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Anthropogenic Induced Geomorphological Change Along the Western Arabian Gulf Coast

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1. Introduction

The term "Anthropocene" (the geological age since the industrial revolution) popularized by the Nobel Prize winner Paul Crutzen is apt for the change that has occurred along the Saudi Arabian Coast of the Arabian Gulf. Goudie and Viles (2010) expand on this concept emphasizing the impact of man on the landscape. This Chapter identifies and quantifies changes in the coastal ecosystems of the Arabian Gulf since 1967, and highlights those remaining valuable natural habitats and environmental assets. There is a paucity of data on coastal changes along the Western Arabian Gulf coast, possibly due to restricted access to coastal areas. The authors however have had a unique opportunity to undertake repeated visits to coastal areas and with the use of remote sensed imagery have been able to document changes.

The genesis of this coastline is principally due to the movement of the Arabian Tectonic Plate which began in the Middle to Late Cretaceous period when it collided with the Eurasian Plate. The result of the compression caused by this collision was the subduction of the Arabian Plate during the Tertiary and the formation of what is now termed the Zagros Fault Zone located in present day Iran (AlNaji, 2009, Haq and Al-Qahtani, 2005). This, with the separation of the African Continental Plate possibly due to the thinning of the crust (Seber et al., 2009, Hansen et al., 2006, Daradich et al., 2003) resulting in a north-westerly tilting and the formation of the Arabian Gulf basin. Erosion of the uplifted plate resulted in the deposition of paleo-deltaic features clearly visible in digital elevations models derived from the space Shuttle Radar Topography Mission (SRTM) data in the current day Eastern Province of Saudi Arabia. During the Quaternary the plate became more arid and the Aeolian influence became more dominant and resulted in the formation of massive ergs that are a major landform of the Arabian Peninsula such as the Rub Al Khali Desert. The west and east coasts of the Gulf are completely different in their structure and geomorphology because of their tectonic origins.

Coastal processes are largely wind driven as the maximum significant wave height is less than 1.5 meters; maximum mean wave period of 3-5 seconds; tidal speed less than 0.3 m/s; and maximum range in tidal water level is from 0.5 – 2.5 meters (Rakha et al., 2007) which are all slight when compared to open ocean levels. This low energy environment is

confirmed by Summerfield (1991); and Viles and Spencer (1995). Current movements along the coastline are from north to south (Kampf and Sadrinasab, 2005, Brown, 1986). There are typical geomorphological long-shore drift features, such as the Ras Tanura Peninsula, as described by Davidson-Arnott (2010) that have been created by this anti-clockwise movement in the northern Arabian Gulf. These features are observed on the satellite imagery based maps of the northern coastline.

Parallel to the industrial growth of the region was the development of remote sensing technology that has allowed for a historic record of the impact of development on the coastal zone. This technology has provided a unique opportunity to document the changes in some coastal regions from a relatively pristine coastline to a highly developed coastal zone. The human population of the Saudi Gulf coastline has expanded exponentially, mostly as a result of hydrocarbon development in the Eastern Province. Residential, commercial, agricultural and industrial land use has thrived in a phase of economic development unknown in the history of Saudi Arabia and continued growth is predicted over the next two decades. The population in the Eastern Province grew from a few hundred thousand in the 1970s, approaching almost 3 million in 2010 (Lahmeyer, J.J., 2006). The Saudi Arabian Gulf coast has also changed significantly since 1967 as a result of the economic growth.

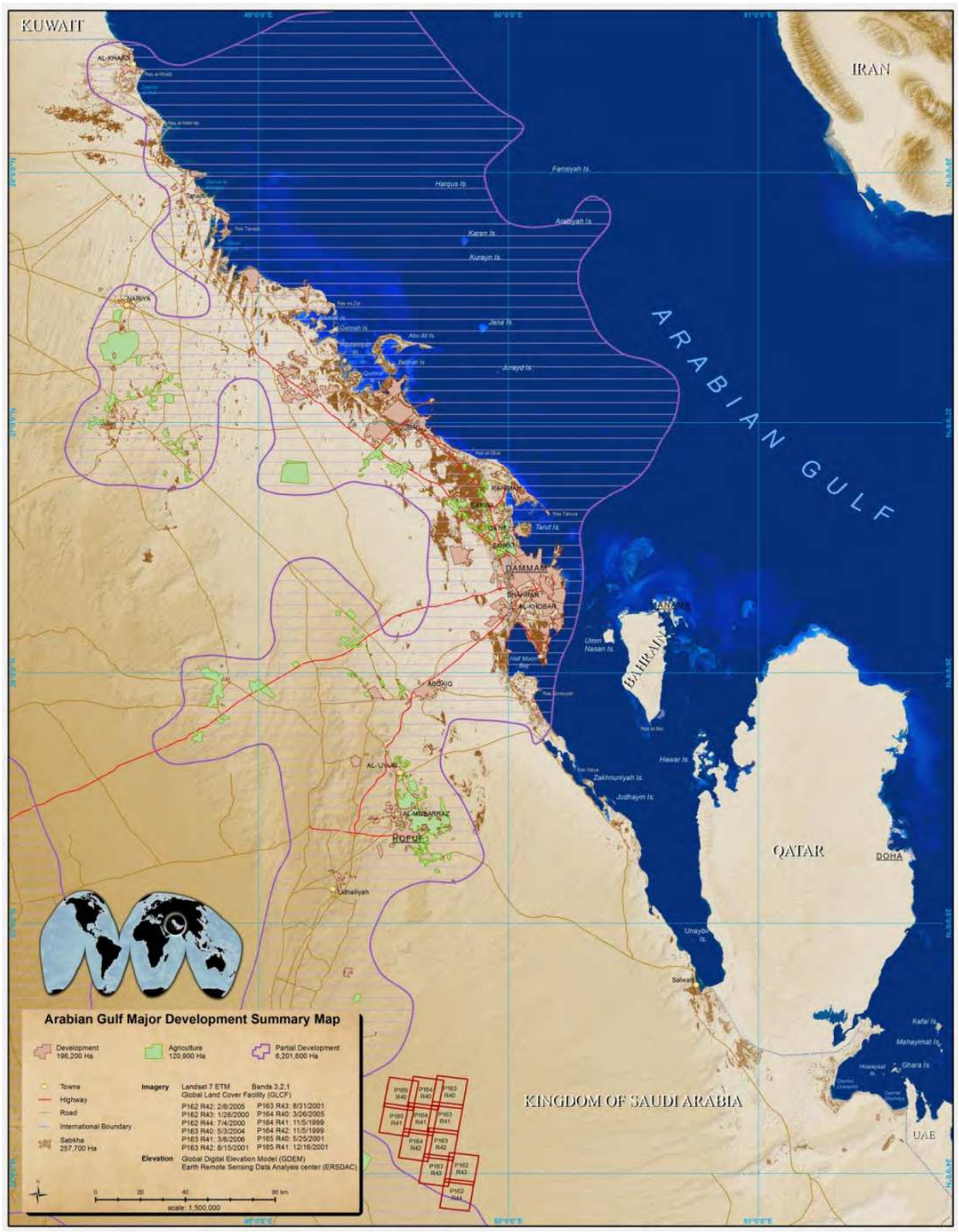
Development to meet increasing demands for residential, commercial and industrial expansion in the coastal zone is illustrated throughout the region. Recent changes in coastal geomorphology adjacent to highly developed coastal areas such as Dammam-Al-Khobar, Tarut Bay and Jubail are local examples of this development. Industry also places an enormous demand on the coastal zone for transport, ground water extraction, power generation, desalinization, sewerage and waste disposal.

Agriculture in the coastal zone (e.g., Qatif Oasis) has an indirect nutrient enrichment affect on the quality and productivity of marine waters such as those in Tarut Bay. The nutrient rich effluent originates from irrigation, particularly following fertilizer applications and can often enrich the natural biota within this coastal embayment (Basson, et. al. 1977). Map 1, Basic Land Cover and Land Use as at 2010, illustrates the development of the landscape in 2010 obtained from satellite imagery. The agriculture and development information in this map are digitized from enhanced satellite imagery; the sabkha derived by supervised classification techniques and density slicing; and partial development subjectively defined by infrastructure and land and water use.

This Chapter firstly describes the current situation and attempts to measure the change since the 1967 Corona imagery was acquired (Tarut Bay description is from 1934 and 1955). We then present a current risk matrix along with a short discussion on restoration programs, environmental awareness, public participation and the government legislative initiatives designed to protect the environment. The Chapter is concluded with a summary and conservation recommendations that will benefit the environmental assets of the Kingdom of Saudi Arabia.

