3 Mangrove Forests of the Persian Gulf and the Gulf of Oman

Alireza Salehipour Milani

Abstract

Mangrove forests are found as isolated units of varying length and width along the coast line of the Persian Gulf and the Gulf of Oman. These forests are scattered within the intertidal and are among emergent plant communities occurring along land-sea margins in the Islamic Republic of Iran, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Oman and a small part of Pakistan in Govatr Bay. *Avicennia marina* and *Rhizophora* spp. are found in this region. Recently, as the effect of industrialization and development, as well as global environmental changes, concern about status, health, damage, disturbance and reducing mangrove area are a big challenge both for ecologists and engineers in these regions. Hence, producing mangrove map distributions and monitoring their change during the time is necessary. Mangrove habitat maps have been used for three general management applications: resource inventory, change detection, and the selection and inventory of aquaculture sites. This chapter quantifies mangrove forest cover and monitors their changes in the Persian Gulf and the Gulf of Oman from 1977 to 2017, using Landsat Thematic Mapper satellite imagery. The mangrove distribution maps are created by using remote sensing (RS) and Geographical Information Systems (GIS). An image processing technique entitled normalized differential vegetation index (NDVI) was used to detect mangrove forests in six countries located within the border study area. Even though the results show negative effects of human activity in some regions, overall, mangrove forests increased during 1977–2017. This increase in mangrove forests in the Persian Gulf and the Gulf of Oman represent sustainable development and management for mangrove ecosystems in this region.

A. S. Milani (✉)
Physical Geography Department, Earth Science Faculty, Shahid Beheshti University, Tehran, Islamic Republic of Iran
e-mail: Ar_salehipour@sbu.ac.ir

Keywords

Mangrove forest · The Persian Gulf and The Gulf of Oman · Coastal Management · Valnerability

3.1 Introduction

Coastal environments and the diverse ecosystems they support have attracted considerable attention within the natural resource management community in recent years. This is largely attributed to the rapid increase in coastal activities such as maritime commerce, rapid expansion in the population of coastal communities, and the worldwide growth in the exploration of near/on-shore petroleum mineral resources in the last few decades. The impact of these activities on coastal wetlands in many parts of the world is poorly understood, yet wetlands are among the most highly altered coastal ecosystems worldwide. Coastal wetlands are renowned for their rich fauna and flora biodiversity. They support unique plant ecosystems, including Mangrove forest stands. Mangroves are woody plants that are widely distributed in estuaries and intertidal zones in the tropics and subtropics regions (Field et al. 1998; Sherrod and McMillan 1985).

There are many benefits to mangrove communities that include serving as breeding grounds to many fish, shellfish, birds, and other wildlife; their physical stability helps to prevent shoreline erosion, providing protection to inland areas during hurricanes and tidal waves (Badola and Hussain 2005; Ewel et al. 1998; Quarto 2005; Stutzenbaker 1999).

Mangrove are largely confined to regions between 30° north and south of the equator. Notable extension beyond this area includes the subtropics and, in some cases, even warm temperate zones such as Bermuda (32° 20′N) and Japan (31° 22′N) to the north, and New Zealand (38° 03′S) and Australia (38° 45′S) to the south (Spalding et al. 1997; Gao 1999).

C. Makowski, C. W. Finkl (eds.), *Threats to Mangrove Forests*, Coastal Research Library 25,
https://doi.org/10.1007/978-3-319-73016-5_3

Coastal habitats across the world are under heavy population and development pressures, and are subjected to frequent storms. The continued decline of the forests is caused by conversion to agriculture, aquaculture, tourism, urban development and overexploitation (Alongi 2002; Giri et al. 2008). About 35% of mangroves were lost from 1980 to 2000 (MA 2005), and the forests have been declining at a faster rate than inland tropical forests and coral reefs (Duke et al. 2007). Relative sea-level rise could be the greatest threat to mangroves (Gilman et al. 2008). Predictions suggest that 30–40% of coastal wetlands (IPCC 2007) and 100% of mangrove forests (Duke et al. 2007) could be lost in the next 100 years if the present rate of loss continues.

As a consequence, important ecosystem goods and services (e.g. Natural barrier, carbon sequestration, biodiversity) provided by mangrove forests will be diminished or lost (Duke et al. 2007).

The world mangrove experts are of the opinion that the long-term survival of mangroves is at great risk due to fragmentation of the habitats and that the services offered by the mangroves may likely be totally lost within 100 years (Duke et al. 2007). Mangrove forests continue to disappear all over the world. They were estimated to cover 18.1 million km^2 worldwide (Spalding et al. 1997) but a more recent estimate indicates that the figure may now be below 15 million km^2 (www.fao.org/forestry/mangroves). With human populations increasing at an astonishing rate in coastal areas, it is crucial that additional and improved management practices and restoration programs are implemented throughout all mangrove-inhabited nations. According mangrove forest decline, Mapping and monitoring mangrove forests is an urgent need for many countries. Mangrove forests represent important ecological resources for the Persian Gulf and the Gulf of Oman countries, as well as worldwide. Large industrial and residential developments have happened in these regions during the last 40 years, affecting the mangrove communities. One of the earliest documented impacts on mangroves was the oil spill resulting from a pipeline breaking near the north-west shore of Tarut bay (Saudi Arabia) during a storm in April 1970 (Spooner 1970). Mangrove loss over time is mainly due to land conversion for shrimp cultivation and for infrastructure development, such as roads and harbors, to the excessive utilization for fuelwood and fodder, and over-grazing by camels.

This research investigates in more details the historical changes in the mangrove communities in these areas including Iran, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Oman Govatre bay in Pakistan. Using Remote Sensing and landsat image processing, providing an update on their current status by focusing on the 1987–2017 period and looking for potential causes and consequences of mangrove change since 1977.

3.1.1 Application of Remote Sensing for Mangrove Forests

The earth observation satellite data (such as Landsat) is useful for change detection applications. The distribution and abundance of mangrove in different regions of the world have been assessed with a variety of techniques. The local variability of studies spans all continents. Several studies have been carried out to investigate and compare the suitability of various classification algorithms for the spectral separation of mangrove. The main motivation for the characterization of these ecosystems are to monitor and manage them. Generally, all the remote sensing application in mangrove ecosystems can be categorized into three broad areas. These broad categories have been identified as resource inventory; change detection; and selection and inventory of aquaculture sites (Green et al. 2000; Vaiphasa et al. 2006). Change detection is a powerful tool to visualize, measure, and better to understand a trend in mangrove ecosystems. It enables the evaluation changes over a long period of time as well as the identification of sudden changes due to natural or dramatic anthropogenic impacts (for example: tsunami destruction or conversion to shrimp farms). Thus distribution, condition, and increase or decrease were the measured features used in the change-detection applications of mangrove.

Remote Sensing and GIS provide quantitative information on understanding the spatial distribution of mangrove forests (Sremongkontip et al. 2000). Remote sensing technology has been applied in various ways to characterize mangrove ecosystems. Some of the documented applications include mapping the area extent, detecting individual species, and providing estimates of structure and parameters such as leaf area, canopy height, and biomass (Heumann 2011). Remotely sensed data is one of the best source of information that can show the location of all areas that have been deforested or degraded or still healthy. Moreover, Landsat Thematic Mapper data can be used to define the degree of degradation of the mangrove forest (Giri 2008). In the field of vegetation mapping, especially the most commonly applied sensors include Landsat (mainly TM and ETM+), SPOT, MODIS, NOAA–AVHRR, IKONOS and QuickBird. But the most important satellite that used to vegetation indexes was Landsat sensor imagery.

Over the past decades, major steps have been taken toward estimating the amount of vegetation cover using Landsat sensor imagery (Hansen et al. 2002).

