharge systems, protecting shoreline from erosion and storms, regulating global hydrology and climate, accepting and assimilating waste and providing food and material can all be destroyed by the reclamation impact.

The scarcity of scientific data on the marine organisms such as those that spend part of their life stages buried in the sediment before moving into the reef environment would hinder predicting the impact on these populations. Representative marine habitats should therefore, be protected in order to preserve their integrity as genetic reservoir and provide control against which the effect of disturbances can be measured. Also, the cost of resource damage should be internalized on the decision-making process and the management of the dredging-reclamation activities.

Bahrain has developed an EIA system relatively recently (Donelly et al., 1998). Articles 20–22 of the Environment Act, 1996 provide for a procedure of project approval from an environmental body. Most EIA consultants in Bahrain have been considered by the environmental authorities as competent providing quality reporting data using sophisticated statistical analysis, hydrographical modelling and scenarios of different options. Data collected during these studies could be utilized in seeking alternative project localities and for general information about the state of the environment. A wider range of information is however required in order to fully assess the cumulative effects of the whole of the coastal developments. Further, there is a need for efficient coastal zone management in order to regulate, and coordinate the exploitation of marine resources in a sustainable manner. Scientific research should be adequately supported to investigate the harmful and beneficial effect of coastal development with a view of setting up standards and advising on appropriate methodologies and best practice.

The study endeavours to cover issues relating to the cumulative impacts on the marine environment considering the economic loss due to reclamation of land from the sea. The reviewed literature included some major coastal development projects around Bahrain. There is a risk that the marine ecosystem could reach to a point of a collapse where it could no longer support the current levels of activities which may affect the fisheries to an unrecoverable point. On the other hand, when the land mass is limited such as in Bahrain and the demand for land is high, reclamation of land from the sea may be unavoidable. Different mitigation measures could however be employed to minimize the environmental damages and create the required balance.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.marpolbul.2012.04.004.

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