2. Surface geomorphology of the Eastern Province of Saudi Arabia

The Eastern Province of the Saudi Arabian landform is characterized by sand movement across gravel plains, sabkha and limestone scarps. The landscape is dominated by sand sheets and widely rolling fossil sand dunes (Barth, 1999). The climate of the Eastern



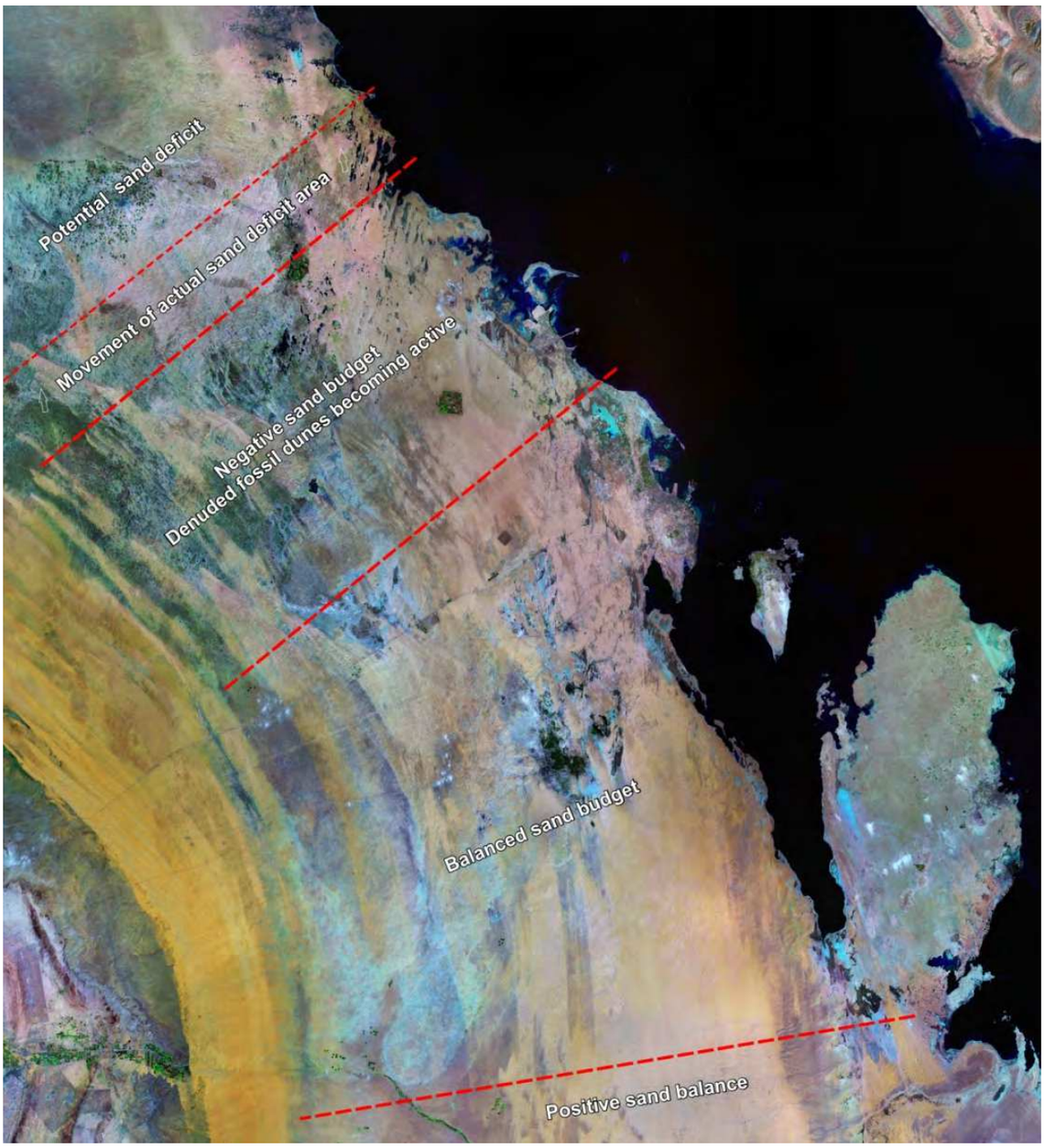
Map 1. Basic Land Cover and Land Use as at 2010. The background image of Map 1 is enhanced using a digital elevation model (DEM). Although the shadowing effect gives the impression of significant relief, in reality the landscape is relatively flat and has little impedance to the movement of Aeolian driven sands from the north to the south – see Section 2.

Province has changed over time with cyclic periods of changing temperature and moisture regimes (Chapman, 1971). It is currently in an arid phase where temperatures range from highs of 47°C in summer to lows of 3°C in winter with restrictive rainfall of less than 100 mm per annum. Wind patterns play a major role in the natural surface landscape development. Holm (1960), Chapman (1971) and Barth (1999 and 2001) all refer to the importance of the wind regime in the movement of sand across the region. The dominant winds come from high energy north-west direction sourced from the Mediterranean and occur from November to February with equally high energy summer Shamals from June to August and are primarily responsible for the inland movement of sand across the Province. Evidence of the directional influence of the prevailing winds creates striations caused by aeolian erosion and are clearly visible on exposed rock (see Figure 1). North of Dammam, coastal convection winds tend to move sand inward before it is transported south, whereas south of Dammam the shallower Gulf of Salwa has lesser convection influence and the sand dunes occur closer to the coast.

Fig. 1. Exposed Aeolian Weathering at Dhahran

Barth (2001) suggests four zones of sand balance within the Eastern Province (see Map 2). There is a potential sand deficit to the north; a negative sand budget in an area that is being denuded of vegetation caused by overgrazing resulting in the reactivation of fossil dunes; a balanced sand budget where sand coming in from the north is equal to sand leaving to the south; and a region of accumulation to the south. The background LANDSAT image also illustrates the generalized landforms based on the presence of absence of sand in the regime (Map 3). Another illustration of this sand movement across the region is the changes suggested by Barth (1999). He suggests that overgrazing has reduced the vegetation cover to such an extent that previously stable fossil dunes have once again become active. It is not unreasonable to assume that the dominant winds will likely increase the sand movement

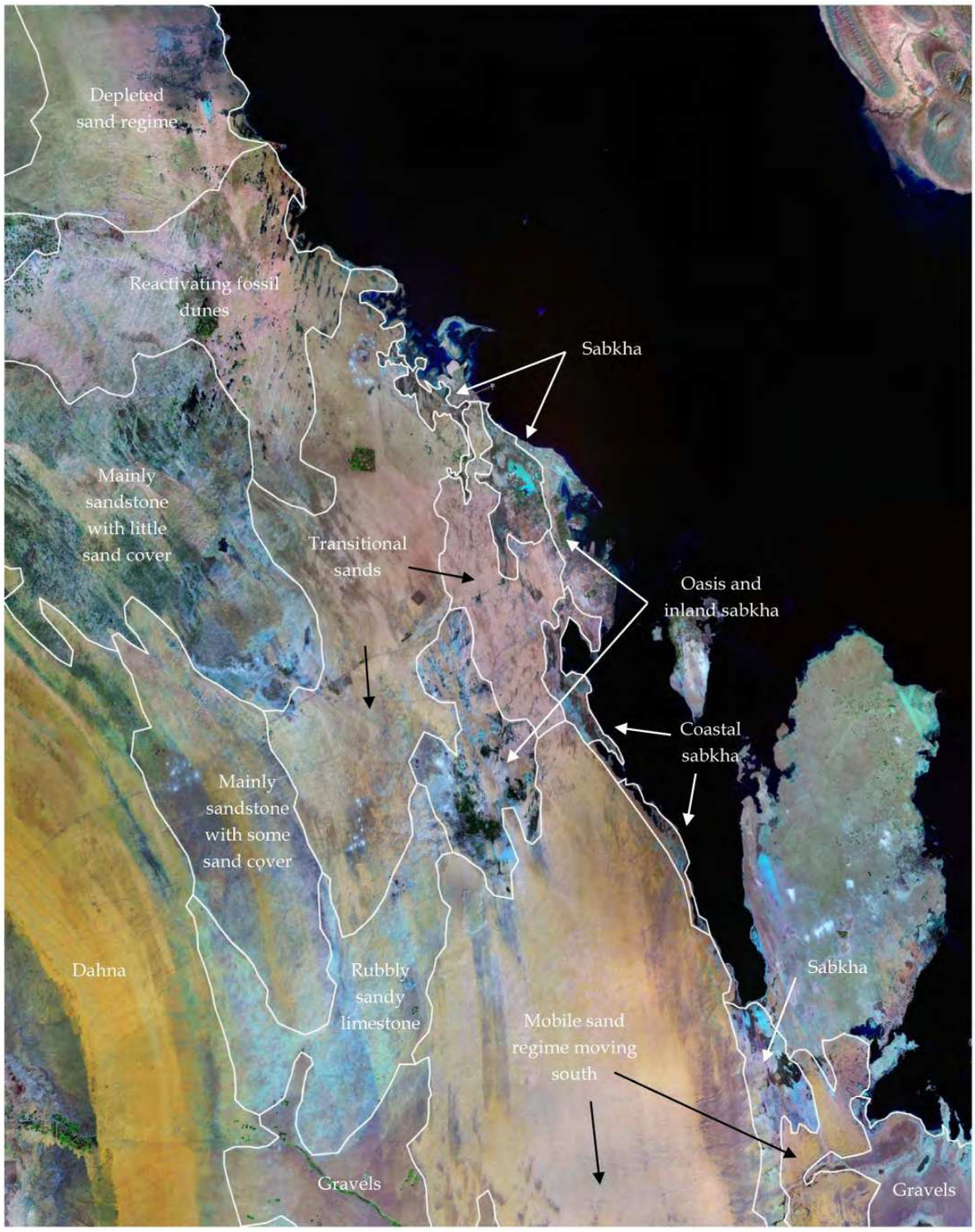
southwards – toward the heavily populated Jubail Industrial City and the Dammam metropolitan area. This assumption has health, logistic and maintenance repercussions on the populous of the region.