The Landsat might have the longest history and widest use for monitoring the earth from space. Since the first Landsat satellite was launched in 1972, a series of more sophisticated multispectral imaging sensors, named TM—Thematic Mapper, have been added ranging from Landsats 4 (1982), 5 (1984), 6 (1993, launch failed) to 7 (1999) (Enhanced Thematic Mapper Plus, ETM+). The Landsat TM and ETM + imaging sensors have archived millions of images with a nearly continuous record of global land surface data since its inception. Landsat 8 is an American Earth observation satellite launched on February 11, 2013. This sensor provides update satellite images and make possible detect and monitoring mangrove changes up to now. Because of this advantages Landsat sensor imagery used as one of the main resources in collecting spatial information for management and planning of land and natural ecosystems, digital satellite data have been greatly developed in the world over the past decade (Darvishsefat 1997). Several studies have been carried out worldwide to develop mangrove forest cover maps using various satellite images (Jensen et al. 1996; Kairo et al. 2002; Aschbacher et al. 1995; Vits and Tack 1995; Rasolofoharinoro et al. 1998; Ramsey and Jensen 1996; Green et al. 1998; Dahdouh-Guebas 2005; Tong et al. 2004; Kovacs et al. 2005).

3.1.1.1 Remote Sensing Methods in Mangrove Forest Detection

Spectral vegetation indices are frequently used to estimate vegetation biophysical/biochemical characteristics. In general, they have been proposed to reduce spectral effects caused by external factors such as the atmosphere and the soil background. A Vegetation Index (VI) is a spectral transformation of two or more bands designed to enhance the contribution of vegetation properties and allow reliable spatial and temporal inter-comparisons of terrestrial photosynthetic activity and canopy structural variations (Huete et al. 2000). There are many Vegetation Indices (VIs), with many being functionally equivalent. Many of the indices make use of the inverse relationship between red and near-infra red reflectance associated with healthy green vegetation. Since the 1960s scientists have used satellite remote sensing to monitor fluctuation in vegetation at the Earth's surface.

Vegetation Indices (VIs) have been historically classified based on a range of attributes, including the number of spectral bands (2 or greater than 2); the method of calculations (ratio or orthogonal), depending on the required objective; or by their historical development (classified as first-generation VIs or second-generation VIs) (Bannari et al. 1995).

For predicting leaf area index, five widely used vegetation indices were investigated. Narrow band vegetation indices involving all possible two band combinations of RVI, NDVI, PVI, TSAVI, and SAVI2 were computed.

The Perpendicular Vegetation Index (PVI)

The Perpendicular Vegetation Index (PVI) of Richardson and Wiegand (1977), used the red and near infrared bands to calculate the perpendicular distance between the vegetation spot on the NIR-Red scatterplot and the soil line. Since vegetation has higher near-infrared and lower red reflectance than the underlying soil, the vegetation spot will be on the top left corner of the scatterplot. As vegetation is increasing in density, the vegetation spot will be moving further towards the top left, away from the soil line. The PVI equation is expressed as the function of the slope and intercept of the vegetation images of the R and NIR band, and the soil images of the R and NIR band (Thiam and Eastmen 1999).

$$PVI = \sqrt{(\rho Gir, s - \rho Pir)^2 + (\rho Gr, s - \rho Pr)^2}$$

where ρr, s and ρir, s is reflectance of soil background in R and NIR bands, respectively; and ρr and ρir = reflectance of vegetation in R and NIR bands, respectively. PVI is determined using the distance between the intersection point (ρGir,s and ρGr,s) and the vegetation image pixel coordinate (ρPir and ρPr) by the Pythagorean Theorem.

Soil-Adjusted Vegetation Index (SAVI)

The weakness of the PVI is the assumption that there will be only one type of soil beneath the vegetation. However, this is not always the case, as there are environments where a mixture of soil types (a mixture of soil and rocks for example) can be found within a very small area. Huete (1988) proposed the Soil-Adjusted Vegetation Index (SAVI) to deal with this problem. SAVI is a hybrid between a ratio index (NDVI) and a perpendicular index (PVI). Its formula resembles the former:

$$SAVI = \left[(NIR - Red)/(NIR + Red + L))^* \; (1 + L)\right]$$

L is a correction factor and its value is dependent on the vegetation cover. For total vegetation cover it receives a value of zero, effectively turning SAVI into NDVI. For very low vegetation cover, it receives the value of 1. Huete (1988) suggested that the value of 0.5 is used when vegetation cover is unknown, as 0.5 represents intermediate vegetation cover. Other indices, such as the Transformed Soil-Adjusted Vegetation Index (TSAVI) (Baret et al. 1989) and Modified Soil-Adjusted Vegetation Index (MSAVI; Qi et al. 1994), followed similar rationale, but proposed different adjustment factors, that appeared to perform better than SAVI in certain cases. Additionally, specific vegetation indices have been proposed in the past, using high spectral resolution data (narrow bands) and looking specifically at chlorophyll and plant vigor. These include the Photochemical Reflectance Index (PRI) and the Normalized Pigment Chlorophyll Ratio Index (NPCI; Peñuelas et al. 1994), as well as the canopy chlorophyll content index (CCCI; Barnes et al. 2000).

The Normalized Difference Water Index

Following the same rationale as the NDVI, the Normalized Difference Water Index, employs the near-infrared band and a band in the short-wave infrared (SWIR) (Gao 1996). Instead of using the red band, the reflectance at which is affected by chlorophyll, a short-wave infrared band in the region between 1500 and 1750 nm is used instead, a region where water has high absorption. The near-infrared band is the same as with NDVI, as water does not absorb in this region of the electromagnetic spectrum.

The NDWI index is expressed with the following equation:

$$[\mathrm{NDWI} = (\mathrm{NIR} - \mathrm{SWIR})/(\mathrm{NIR} + \mathrm{SWIR})]$$

The black and white NDWI image on the right above represents the NDWI values for each pixel. As with the NDVI image, dark pixels have low values, white have high and gray have average. Notice that in the NDWI image the sea has high values, whereas for the NDVI image it appears dark. In general, it appears that all agricultural fields give high NDWI values, which suggests that the fields are adequality irrigated. Barren fields, appear dark in the NDWI image, which shows that those fields are drier, since they do not receive any irrigation.

Mangrove Plant Reflectance and Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is the most widely used vegetation index to distinguish healthy vegetation from others or from non-vegetated areas (Manandhar et al. 2009). Reflectance is the ratio of energy that is reflected from an object to the energy incident on the object. Spectral reflectance of a crop differs considerably in the near infrared region (λ = 700–1300 nm) and in the visible red range (λ = 550–700 nm) of the electromagnetic spectrum (Kumar and Silva 1973). Healthy plants absorb most of the visible light and reflect the large amount of the far-red and near-infrared light (Fluor Cam 2014). Plants generally have low reflectance in the blue and red portion of the spectrum because of chlorophyll absorption, with a slightly higher reflectance in the green, so plants appear green to our eyes. Near infrared radiant energy is strongly reflected from the plant surface and the amount of this reflectance is determined by the properties of the leaf tissues: their cellular structure and the air cell wall-protoplasm-chloroplast interfaces (Kumar and Silva 1973). These anatomical characteristics are affected by environmental factors such as soil moisture, nutrient status, soil salinity, and leaf stage (Ma et al. 2001). The most commonly used is the Normalized Difference Vegetation Index (NDVI). It relies upon differential reflectance of the mangrove canopy (which is always green) in the red wavelength (here the response is mostly determined by the absorption band by the chlorophyll) and in the NIR wavelength, where the response is the result of scattering determined by the cuticles of leaves and the density of the cover.

$$NDVI = \frac{NIR - VIS(red)}{IR + VIS(red)}$$

Couple of studies have been used NDVI index in to mangrove forests in Bangladesh (Emch and Peterson 2006) Taiwan (Tsai-Ming and Hui 2009), Mexico (Arturo et al. 2010), and Alabama (Rodgers et al. 2009).

This study attempted to assess the distribution and changes in the area of forests in the Persian Gulf and the Gulf of Oman using an integrative method combining NDVI. The results could be used as a model for future planning in landscape management and planning of mangrove forests in the Persian Gulf and the Gulf of Oman.

3.2 Discussion

3.2.1 Study Area

The study areas are the Persian Gulf and the Gulf of Oman. Mangrove forests are found as isolated units of varying length and width along the coast lines of this regions. These forests scattered in intertidal and emergent plant communities that occur along the land-sea margins Iran, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Oman and small parts of Pakistan in Govatre Bay.