Map 2. Sand Transportation Zones affected by Prevailing Winds. (Adapted from Barth, 2001, Image Global Land Cover Landsat circa 2000)

Natural coastal change in this relatively low energy environment would involve the transportation of marine sediments and terrestrial sands from north to south over an extended period of time. Mobile dune systems would be expected to traverse the landscape and be initially arrested and slowed by sabkha and surface water with the following dunes

continuing their southeasterly journey. However, transitional sands are being severely impacted through development requirements contributing to a lessening of the balanced sand budget referred to previously. The natural process pales into insignificance when the anthropogenic changes that have occurred since 1967 are taken into consideration.



Map 3. Generalized Geomorphologic Units of the Eastern Province (Image Global Land Cover Landsat circa 2000)

3. Development of the coastal zone

Some coastal habitats are under severe threat as a result of coastal development, and these areas are mostly within close proximity to human development or activities. Examples include salt marsh, mangrove and seagrass habitat areas. As mangroves have limited distribution, occurring in the central and northern areas within embayments surrounded by major development, they are under even greater risk of impact. The last major stands of mangrove occur in the Tarut and Musalmiyah Embayments with the largest trees occurring on and around Tarut Island. These mangrove ecosystems have been subjected to various impacts as a result of coastal development, with the most serious being smothering by land filling and as a result all mangrove habitats should be considered for immediate protection. Simultaneously aggressive mangrove rehabilitation programs need to be conducted to safeguard the genetic diversity of the mangrove populations and sustain fisheries and bird populations.

Subtidal muddy and sandy habitats are productive components of the marine ecosystem and are often ignored because attention usually focuses on more colorful and high profile habitats such as coral reefs. Seagrass habitats are widespread within the low energy subtidal areas of the coast and unfortunately vast areas of subtidal habitat are impacted each year through dredging and reclamation work. Reducing the footprint of dredging and reclamation operations on the productive shallow water habitats of the Gulf would be environmentally beneficial. Avoidance of nonessential marine dredging and reclamation works within these areas is the best strategy to minimize damage to these ecosystems.

4. Detecting change over time along the Gulf coastline

Aerial photography and freely available satellite imagery were used to determine coastal change. These types of data and related dates are listed in Table 1.

All LANDSAT satellite imagery used was downloaded with geo-location properties included. ASTER data were geo-referenced using the satellite ephemeral data and block adjusted where necessary. The 1934 aerial photography was 3rd order polynomially geo-referenced using common features located on the 1967 Corona imagery and the 1955 uncontrolled mosaic was triangulated to the same Corona data. All data were projected to UTM Zone 39 in WGS84 datum.

The coastline for each data set was determined using heads-up digitizing techniques from data enhanced to discriminate the land-water interface. Land use/cover classes (developed, agriculture and partial developed) were captured in the same way. Caution was exercised in compiling coastline changes due to the differing spatial resolutions of the imagery used; the methods of geo-location; and the state of the marine environment at acquisition. Some adjustments were necessary to increase the accuracy of the data. From the initial observations of the imagery it became obvious that there had been little change between 1934, 1955 and 1967 with minor changes detected in the 1972/73 data. A base coastline was established using the 1967 Corona data set that covered 95% of the coastal region of the Saudi Arabian Gulf. The area of sabkha was initially determined by Mah (2004) using supervised classification techniques. Small areas of in-fill were determined using a density slicing technique and both results combined into a single dataset. All coastal and land cover

data were included in a database to calculate areas and distances, and where required statistics were calculated.

Date	**Remote Sensing System**	**Spectral Attributes**	**Spatial Res**	**Comments**
1934	Aerial photography	Panchromatic		Part of Tarut Bay
1955	Aerial photography	Panchromatic		Uncontrolled mosaic of Dammam Area and Tarut Bay
1967	Corona Imagery	Panchromatic	1 meter	95% Coastal Coverage
1972-1973	LANDSAT 1 & 2	Multispectral	60 meters	
1980	LANDSAT 3	Multispectral	60 meters	Sensor failing
1990	LANDSAT 4	Thematic Mapper	14.25 meters	USGS Mosaic
2000	LANDSAT 7	Thematic Mapper	14.25 meters	USGS Mosaic
2005	LANDSAT 7	Thematic Mapper	14.25 meters	Sensor failing
2005	ASTER	VISN	15 meters	Selected areas only
2006	ASTER	VISN	15 meters	Selected areas only
2009	GeoEye	Bands 1-3	0.6 meters	Selected areas only
2010	LANDSAT 7	Thematic Mapper	14.25 meters	Sensor failing

Table 1. Remote Sensing Systems Used to Determine Change

The Saudi coastline was divided into three coastal areas, Northern, Central and Southern coastlines. Data presented in this Chapter will illustrate changes in these coastal areas caused by development. A summary of changes along the entire Gulf coastline is also included.

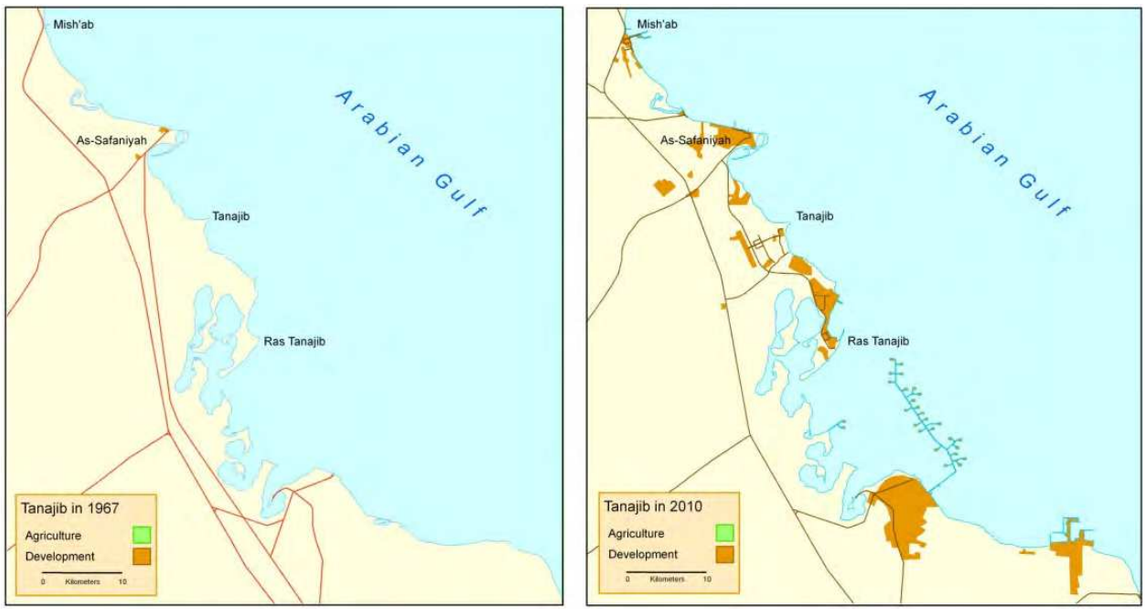
5. Results

5.1 The Northern coastline

The upper part of the Northern Saudi coastline remains relatively undeveloped and contains interesting features such as mangrove and salt marsh habitats, coastal sand dunes, rocky shorelines, cliff formations and tidal creeks (Khores). Al Khafji Creek is the largest of the tidal creeks and has shoreward development. The mangrove and salt marsh habitats of Al Khafji Creek are threatened by this activity and other development, and the general discharge of waste. The remnants of an early mangrove plantation established in the 1980s appear to be growing well, however the need for protection against landfill encroachment at the head and mouth of the Creek is urgently required. There are around 2.5 ha of mangrove habitat in the Al Khafji tidal creek. Large expanses of salt marsh also occur, however, these continue to be impacted by ongoing land filling. This poses a serious risk to the Creek's ecosystem as there is a high probability that the Creek's waters and sediments will become polluted from leaching toxic materials sourced from illegally dumped wastes. Private sector partnerships are now undertaking a program to enhance the mangrove habitats of the Creek

through annual mangrove plantations. It is envisaged that with the development of additional mangrove intertidal habitat, that the Creek's ecological value will increase, and the area will became an important nursery habitat for fish and crustaceans as well as migratory birds.

Tanajib – Manifa Embayment on the northern coastline is the most recently developed coastal area to facilitate the expansion of the oil industry. The embayment is very shallow and to allow oil operations in the area; and to minimize impacts associated with dredging, boat traffic, cable networks, pipelines and oil spills; a causeway and marine pads (small islands used for drilling) were developed (Map 4). To further reduce the impact of these structures on the marine ecosystem, the company responsible went to great lengths to minimize the overall footprint of the causeway and pads (width and length reduced by almost half), and there was no dredging allowed within the embayment. The direction and exact location of the causeway was also redesigned to minimize impact on subtidal habitats and the natural water circulation patterns. Water circulation was modeled and changes were made to the design of the causeway to maximize circulation, resulting in the causeway being built parallel to the water current direction, and incorporating 14 bridges. Existing fishing navigation channels remained intact, and constant monitoring was instigated during all construction and initial operation work to ensure compliance with marine environmental standards.



Map 4. Change in Land Use and Coastline for Tanajib from 1967 until 2010

The majority of the population in this area are employees who work at the Tanajib industrial facilities. The change in the district has occurred as the offshore oil reserves have required primarily industrial infrastructure development. This expansion included offshore causeways, rig pads and service facilities for production platforms. Development was estimated to cover only about 200 Ha in 1967 and apart from recent oil and gas processing facility construction of just under 12,000 Ha at Manifa, little has changed within the general

coastal zone. Map 4 geographically illustrates these changes. Coastal infrastructure accounts for 1,100 Ha of environmentally sensitive causeways and drilling pads.