The Persian Gulf is inland sea of some 251,000 km^2 (96,912 mi^2) is connected to the Gulf of Oman in the east by the Strait of Hormuz; and its western end is marked by the major river delta of the Arvand River, which carries the waters of the Euphrates and the Tigris and karoon. Its length is 989 km (615 mi), with Iran covering most of the northern coast and Saudi Arabia most of the southern coast. The Persian Gulf is about 56 km (35 mi) wide at its narrowest, in the Strait of Hormuz. The waters are overall very shallow, with a maximum depth of 90 m (295 ft) and an average depth of 50 m (164 ft). Countries with a coastline on the Persian Gulf are (clockwise, from the north): Iran, Oman's exclave Musandam; the United Arab Emirates; Saudi Arabia, Qatar, on a peninsula off the Saudi coast; Bahrain, on an island; Kuwait; and Iraq in the northwest. Various small islands also lie within the Persian Gulf.

The Persian Gulf presents stressful environmental conditions: extreme heat (>30 °C) in summer and cold (<10 °C) in winter (Khosravi 1992; Behrouzirad 1998; Zahed et al. 2010). Annual rainfall is less than 200 mm in north parts of the Persian Gulf and about 78 mm in Qatar in South of The Persian Gulf (Al Mamoon et al. 2016). The salinity of Persian Gulf is also high: between 38 and 50 g/L in mangrove area. Petroleum hydrocarbons are detectable in nearly all parts of the region. It is believed that *Avicenna marina* tolerance for temperature and salinity changes contributes to its being the dominant specie in Iranian mangrove forests and Persian Gulf.

The Gulf of Oman, are located in northwest of the Arabian Sea, between the eastern portion (Oman) of the Arabian Peninsula to the southwest and Iran to the north. The gulf is 200 mi (320 km) wide between Cape al-Ḥadd in Oman and Govatre Bay on the Pakistan–Iran border. It is 350 mi (560 km) long and connects with the Persian Gulf to the northwest through the Strait of Hormuz. Of the 45-mangrove species in the world, *Avicennia marina* is the most commonly found species in Oman (Nizwanet 2014) (Fig. 3.1).

3.2.2 Mangrove Forest Distributions

3.2.2.1 Iran

Mangrove forests in Iran are located in the coastal areas along intertidal zone as discrete or connected small and large communities. These forests are conceived as the western most mangrove forests in Southwest Asia. the highest mangrove distribution and extend of mangrove forests are find along 1250 km in Coastal Zone of Iran. Mangrove forests in Iran begin from the easternmost part of the border in the Oman Sea (Govatre Bay) and continues to the western parts of the Persian Gulf ending in Poozeh-Mashe area (Bushehr Province).

Iranian mangrove forests occur between 25°, 11′ and 27°, 52′, in the north part of the Persian Gulf and Oman Sea. The areas of maximum area Iranian mangrove forests are located between Khamir Port and northwest of Qeshm Island. The entire area of the Khouran Straits (including Qeshm Island and KHouran Rivers mouth) is protected under several international convention and reserves, Ramsar Site in 1975, UNESCO (MAB) Biosphere Reserve in 1976 and "Important Bird Area" (identification by Bird Life International in 1994) (Mahdavi 2001; Scott 1995; Shariatnegad 2005).

- Bushehr province
  Zone 1: In the Poozeh-Mashe area, vicinity the Mel-e-Gonze village and near of the Omolgarm Island, occurring south of the Bordekhoon area. Zone.
  Zone 2: In the Bardestan estuary, adjacent the Dayer harbor.
  Zone 3: In the Nayband Bay, occurring in the Assaluyeh and Basatin estuaries.
- Hormuzgan Province
  Zone 4: Within the confines of the Khamir estuaries and mouth of the Mehran River to the Persian Gulf.

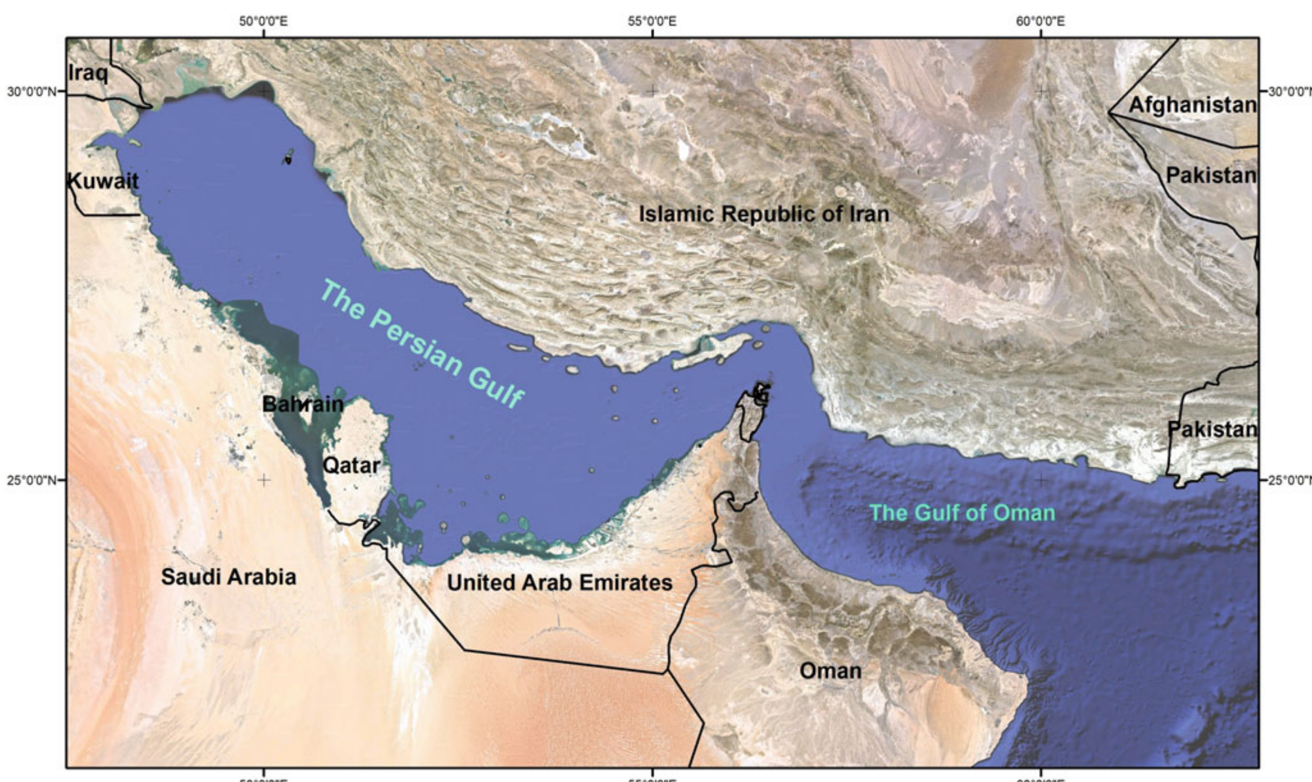


Fig. 3.1 The Persian Gulf and the Gulf of Oman study area (International Border in all maps do not have much accuracy)

Zone 5: Within the northwest estuaries of the Qeshm Island, in Khoor-e-Khooran and sandy Islands opposite villages of Tabl and Laft to Gooran (Harra Protected Area).

Zone 6: Close to the east of the Bandar Abbas, adjacent to the Kouleghan areas occurring within Jalabi and Hassan- Langi region and mouth of the Shoor River.

Zone 7: In the Tiyab and the Kolahi regions within estuaries of the Moshdar, Behine, Kargan, and the Minab.

Zone 8: In Sirik region, between the Gaz River and the Harra River (or Hiva River) occurring along 12 Km within estuaries of the Pachvar, Nakhl-e-Ziyarat, Garandhoo, Ziyarat, Ganari and the Kartan.

Zone 9: In Jask region, within the Gabrik and Jegin estuaries, the mouth of Shahr-e-Now River (in coast of the Lash village) and estuaries of the Yekdar, Surgolom and lagoons of the Kashi River and in part of the west of Jask, in area of ancient Jask city.

- Sistan and Balouchestan province

Zone 10: Chabahar Bay, East of Chabahar bay, Estuary of Shor River.

Zone 11: Within Govatr Bay, occurring in delta of the Bahookalat River – part of Gandoo Protected Area and Bahoo wetland (Behrouzi 1996, Danehkar 1998, 2001; Khosravi 1992) (Fig. 3.2).

Avicenna marina is the dominant specie within Iranian mangrove forests, as *Rhizophora mucronata* is found only in the Sirik region (Khosravi 1992; Danehkar 1996, 2001), *Rhizophora mucronata*. Macrunata trees occur in estuaries within the Sirik region (center part of the Tiyab Tiyab region) along the coasts of Garandhoo, Hookze, Badgard, Ganari, Ziyarat, Pachvar, Kartan, and Sorgolom villages (Danehkar 1994, 2001).

3.2.2.2 Pakistan

- Zone 12. During this research, mangrove forests in the Lura Region of Pakistan's Govatre Bay are also studied as mangroves of the Gulf of Oman Boundary.

3.2.2.3 Oman

Oman has a coastline stretch of 3165 km which had been perceived as entirely covered by mangroves long time ago. In Oman, Khawrs and mangroves are considered very special environments since they can be productive and valuable source for fish breeding and nursery areas in addition to their natural beauty for recreation. Mangrove vegetation is spread sporadically in the coastal areas of the country. Mangrove forests are scattered in Northern Batinah, Muscat, Eastern Sharqiyah, Mahawt Island and Salalah. It now covers

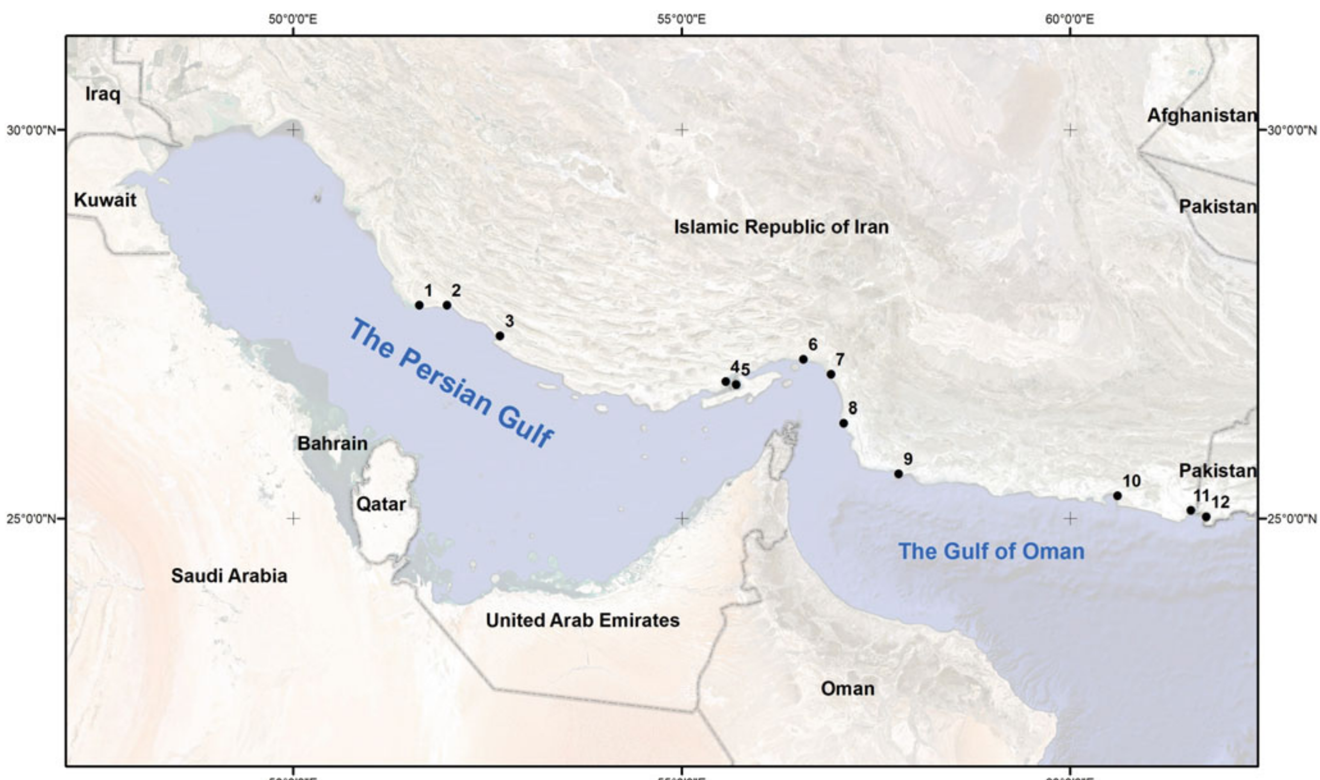


Fig. 3.2 Iran and Pakistan mangrove forest locations in the Persian Gulf and The Gulf of Oman

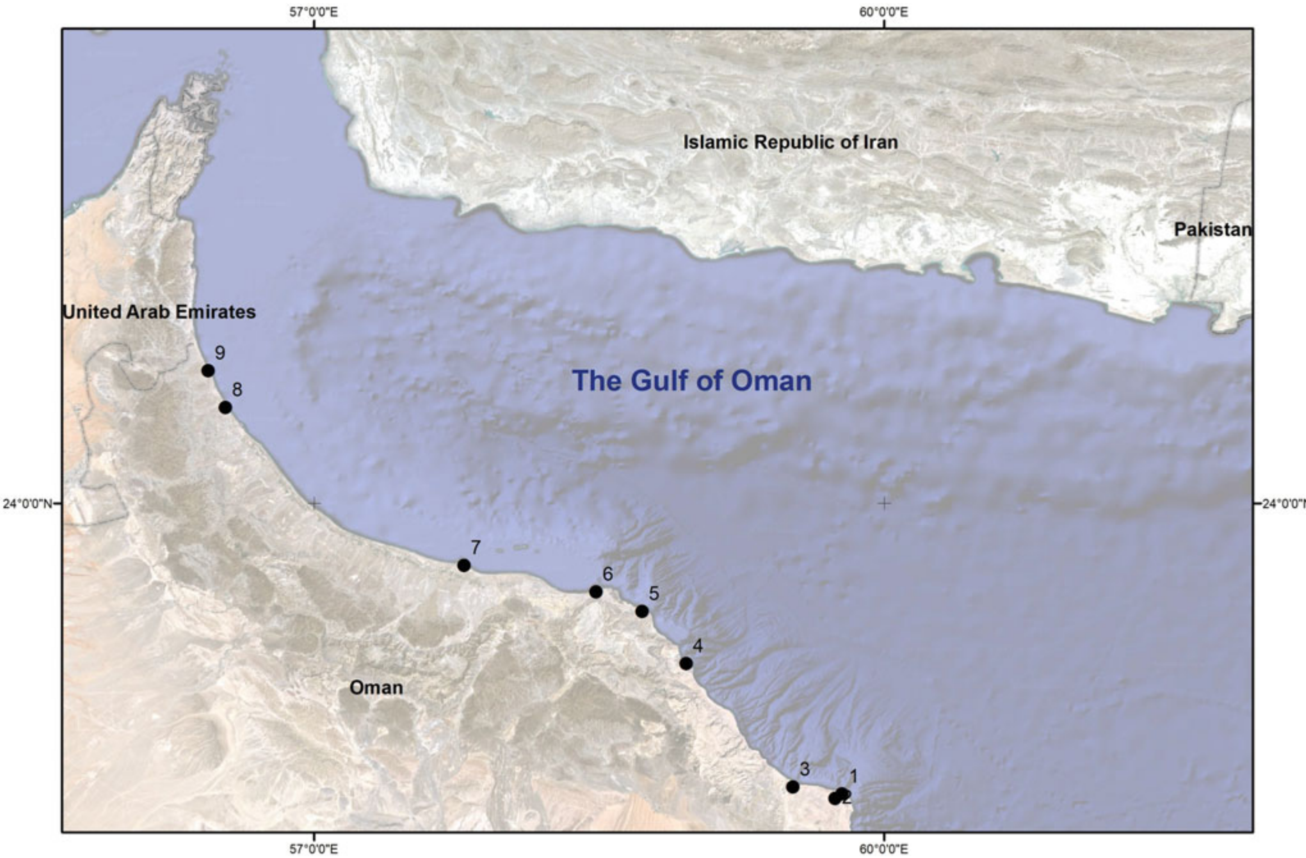


Fig. 3.3 Oman mangrove forest locations in The Gulf of Oman

a total of 1100 ha not only in The Gulf of Oman but also in Arabian Sea. There are few outstanding islands in Oman which include Dimaniyat, Masirah and KuriaMurai (Hallniyat). Except for Dimaniyat, all other islands are still in the proposal state to become protected areas (Directorate-General of Nature Conservation 2010). We found nine regions and enclose soundings that mangrove forest grew in it. All regions are located in intertidal channel from east to west including Zone 1 and 2 in Ras Al Hadd, 3; Sur, 4: Daghmar, 5: Khayran, 6: Dimaniyat, 7: Barka, 8: Liwa and 9: Shinas (Fig. 3.3).