5.2 The Central coastline

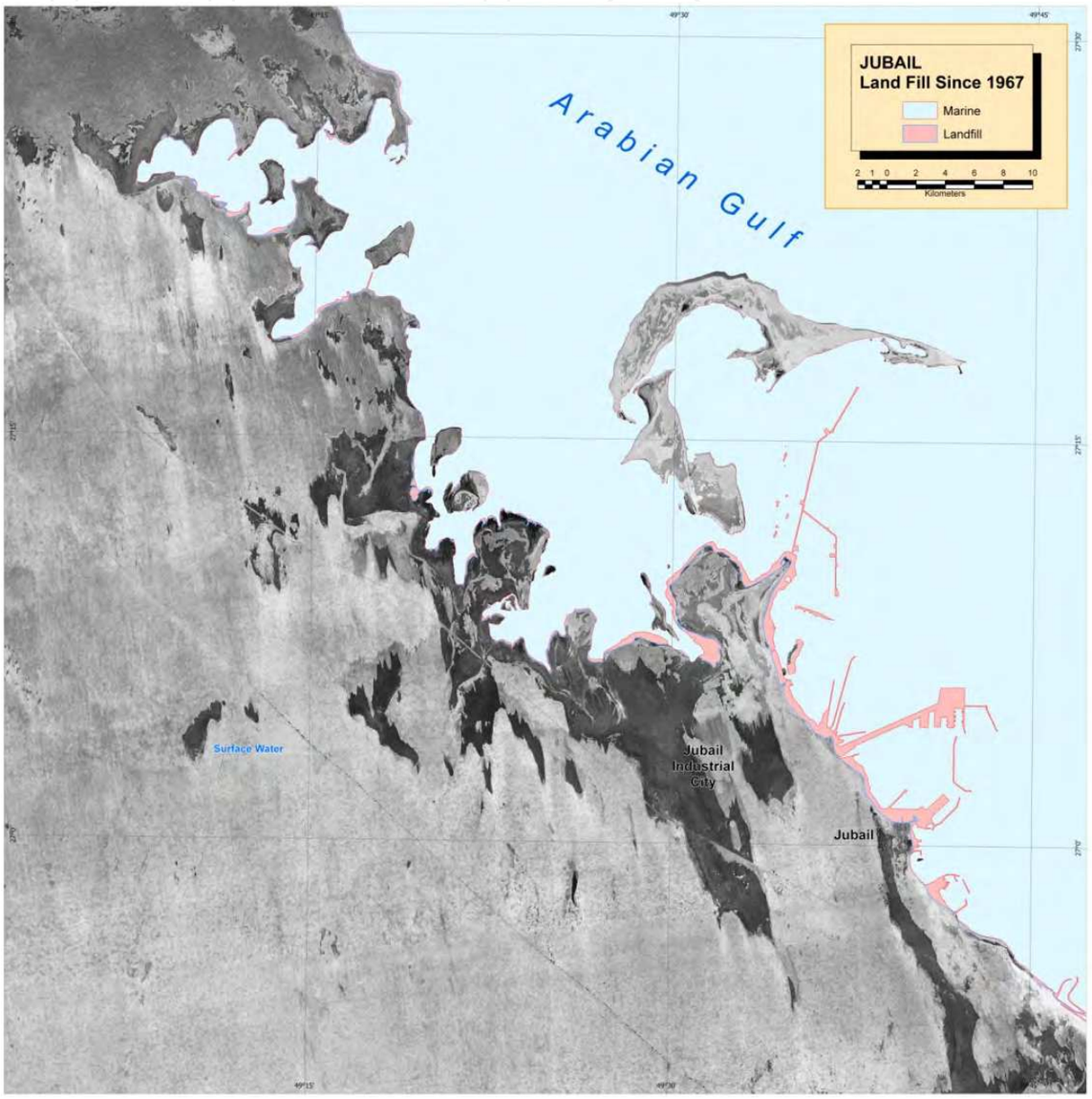
This part of the coastline includes Jubail and Dammam areas, considered the most populated and developed areas of the Saudi coastline. Since the establishment of the Royal Commission in 1975, the Jubail area has experienced significant coastal development. The population of Jubail has grown from 140,800 in 1992 to 337,800 in 2010. It is expected that this increase will continue as the Industrial City is further developed. Unlike the Dammam area, there appears to be areas of the coastal zone relatively untouched. Map 5 illustrates the developed coastline and regions reclaimed from the marine environment to landfill and development. Much of these data are interpreted from satellite imagery from 1967 to 2010. From no development in 1967 there has been a steady growth to 44,000 Ha in 2010. There has been a small agricultural component of just over 2,500 Ha within this study area. A total of 4,100 Ha of coastal change has occurred. This development is set to continue with recent development announcements for the area. Map 6 clearly shows the development between 1967 and 2010.

Large areas of sabkha, salt marsh and mud flat remain relatively undeveloped to the north of Jubail Industrial City, although coastal recreational activity is apparent from field surveys. Reed (*Phragmitus australis*) growth occurs on the sewage outflows that spread over large areas of sabkha near to the coastline (see figure 2). This area is a haven for wildlife, and large numbers of birds of prey were observed hovering above its margins searching for food. The sewerage outflow, containing fresh water and nutrients, allows a wetland ecosystem to develop where it might not otherwise exist. Early in the development of Dhahran, it was recognized that the "Dhahran Ponds" were a source of food and a resting place for migratory birds (Evans, 1994) and were registered as a significant wetland.

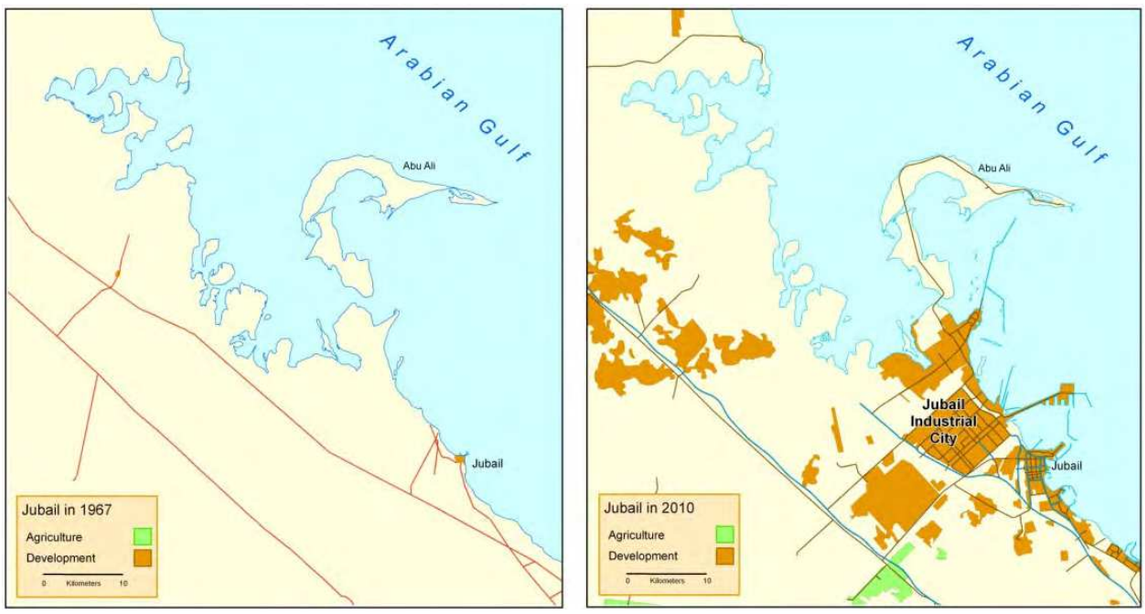
Dredging at Jubail is significant, especially around Gurmah Island where there is a thriving mangrove community of approximately 63 ha. This mangrove community was severely polluted by oil as a result of the 1991 Gulf War, however it has since recovered. Map 7 illustrates the impact of dredging and reclamation in this region. Figure 3 shows the view from the developed shoreline east and north to Gurmah Island and the associated mangroves. The demarcation between the natural shallow water (light blue) and the dredged channel (darker blue) is apparent.

The embayment at Jubail has been largely unaffected by development except for dredging for landfill (Map 7). Mangrove, salt marsh and mudflat habitats are present in this area although they may not be as prolific as in Tarut Bay. There are a number of smaller areas within the Jubail region that are protected from the prevailing northerly winds. Seagrass, coral and salt marsh are all represented in these areas. The leeward side of Abu Ali Island protects 48 ha of mangroves from the incessant northern winds (shamal).

This entire embayment needs to be protected from further development, particularly any large industrial operations on the coastline. The Saudi Wildlife Commission has identified a large portion of this area (see Map 13 Section 6.3) as a proposed protected area. Gurmah Island with its rich mangrove habitats also needs protection, especially given that this island has significant mangrove research potential due to its polluted state during the 1991 Gulf war and its subsequent recovery.

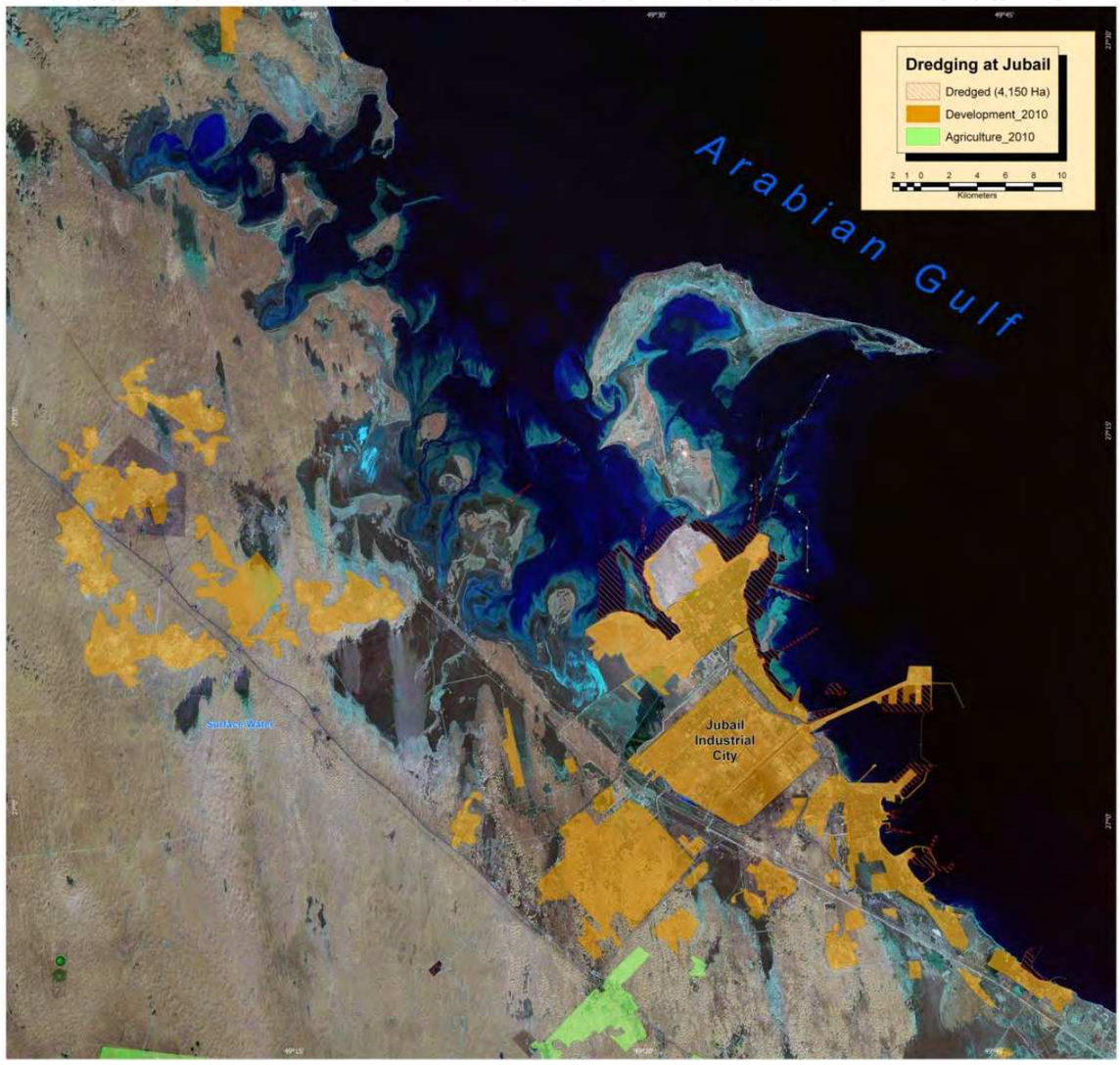


Map 5. Developed Coastline at Jubail from 1967 until 2010 (Corona Imagery 1967)



Map 6. Change in Land Use and Coastline for Jubail from 1967 until 2010

Fig. 2. Reed Bed Sustained by Sewage Outflow Near Jubail.



Map 7. Dredging and Reclamation at Jubail Area (Image Global Land Cover Landsat circa 2000)

Fig. 3. View across the Dredged Channel to Gurmah Island and its Mangrove Habitat

5.3 Tarut Bay

The lower part of the Central Coastline is the Dammam area, which includes the highly productive Tarut Bay. The Saudi Wildlife Commission has identified Tarut Bay as a Resource Use Reserve. This is equivalent to the IUCNR classification for reserves as V – Protected Landscape or Seascape and VI – Managed Resource Reserve (Convention on Biodiversity, 2004; Sulayem and Joubert, 1994). The reserve category chosen is an attempt to prevent further deterioration of the Bay's environmental values while continuing to encourage its traditional exploitation. It does not seek to prevent development, but to have it occur with environmental values included in the development plan. It allows the traditional uses of the landscape or seascape to continue while discouraging massively destructive development.

The population growth of the Dammam area is illustrated in figure 3 with a rapid increase occurring from the 1970s. This growth was undoubtedly fuelled by the ongoing exploitation of oil and gas resources in the Gulf and subsequent significant global rises in oil prices with the Eastern Province being the center of this economic activity. Development has impacted the coastline at many locations as illustrated in Map 8. Landfill continues to expand into Tarut Bay and new canal projects are becoming a development trend in the Half Moon Bay area. Analysis of aerial photography and satellite imagery reveal that development in the Dammam region has increased from 5,000 Ha in 1967 to 70,000 Ha by 2010, while agriculture increased from about 8,500 Ha to 10,000 Ha mostly in the Tarut Bay area (however, the spatial context changes dramatically). Within the Tarut Bay area development has increased from 2,500 Ha to 28,000 Ha. There have been nearly 8,000 Ha of landfill expansion operations since 1955 for the Dammam area, while the Tarut Bay area totals 6,600 Ha. Each of the coastlines shows an ever increasing encroachment into the marine environment.

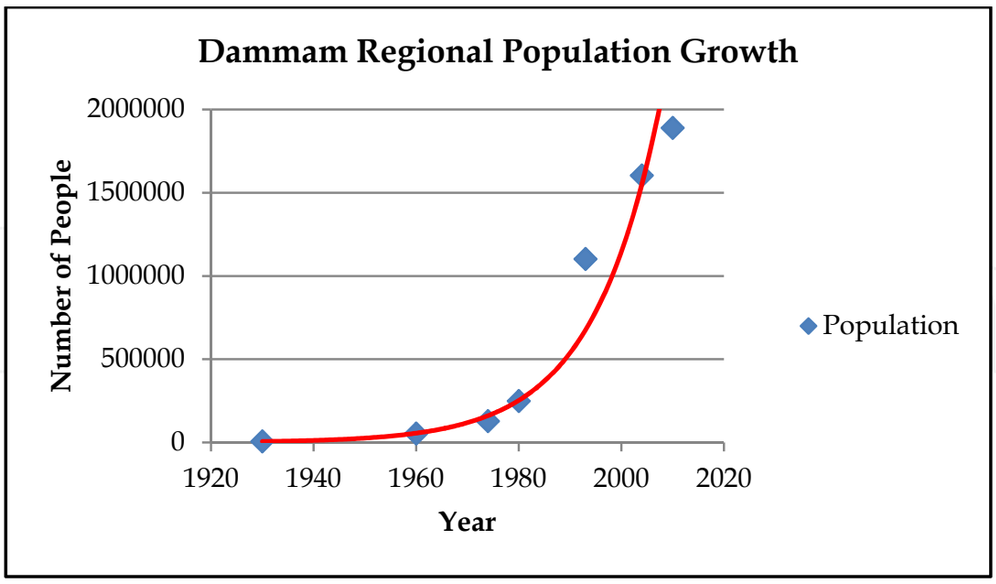


Fig. 3. Dammam Regional Population Growth from 1930 until 2010 (Data Source: Brinkhoff, 2011).

Tarut Bay is adjacent to the ancient Qatif Oasis, a natural fossil groundwater aquifer close to the surface that appears as a number of surface water pools, springs and small lakes. The development of the Oasis into a highly productive agricultural area to supply the needs of the growing population in the 1970 - 1990 period resulted in the use of chemical fertilizers, altered irrigation methods, and wetland drainage. Basson et. al. (1977) recognized that the high productivity of Tarut Bay was attributed to the influence of agricultural activity in the Qatif Oasis. The abundance of fish could be implied by the number of traditional fish traps (297) in the 1967 Corona satellite imagery. During this period there were still many hectares of healthy mangrove stands ideal as a protective nursery for many species of fish and crustaceans. It is estimated some 485 Ha (equivalent to 700 football fields (ff)) of mangrove have been lost and that 3,810 Ha (5450 football fields) of landfill development has encroached into the marine environment of Tarut Bay. Table 2 indicates the areal extent of the mangrove habitats at risk and the current ongoing threats.

The dramatic changes along the coast are clearly illustrated in Map 9a & 9b where land use and the actual coastline of 1967 have been extensively modified. The 2010 map shows the expansion of development. While some agriculture has been lost, the most significant modification has been to the natural coastline (Map 8). Map 10 shows successive landfill operations around Tarut Island. The result of such development is the loss of 134 Ha of mangrove forest (190 ff), an estimate of 440 Ha of salt marsh (630 ff) and 752 Ha of subtidal habitat (1075 ff) on Tarut Island alone.

What remnant mangrove habitats that remain in Tarut Bay are in urgent need of protection. In early 2011 the estimate of mangroves within this area was 325 Ha of varying density. This number included newly established mangrove plantation sites whose coverage is still very small at the present time. The mangrove habitat areas in immediate risk are estimated to be 89 Ha. These are at risk due to continued landfill and infrastructure development.