3.2.2.4 United Arab Emirate

Mangrove forest area in the Emirates have natural and planted mangroves, which provide a rich natural habitat and safe breeding ground for several fish species, sea snakes, turtles and commercially important shrimp, snapper, grunt fish and sea bream. Sea birds also find safe nesting and egg laying areas in the vast mangrove forests. The average height of the trees found in Abu Dhabi is 3–5 m, and can reach up to a maximum of 8 m in some areas. Grey mangrove (*Avicennia marina*) is the only mangrove species that grows widely in the Emirates. However, the Environment Agency-Abu Dhabi (EAD) has succeeded in reintroducing the mangrove species (*Rhizophora mucronata*) which once grew in the Emirates and became extinct due to overexploitation. (EAD) has been able to cultivate a large number of these seedlings in the waters of Ras Ghanada Island after 100 years of its extinction. Besides, Mangrove National Park Located along the Eastern Ring Road, the Mangrove National Park, which opened its doors to the public on October 1, 2014, is the closest mangrove forest to Abu Dhabi City. there are vast areas of mangrove forests in Emirate, only kalba mangrove forests regions are located in the Gulf of Oman Coast (Zone 1), Other mangroves located in The Persian Gulf Coast including: Zone 2: Qurm, Zone 3 Mina Al Arab, Zone 4: Oum Al Quvain, Zone 5: Ajman,Zone 6: Ras Al Khor (Dubai), Zone 7: Ghanadah, Zone 8: Khorfarideh, Zone 9: Al Dhabeia, Zone 10: Al Aryam Island, 11: Al Dhabeia, Zone 12: Abu Al Abyadh Island,Zone13: Bu Tinah, Zone 14:L Al-Rawis and some little area enclosing these regions in The Emirate (Fig. 3.4).

3.2.2.5 Qatar

Qatar is home to the *Avicennia Marina* species; it is known as the grey or white mangrove trees, with the largest eight forests located in the east coast of the country. The oldest and largest mangroves can be found at Al Dhakira and Al

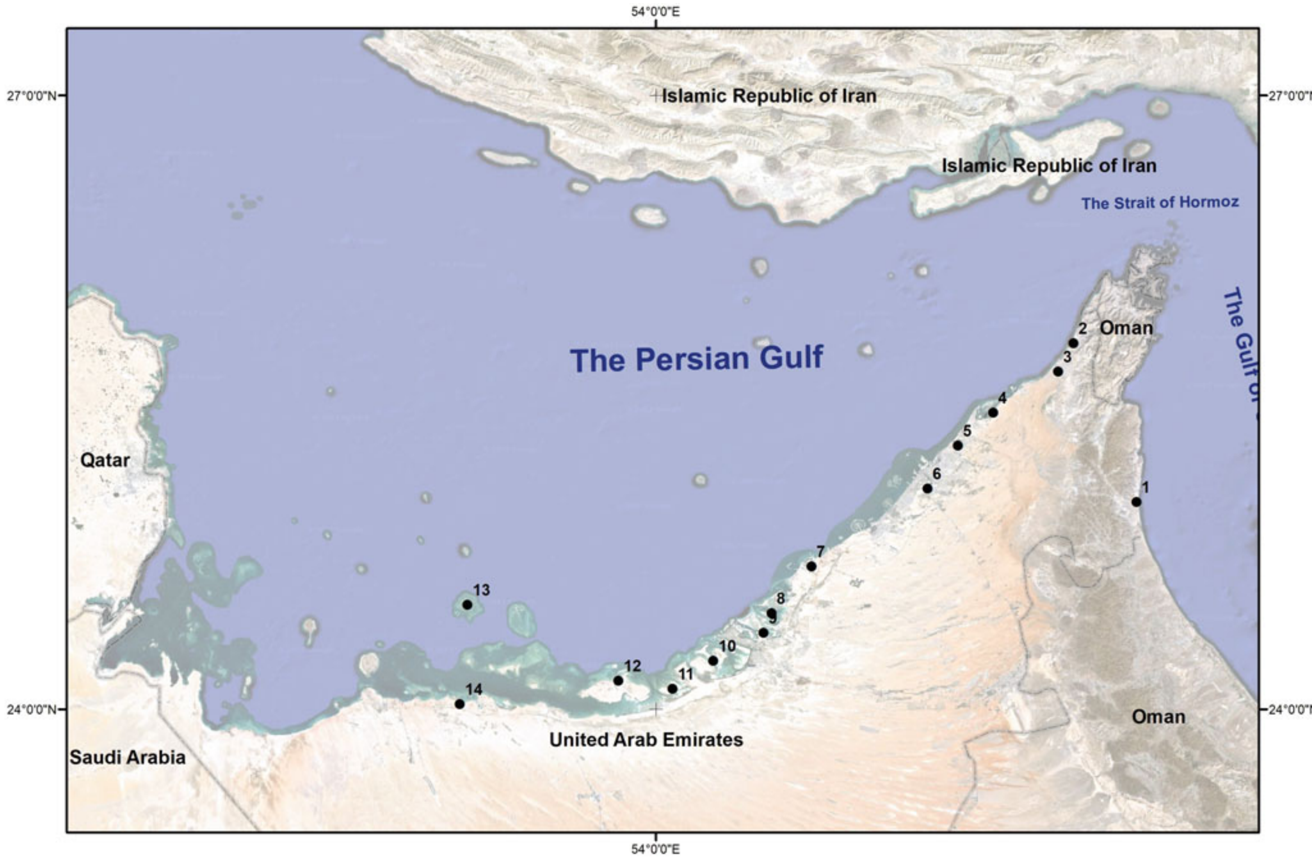


Fig. 3.4 United Arab Emirate mangrove forest locations in The Persian Gulf and The Gulf of Oman

Khor. A well-developed mangrove swamp stands around Al Dhakira and large population of resident and migrant birds reside in this area. *Avicennia marina*, the only mangrove species exists in Qatar. Along the northern and eastern coast of Qatar, mangrove vegetation was sparse and mixed with the salt marsh (Sabkha) frontier vegetation (Although the government have starting a replanting project around the country, the mangrove lake at Al Wakra was recently uprooted for development. In a country where the harsh desert conditions limit the vegetation growth, mangroves in Qatar provide a heaven for birds, fish and mammals. Recent studies have shown that *Avicennia Marina* populations have the ability to adapt to the varying weather along the Qatar coastline through the evolution of genetic variations in the different mangrove forests (Khader 2015) (Fig. 3.5).

3.2.2.6 Bahrain

There are three areas in Bahrain (so far) designated as Protected Areas; Mangroves at Ras Sanad (Tubli Bay), Hawar Islands and Al-Areen Wildlife Park. Tubli Bay is an inshore coastal area situated in the north-east of Bahrain. Manama, the capital city, lies north of the Bay. Tubli Bay is characterized by its unique ecology. It is one of the only sheltered, low-energy areas in Bahrain and rich ecologically. It provides an important coastal habitat. The main plant species that Tubli Bay is mostly recognized for are mangrove trees. The Bay (and closely surrounding areas) is the only place in Bahrain where these ecologically important species still survive. Only one type of mangrove species exists and that is known as the Black Mangrove; *Avicennia marina*. The protected mangrove reserve at Ras Sanad has a tree density of 100%. The highest mangrove tree was approximately 3.5 m tall. (Fig. 3.5).

3.2.2.7 Saudi Arabia

Saudi Arabia mangrove ecosystems along Persian Gulf are found in tiny patches in the North, on Jazeerat Qurma (which means Mangrove Island) and in the Damman area (Tarut Bay), where they form up well developed communities consisting of *Avicennia marina* (Fao 2005).

Tarut Bay are located in Northwestern of Bahrain (Fig. 3.5) is characterized by its heavy production and was reported (Czudek 2006) as the most important site on the Saudi area of The Persian Gulf Coast for wintering and migrating waders and other water birds, with a total of 58,000 water birds. The mangrove in Tarut Bay consists mainly *Avicennia marina*, which are capable of enduring extreme environmental conditions. These species are present

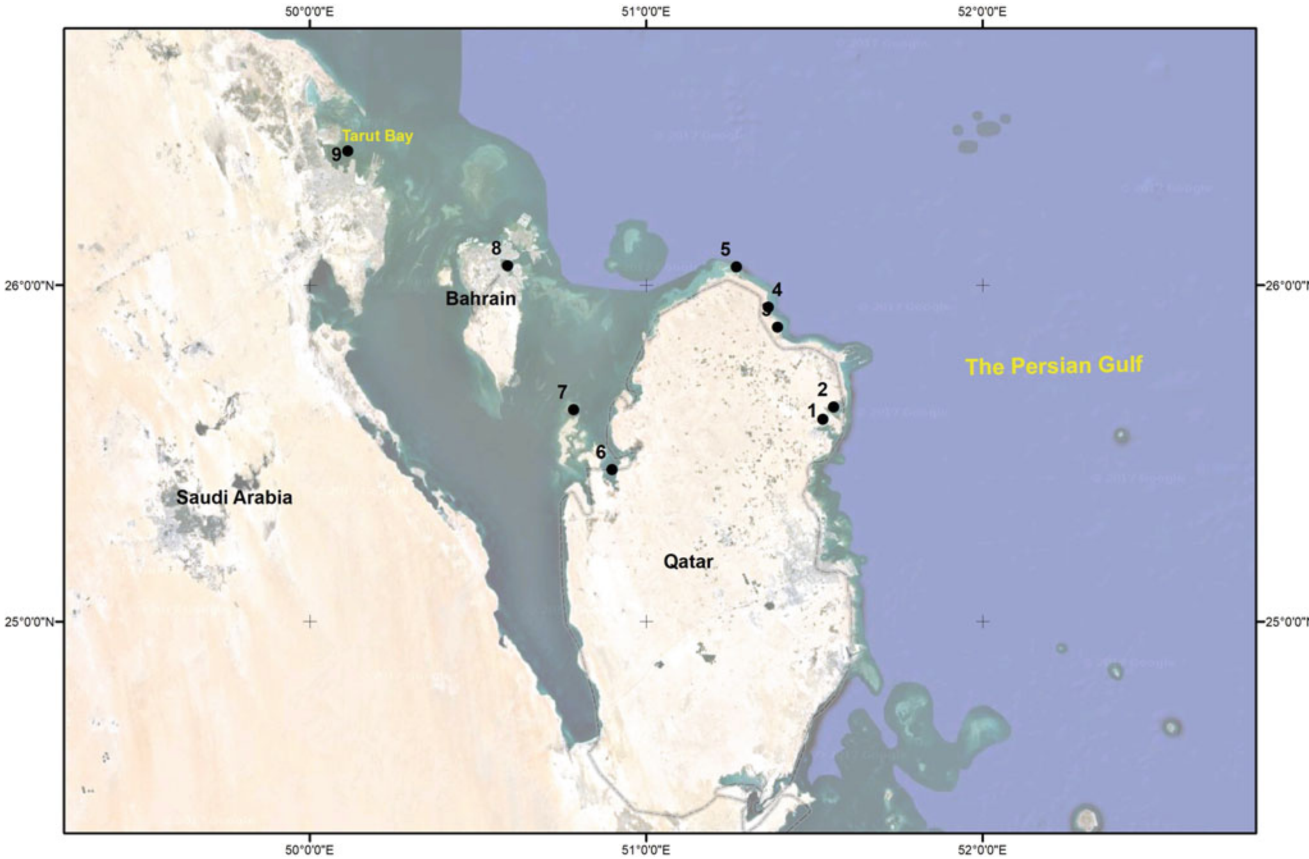


Fig. 3.5 Qatar mangrove forest locations 1: Al khor,2: Al Thakira,3: Sidriyat,4: Fuwayrit,5: Al Mafjar,6: Zekret and in Bahrain Country,6: Hawar Island and 7: Tubli Bay and 9: Tarut Bay in Saudi Arabia

in Tarut Bay in relatively higher density when compared to elsewhere in the world.

There are no native mangroves in Kuwait; several experimental plantations have been established since 1968 to study the adaptability and growth performance of *Avicennia marina*. However, the first relevant success was reached only in 2001 and mangroves are currently present in the localities of Shuwaikh, Doha, Sulaibhikhat and Sabiya (Samira 2004).

3.2.3 Mangrove Forest Threats in Study Area

The mangrove forests of study area in the Persian Gulf and the Gulf of Oman coast are remarkably tolerant to extreme environmental conditions and are highly productive (Field et al. 1998). Besides pollution through riverine inputs from adjacent countries (Iran, Iraq, Kuwait, Saudi Arabia, United Arab Emirate and the Emirates of Bahrain, Qatar and Oman), the Persian Gulf has been exposed to various additional contaminants as a consequence of marine transports, marine accidents in recent years. Industrial areas situated around the main ports on the coast are the main potential pollution sources. In the Persian Gulf mangroves have been principally affected by the large oil spill from the Persian Gulf War (1991) and even though they have mostly recovered from this event, oil pollution still represents one of the main threats. Camel grazing has been reported as another relevant threat, while shrimp aquaculture represents one of the emerging threats to this ecosystem.

In Iran, mangrove loss in some years was mainly due to land conversion for shrimp cultivation and for infrastructure development, such as roads and harbors, to the excessive utilization for fuelwood and fodder, and over-grazing by camels. On the other hand, some mangrove reforestation has been undertaken in the early 1990s (1991 and 1993) on around 400 ha in the coastal area of the Persian Gulf and of the Oman Sea for rehabilitation purposes.

Conversely many areas in emirates are increasingly threatened by oil and other kind of pollution. Landfill associated with urban and industrial development also threatened mangroves in many areas in United Arab Emirates.

In Saudi Arabia, mangroves have been principally affected by the large oil spill from the Persian Gulf War (1991), and even though they have mostly recovered from this event, oil pollution still represents one of the main threats in the country. Camel grazing has been reported as another relevant threat, especially at Khor Itwad in Saudi Arabia. Significant cutting has been reported in different sites, leading to reduction in tree density, abundance of multi-stemmed trees, and passages to the inner parts of the forests for the camels. Mangrove health is also compromised by the modifications of the coastal area topography, desertification and infilling caused by infrastructure development. Consequently, even if the area change over the last two decades may have been relatively small, several sites have been severely degraded and trees are suffering of a high mortality rate (Böer 2005; PERSGA/GEF 2004; Saenger 1993).

In Qatar, Mangrove use in this country is very small, although they are used in some areas as fodder for camels, goat and sheep, for fuel, and as stakes for fishing. These uses are probably decreasing in line with increasing wealth in the region. Conversely many areas are increasingly threatened by pollution, especially caused by oil, which is widespread in many areas of the Persian Gulf and Straits of Hormuz. Landfill associated with urban and industrial development also threatens mangroves in many areas (e.g. Al Khor and Al-Dhakirah) (Supreme Council for the Environment and Natural Reserves 2004).