Map 8. Changes in the Coastline from 1955 until 2010 (Image modified from ARAMCO Aerial Photography Mosaic 1955)

Location	Ha of Mangrove	Current Threats	Comments
Dammam Port	1 (1.5 football fields)	Road construction	Road widening for port traffic
Tarut Island	12 (17 football fields)	Landfill	Further expansion of landfill that will impact large areas of mangrove
Qatif	4 (6 football fields)	Landfill	Already closed from tidal flushing and remaining mangroves are under extreme stress
Safwa	72 (107 football fields)	Road construction	Direct landfilling and the resulting restricted water circulation following recent construction of a causeway (*See below)
Total	**89 (131.5 football fields)**		

This table is graphically presented in Map 12.
*If circulation within Raheema Bay is unaffected by the construction of a new causeway then the risk to mangroves decreases to 2 Ha.

Table 2. Mangrove at Risk in Tarut Bay

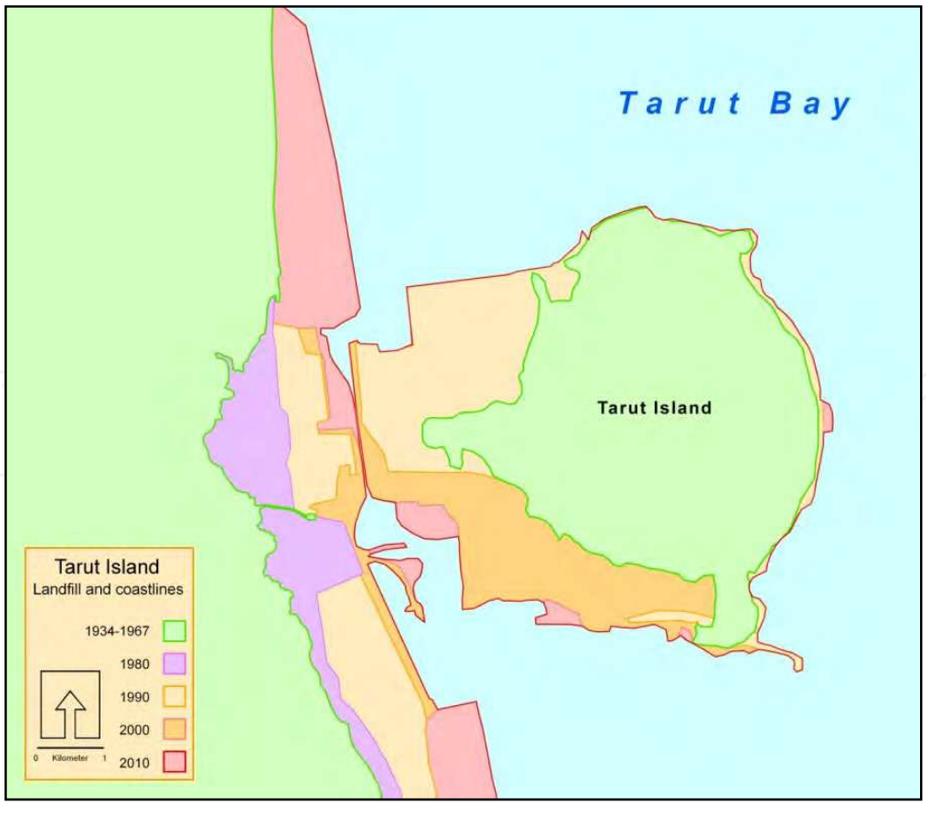
a. b.

Map 9. a. Development in Tarut Bay in 1967; b. Development in Tarut Bay in 2010

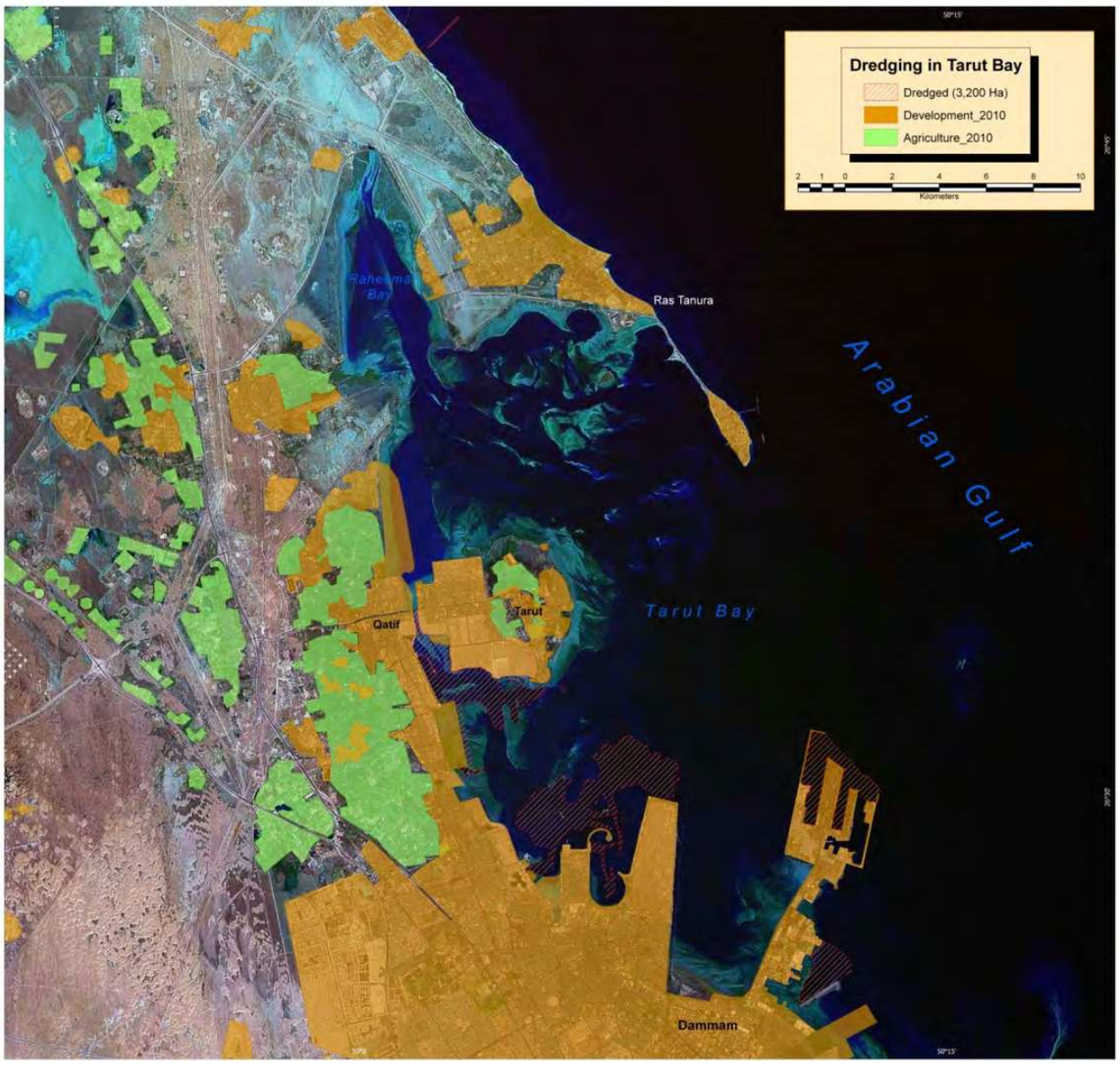
Map 11 illustrates a satellite image with the dredged marine environment overlaid. This dredging was initially undertaken for access to Port but became a source of material for the extensive landfill developments along the coastline over successive decades. Landfill material today is usually building rubble and other construction waste. Illegal dumping still occurs and a concerted effort is required to prevent this practice continuing. Map 11 also shows that only about 15% of the coastline of Tarut Bay remains undeveloped. Map 14 in

Section 6.3 illustrates the extent of a proposed reservation by the Saudi Wildlife Commission and the IUCNR (Saudi Wildlife Commission, 2010).

Within Tarut Bay there are very few undeveloped coastal landscapes. Maps 9a and 11 highlight these areas. This region is the major population center for the Eastern Province and as such has suffered the greatest anthropogenic induced change on the coastal environment. Map 12 illustrates the location and density of remnant, transplanted and new mangroves plantations within Tarut Bay. These maps also indicate those mangrove areas that are at immediate risk due to continuing impacts. There is a real possibility that the Raheema Bay mangroves could be seriously impacted if circulation is restricted by the new causeway presently under construction across the mouth of the Bay (Safwa – Raheema). For this reason all of the mangroves in Raheema Bay have been designated as at potential risk. Confidence is expressed in the environmental legislation and good environmental engineering design that should prevent such an occurrence. This prospective loss of mangrove habitat in Tarut Bay is indicated on Map 12 by a red outline to the icon representing the actual areal extent (Ha) of mangrove habitat at the different locations. It must also be noted that the self-propagation of mangroves indicates the resilience of the environment despite large scale developments. For example mangrove has shown resilience by self-sowing where none have existed before (e.g. Dammam Port). There are also concerted efforts within the Kingdom to recover and replace lost mangrove habitat. Design considerations for infrastructure in coastal areas are now also promoting environmental awareness and protection of habitats.



Map 10. Changes along Tarut Island and the adjacent coastline since 1934.



Map 11. Dredging Activities in Tarut Bay (Background image is Global Land Cover Landsat circa 2000)

Tarut Bay has been recognized as a landscape that requires protection, but still allows access for public use (IUCNR/MEPA, 1987).

Map 12. Mangrove Areas in Tarut Bay with Mangrove at Risk in Red

5.3 The Southern coastline

Unlike the northern and central coastlines, the southern coastline is mostly undeveloped and has less anthropogenic impacts. As such, the southern part of the Saudi coastline has been recommended as a nature reserve by the Saudi Wildlife Commission (Map 15). There has been some limited development at the northern end of this area such as at Qurayyah and Half Moon Bay consisting of salt water injection plants, power stations, desalination plants and recreation facilities. These facilities are relatively small in scale and scattered along the coast. They are required to support existing infrastructure within the central coastline areas around Dammam.

As a result of the areas relative pristine condition, wildlife extensively utilizes the coastal and marine areas of the southern region, with large bird populations inhabiting Zakhnuniyah and Judhaym Islands. These islands are of international significance as breeding sites for Socotra cormorant *(Phalacrocorax nigrogularis*), and it is important that these islands be given protection from development or disturbance. The Gulf of Salwa is known as one of the most important sites in the world for the endangered dugong (*Dugong dugon*), with this area containing significant seagrass habitat that enables the largest known single congregation of dugongs ever observed to exist in this area. Map 15 illustrates the reservation proposals from the Saudi Wildlife Commission for the Eastern Province including this important part of the Gulf coastline.

Al Uqair is a unique coastal port occurring on the coast of the Gulf of Salwa. The area has significant heritage sites of regional importance, consisting of an old trading fort and customs house area. This Port was once the major trading point from the Eastern Province to the then known world. In contrast to the high salinity of the Gulf of Salwa, the area contains fresh water springs with associated freshwater vegetation and fish inhabiting these areas. The area is also surrounded by sand dunes and has been recently proposed as a major tourist development site by the Saudi Commission for Tourism and Antiquities. In keeping with the Commission's philosophy the area's cultural and natural heritage should also be conserved as part of this development.

Ras Abu Qameess is the most isolated Gulf coastline of the Kingdom located between the United Arab Emirates and Qatar borders along the southern Gulf coastline. This rocky headland is in pristine natural condition and contains rich intertidal coastal rocky habitats, a large breeding population of Osprey (*Pandion haliaetus*) and Sooty Falcons (*Falco concolor*) and significant numbers of dugong (*Dugong dugon*). There has been little development along this coastline. There are no major coastal encroachments and it has been recommended by the Saudi Wildlife Commission that a conservation reserve be established to protect this unique coastline in its natural condition (see Map 15 in Section 6.3).

6. Remediation programs

6.1 Coastal habitat restoration programs

Mangrove habitats have been the main focus for coastal restoration programs along the Gulf coast because they are an important intertidal habitat that is under threat from land development. It is estimated that 90% of the original mangrove ecosystems along the Gulf coast have been lost mostly as a result of coastal urban development. The current estimate of

mangrove habitat within the Saudi Arabian territories of the Gulf is 412 ha, comprising 55 ha of plantation. Over the last few decades, influential private sector companies in association with partners such as the Ministry of Agriculture, King Fahd University of Petroleum and Minerals, Saudi Commission for Wildlife Conservation and local schools have been establishing mangrove plantations in the Eastern Province. The growth in some plantations has been promising and has resulted in private sector companies embarking on comprehensive mangrove restoration programs that include establishing strategic mangrove nurseries and plantation sites along the Eastern Province coastline. Restoration of mangroves needs to be undertaken on a large coordinated scale over an extended period and could also be supported by other industry and business in the region. Without this work there is a distinct possibility that mangroves would become locally extinct due to continuing development pressure.

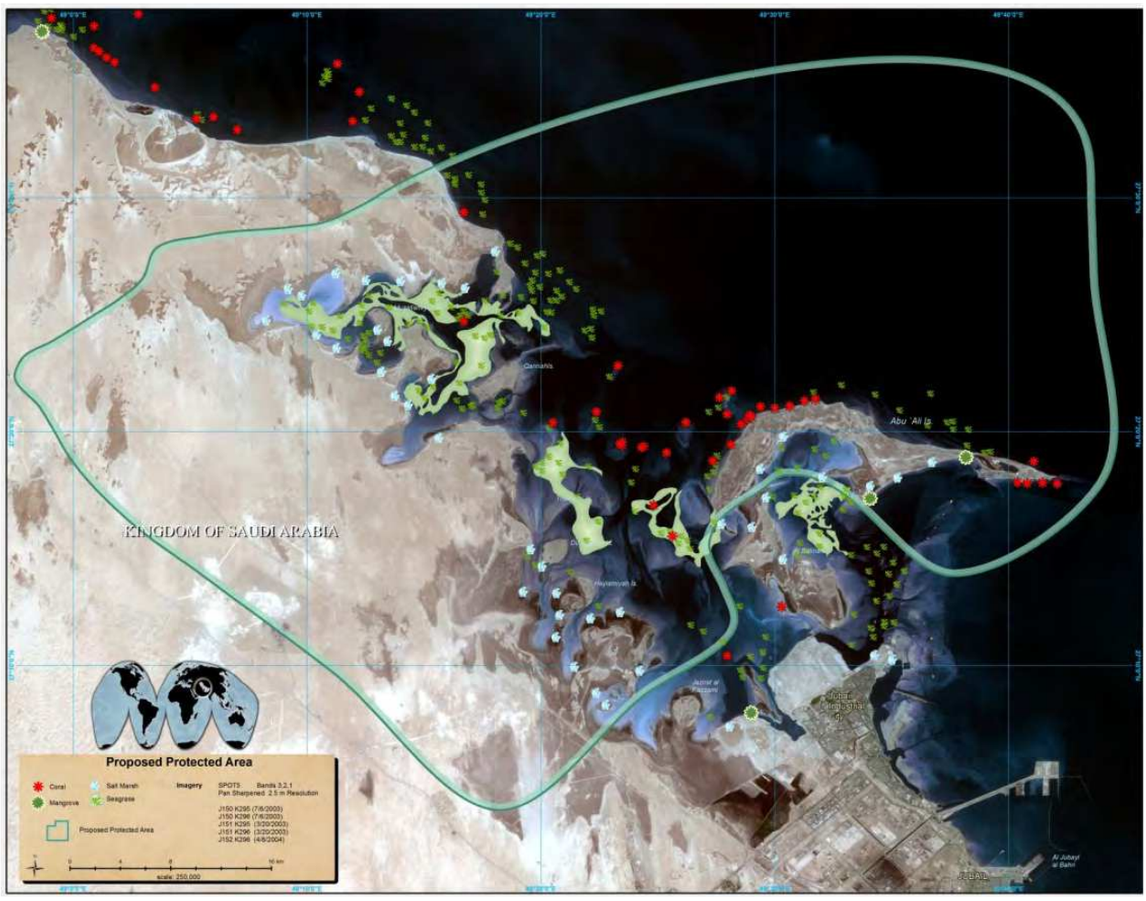
6.2 Environmental awareness and public participation

The concept of public involvement with the management and conservation of the environment has been promoted as a potential solution to some environmental problems. Current public anti-littering and recycling campaigns, mangrove plantation programs and coastal clean-up events are examples of how the public can participate in protecting their environment. Environmental awareness requires a consistent and prolonged program of environmental education through the public schooling system. These topics need to be incorporated into the curriculum with teachers being trained (train the trainer) and students being assessed on their knowledge regarding their environment and their responsibilities towards protecting it. The goal should be on changing current behavior patterns that are not environmentally friendly. These same programs need to have a public focus, and the existing media sector is capable of achieving results that have proven successful for commercial marketing, by using national sport and entertainment personalities to promote good environmental behavior. As the majority of the Saudi population is under 25 years of age, these programs could very quickly change the environmental awareness within the Kingdom, with the same approach having proved successful in other countries. Public recognition of individual and community environmental achievements is also important to reinforce environmental responsibility, and government departments, educational institutions and private companies should all be encouraged to promote environmental champion programs among their respective staff and students.

6.3 Reservation proposals

Maps 13, 14 and 15 indicate the areas along the Arabian Gulf coastline that have been recommended for conservation. Some areas in the north and central regions such as Jubail and Tarut Bay have been nominated for multiple use reservations where sustainable utilization of the natural resources can continue along with the protection of the environmental, cultural and economic values of these areas. This is particularly true for the mainland coastal areas where there has been a long history of human settlement and natural resource exploitation. The offshore islands in the northern region are however designated due to their biodiversity value, with these areas being major centres of marine biodiversity in the region. Reservations in the southern region such as those proposed for the Gulf of Salwa and Ras Abu Qameess are nominated because these areas represent the last large

areas where natural habitats dominate and wildlife populations flourish. The establishment of these reservations is required urgently if these areas's current values are to be protected indefinately.



Map 13. Saudi Wildlife Commission Marine Sanctuary Reservation Proposal for Jubail.