Tubli Bay in Bahrain, location of the only remaining stand of mangroves in the country, is located in an urban and industrial area with high human pressure, such as land-fill and land reclamation for infrastructure development, uncontrolled fishing, sewage disposal and discharge. Oil spills, oil shipping and loading operations represent major threat to the wetlands. Ras Sanad mangroves were declared Wildlife Reserve in 1988 and reforestation activities were undertaken in order to restore former areas, but with limited success. Despite its protected status, the area is still under threat of damage.

In the Gulf of Oman there is very little human use of the mangroves, although they are used in areas as fodder for camels, for fuel, and as poles or stakes for fishing. These uses are probably decreasing in line with increasing wealth in the region. Conversely many areas are threatened by pollution, especially caused by oil and landfill associated with urban and industrial development. Natural regeneration and reforestation for environmental protection purposes seem to have balanced the loss of mangroves especially at Batinah, Sharquiya and Dhofar Regions. In addition some attempts of *Rhizophora stylosa* plantations have been made during the last 20 years on experimental plots in Qurm creek and near Salalah (Alkathiri 2004; Scott 1995; UNEP 1999).

Environmental conditions in Kuwait are dominated by harsh arid growing conditions, which do not advantage mangrove's growth. The soil and the sea salinity reach very high values and in addition to this the oil spill decrease mangrove's growth performance. During the Persian Gulf War in 1991, a large oil spill polluted over 700 km of coastline from southern Kuwait to Abu Ali Island, endangering most of local fauna and flora. Around 50% of the mangrove trees present at that time were affected by the oil and some 30% died off. However, restoration in these forests was quicker than expected and natural regeneration started just only 2 years after the impact. Nowadays only few dead trees remain to document that devastating oil spill (Barth 2001).

3.2.4 Mangrove Forest Change Detection in the Persian Gulf and the Gulf of Oman (1977–2017)

3.2.4.1 Methodology

In order to develop maps of mangrove extent over 40 years ago, all available Landsat images since 1977 were reviewed for quality, and cloud-free scenes selected for analysis. Landsat imageries in 1973, 1977, and Feb 2017 were collected from the USGS via the website. Most of Image acquisition date were in April. The Landsat Mss (1977), TM (1989), ETM+(2000) and OLI (2017) were used to monitor mangrove forests in the Gulf of Oman and The Persian Gulf. The Multispectral Scanner (MSS) sensor acquired imagery of the earth from July 1972 to January 1999 on board Landsats 1 through 5. Imagery collected during the first decade of these missions predates most other operational imaging efforts, providing a unique view of the earth not available elsewhere. These early missions also offered the first digital remote sensing products to the earth science community.

As the results of image acquisition, the date determined image quality. Complete list of the Landsat Multi-Spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) data used in this study is shown in Table 3.1. Thus, reflectance normalization was performed with a histogram matching model which was developed on 56 satellite images by using ERDAS IMAGINE.

Geometric correction of the imagery is required because raw satellite imagery usually contain geometric distortions. These distortions must be corrected before the satellite scenes can be used as a geographically accurate map. Geometric correction of the imagery is required because raw satellite imagery usually contain geometric distortions. These distortions must be corrected before the satellite scenes can be used as a geographically accurate map. Multiple images in to a single image. Color corrections were done via color balancing and histograms matching to make the images being mosaiced correspond. Spectral bands (Red and NIR) combination used in the calculation of NDVI has unique spectral characteristics for detection of stress vegetation. For example, red band is sensitive to changes in chlorophyll contents in the visible spectrum and NIR has a capacity to characterize vegetation varieties and conditions. The index has been successfully used for characterizing vegetation

Table 3.1 Satellite images were used in this study

S. No.	Date of images acquisition	Satellite	Sensors	Resolution (m)	Bands	Number of satellite images were process in study area for each country	Total satellite images
1	1977/4	Landsat4	Mss	80	4	Iran (7), Oman (2), Emirate (3) Qatar and Bahrain (2), Saudi Arabia (1)	15
2	1989/4	Landsat -5	TM	30	7	Iran (8), Oman (3), Emirate (3) Qatar and Bahrain (2), Saudi Arabia (1)	17
3	2000/4	Landsat 7	ETM	30	9	Iran (8), Oman (3), Emirate (3) Qatar and Bahrain (2), Saudi Arabia (1)	17
4	2017/4	Landsat -8	OLI/ TIRS	30	11	Iran (8), Oman (3), Emirate (3) Qatar and Bahrain (2), Saudi Arabia (1)	17

Table 3.2 Mangrove forest area and changes from 1977 to 2017 in the Persian Gulf and the Gulf of Oman

	Mangrove forest area (ha) in 1977	Mangrove forest area (ha) in 1989	Mangrove forest change (ha) 1977–1989	Mangrove forest area (ha) in 2000	Mangrove forest change (ha) 1989–2000	Mangrove forest area (ha) in 2017	Mangrove forest change (ha) 2000–2017	Mangrove forest change (ha) 1977–2017
Iran	4735	6052	1318	8015	1962	9403	1388	4667
Emirate	1327	1949	622	4777	2828	7926	3149	6599
Oman	206	153	−53	168	16	530	362	324
Saudi Arabia	97	107	10	146	39	837	691	740
Qatar	16	184	168	283	100	1002	719	986
Bahrain	31	25	−6	43	17	48	5	16
Total	6411	8470	2058	13,432	4962	19,746	6314	13,334

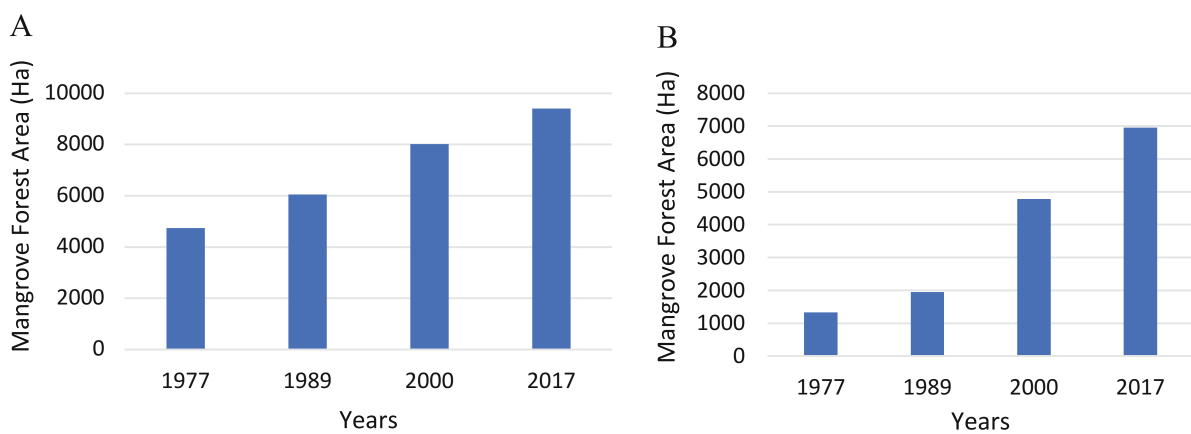


Fig. 3.6 Mangrove forest area change in Iran1977–2017. (**a**) Iran, (**b**) Emirates

cover and it is still considered a great potential for application in environmental monitoring because of it low cost compared to hyperspectral data.

3.2.4.2 Mangrove Forest Changes in Study Area (1977–2017)

Mangrove Forest in 1977

Multispectral scanners (MSS) onboard Landsat satellites 1–5 provide the earliest record of mangrove forests in the Persian Gulf and the Gulf of Oman. In this research, we use MSS image data in April and march 1977 in study area, totally 15 satellite Images used to detection, mangrove forest distribution. Area of mangrove forests in Iran were about 4735 ha (47.3 km (Table 3.2, Fig. 3.6a). maximum coverage of mangrove forest area in Iran are located in Zone 4: Within of the Khamir estuaries and 5: northwest estuaries of the Qeshm Island (Harra Protected Area). In this area of mangrove forests are about 3744.15 ha (37.4 km^2). This area (Qeshm Island) is the biggest community of the mangrove forests in the Persian Gulf and the Gulf of Oman.