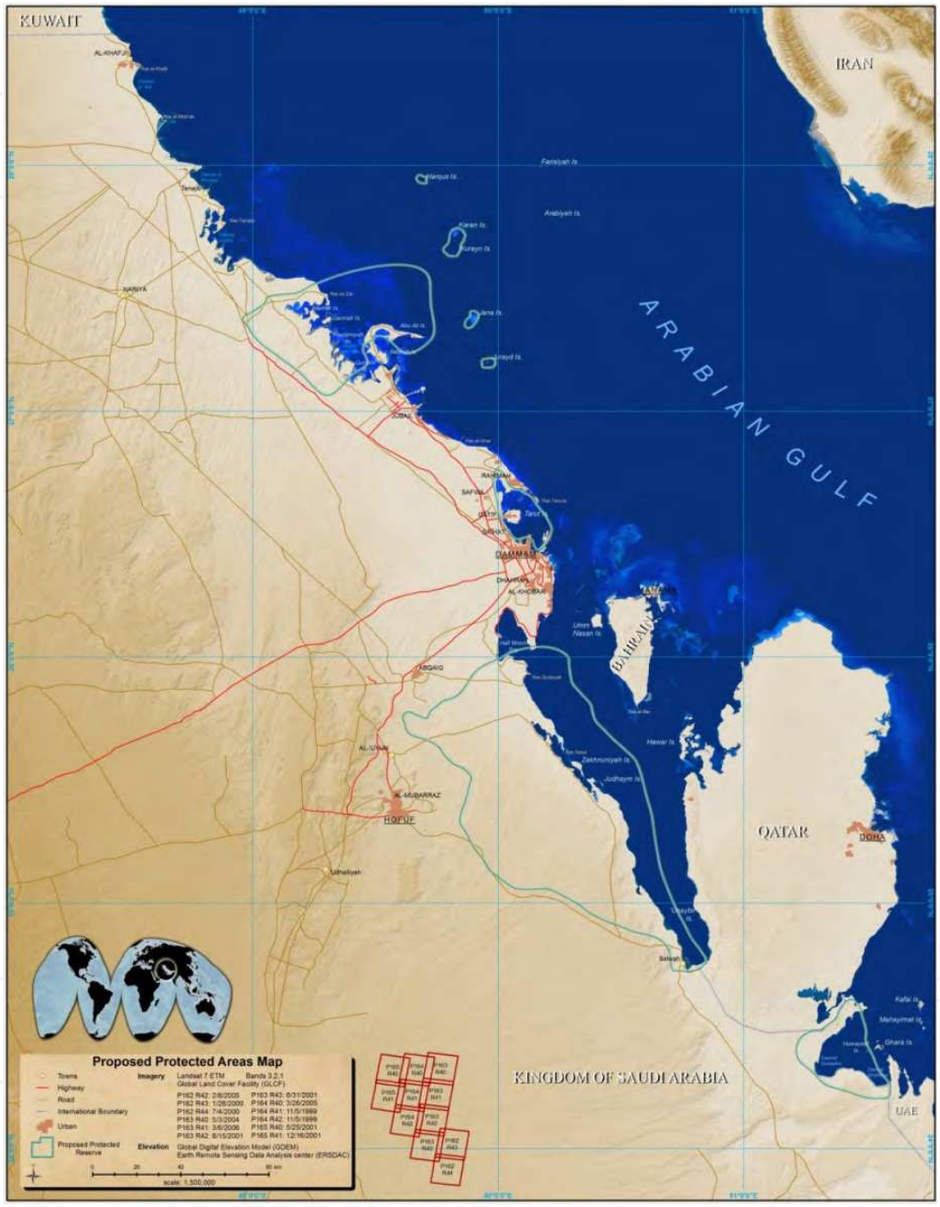
6.4 Environmental legislation and law enforcement

There have been a number of government initiatives to protect the environment. The establishment of the Presidency for Meteorology and Environment (PME) has provided a guiding vehicle for legislation. Key documents such as the General Environmental Law, with rules for implementation and environmental protection standards provide guidance on protecting the environment (PME, 2004). The environmental law anticipates that the PME will liaise with other public authorities regarding the development and enforcement of environmental issues. The Saudi Wildlife Commission has created landmark documents such as the First Saudi Arabian National Report on the Convention of Biological Diversity. Saudi Arabia has also completed a National Biodiversity Strategy and Action Plan for the Country. There are 10 separate legislative acts dealing with the protection of the environment (AbuZinada et al. 2004). The Fishing Exploitation and Protection of Live Aquatic Resources in the Territorial Waters of Saudi Arabia Act – 1987, the Wildlife Protected Areas Act – 1995 and the Environmental Code – 2002 are relevant to the marine

Map 14. Proposed Saudi Wildlife Commission Reservation Area for Tarut Bay

environment. There are prescribed prison sentences and fines for breaches of these acts (Evans and Abuleif, 2003). The National Coastal Zone Management Plan (NCZMP) is based on work undertaken by the PME and International Union for the Conservation of Natural Resources (IUCNR) in 1987 where Coastal Zone Management Programs were produced for the Red Sea and the Arabian Gulf (NCWCD, 2004). The plans were submitted for approval in 2003 (AbuZinada et al. 2004). The Gulf coastline has some of the most unique and productive habitats in the region and the Kingdom has appropriate legislation in place to protect it including a coastal setback policy of 400m (Royal Decree 1004 20/1/1419H) for

any new developments, and an approval process (Committee of Four - Royal Decree 982/M 15/9/1419H) for any projects (particularly land filling) in the coastal zone. This Committee of Four consists of the Ministry of Municipal and Rural Affairs, Coast Guard, PME, and Ministry of Agriculture.



Map 15. Proposed Saudi Wildlife Commission Conservation Reservations for the Eastern Province

7. Conclusions and conservation recommendations

This Chapter reports the rapid change from 1967 for the Arabian Gulf coastline of Saudi Arabia and highlights the development trends and land use changes until 2010 within the

coastal zone. This Chapter indicates areas where urgent additional conservation actions are now required to protect the remaining natural habitats and wildlife populations from continued impact resulting from rapid and hastening coastal development.

Serious consideration should be given to prevent coastal development for industrial purposes, and instead have this development moved inland with resources currently used for coastal landfill employed instead to create inland connective waterways. This would free up these productive and attractive coastal regions for conservation, recreational and managed tourism and residential land use. This would significantly enhance the quality of life for the residents of the Eastern Province.

Other areas of the coastline are also extremely important for wildlife, and these areas tend to be the more remote locations such as the Offshore islands and isolated coastal regions such as the Gulf of Salwa and Ras Abu Qamees. Wildlife populations flourish in these areas due to the lack of physical disturbance from human related activities and also due to the large areas of relatively undisturbed habitats. These remote nesting, roosting and refuge locations, coupled with an abundance of nearby foraging resources results in very large populations of marine mammal (dugong and dolphin), marine turtles and marine birds inhabiting and breeding each year in these areas. These populations are not only significant within the Kingdom, but are also of regional and international importance. With increasing human populations and increased development pressure on the coastal zone, these remote undisturbed areas are becoming smaller and geographically closer to human settlements, and eventually wildlife populations will have no remaining undisturbed wilderness areas in which to exist, and this will be a great loss for the Kingdom, particularly for its future generations.

The Kingdom of Saudi Arabia has good environmental strategies and legislation in place to protect the environment and these strategies and legislation only need to be effectively enforced. Changing public attitudes and behavior towards the environment is also a major objective that needs immediate attention with the development and implementation of environmental awareness and education programs aimed at all levels of society.

There are existing proposed conservation reservation areas along the Gulf coast (Maps 8 and 13) and these incorporate the remaining few natural regions of the Gulf coastal zone including Ras Abu Qamees, the Gulf of Salwa, Tarut Bay, the Jubail Embayment and the offshore coral islands (Map 15). These recommendations should be immediately reviewed and alterations made that ensure the conservation of these areas' biodiversity is guaranteed while at the same time promoting sustainable development and use by the areas' stakeholders. Conservation reservations do not have to exclude all other uses and activities, and in fact some hydrocarbon coastal reservation areas are testament to this, with these areas containing the greatest proportion of undisturbed coastline and intact habitats (e.g., mangroves) than many other areas along the Gulf coastline. Good environmental stewardship can allow nature conservation and sustainable development to flourish within the same geographical areas, it is really all about management of the area's natural resources to ensure that their inherent values are maintained and where possible enhanced. The earlier recommendations of the United Nations Environmental Program for Tarut Bay had this particular notion in mind when they nominated Tarut Bay as a Class V and VI reservation. This identified the Bay as a significant public use and amenity resource where traditional activities such as fishing could continue, and new developments that were in

keeping with the Bay's environmental uniqueness and values could be undertaken, with the collective goal of protecting this productive Bay for present and future generations.

8. Acknowledgements

We acknowledge the contribution to this paper by Abdullah Mah who assisted in identifying and quantifying remnant mangroves in the region; provided data on sabkha; and contributed to the discussion. Saudi Aramco is also acknowledged for its Environmental Protection Program and the dedication of its staff to protect, restore and establish ecosystems vital for the ongoing health of the environment.

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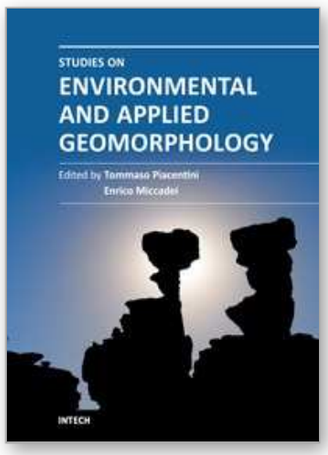

Studies on Environmental and Applied Geomorphology

Edited by Dr. Tommaso Piacentini

ISBN 978-953-51-0361-5
Hard cover, 294 pages
Publisher InTech
Published online 21, March, 2012
Published in print edition March, 2012

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How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Ronald A. Loughland, Khaled A. Al-Abdulkader, Alexander Wyllie and Bruce O. Burwell (2012). Anthropogenic Induced Geomorphological Change Along the Western Arabian Gulf Coast, Studies on Environmental and Applied Geomorphology, Dr. Tommaso Piacentini (Ed.), ISBN: 978-953-51-0361-5, InTech, Available from: http://www.intechopen.com/books/studies-on-environmental-and-applied-geomorphology/anthropological-induced-geomorphological-change-of-the-western-arabian-gulf-coast

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