In Oman Country in 1977, area of mangrove forests was about 206 ha (2.06 km^2), and maximum area belongs to Zone

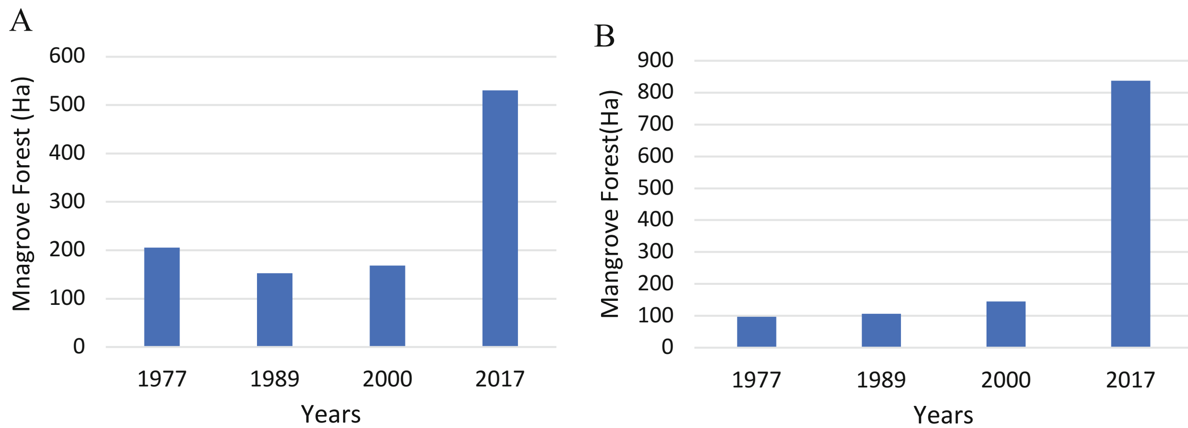


Fig. 3.7 Mangrove forest area changes 1977–2017, (**a**) Oman, (**b**) Saudi Arabia

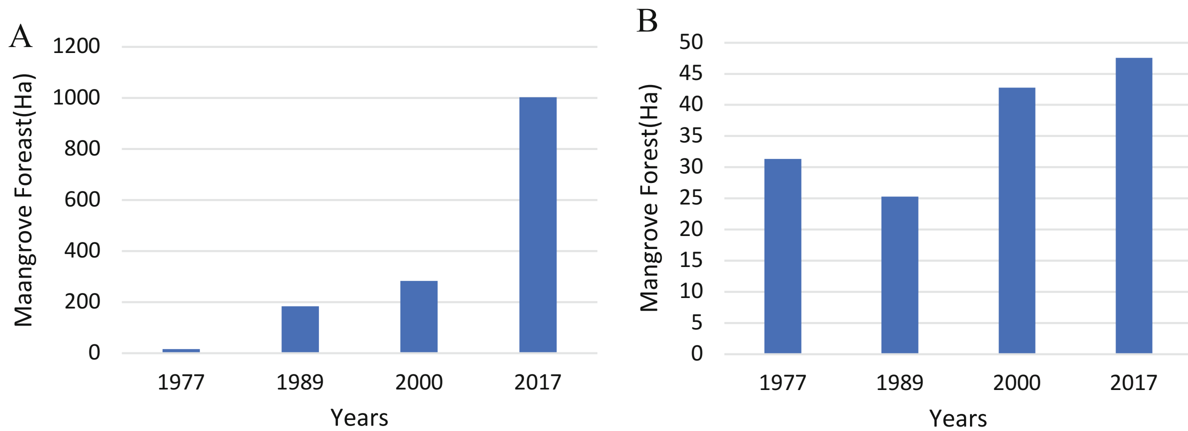


Fig. 3.8 Mangrove forest area changes 1977–2017, (**a**) Qatar, (**b**) Bahrain

5; Khayran Estuary with15 ha (0.15 km^2) and Qurm Bay (Table 3.2, Fig. 3.7a).

United Arab Emirate has about 1327 ha (13.14 km^2) in 1977. After Iran, this country has maximum distribution and area of mangrove forest in the study area. Al Dhabeia estuary near Abu Dhabi has maximum mangrove forests area 203 ha (2.03 km^2) in this country (Table 3.2, Fig. 3.6b).

In Qatar satellite can detect about 16-ha (0.16 km^2) mangrove forest especially in al Dhakira and al Khor in eats part of this peninsula (Table 3.2, Fig. 3.8a) In Bahrain, there were about 31 ha (0.03 km^2) in Howar Island and Tubil Bay (Table 3.2, Fig. 3.8b).

In this research, we can detect about 100 ha (1 km^2) in Tarut Bay in Saudi Arabia (Table 3.2, Fig. 3.7b). Total mangrove forest area within these years in the Persian Gulf and the Gulf of Oman was about 6411 ha (64.11 km^2) (Table 3.2, Fig. 3.9).

Mangrove Forest in 1989

NDVI processing on TM Satellite images on 1989 in study area indicated, the mangrove forests cover increased during 1977–1989, in study area and reached 8470 ha (84.70 km$^{2)}$. (Table 3.2, Fig. 3.9). The mangrove forests of Iran increased by 27.8% (1318 ha, 13.18 km^2) and reach to 6052 ha (60.52 km^2) from 1977 to 1989 (Table 3.2, Fig. 3.6a). In Qeshm Island (Zone 4 and 5) area of mangrove forest increased about 1120 ha (11.2 km^2) and developed more than 30% compare to 1977 (Fig. 3.10a). But the highest increase in percentage found in Govatre bay (Zone 11 and 12(in Pakistan Border). Images processing indicate mangrove forests in this bay increase from 77 ha in 1977 to 252 ha in 1989 and shows 326% increase in area of mangrove forest during these times. However, in some mangrove forest area including Zone 11 mangrove forests decrease.

In Oman mangrove forest area decrease about 53 ha and (26%) during 1977–1989. In 1990 mangrove forest reach to 153 ha (1.53 km^2) while in 1977 area of mangrove forests in

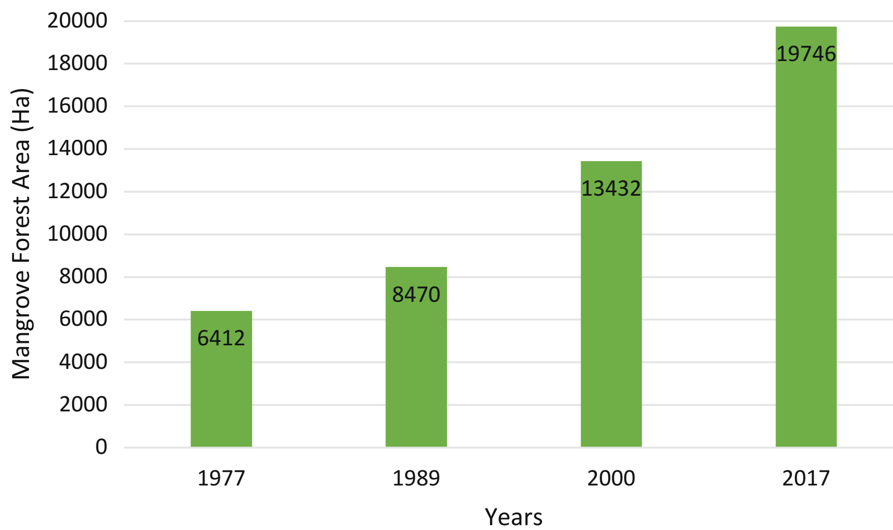


Fig. 3.9 Mangrove forest changes in The Persian Gulf and the Gulf of Oman 1977–2017

this country was 206.6 ha (2.06 km) (Table 3.2) but in some regions, like as Qurm Bay in mangrove forests increase during these times (Fig. 3.11a).

Satellite images present Mangrove forest area in United Arab Emirate increased from1977 to 1989 especially in Abu Dhabi region (Fig. 3.12a). During this time about 622 ha (46%) mangrove forest develop in this country and area of this forests increase to 1949 ha (1224 ha in 1977).

The maximum increase percentage of mangrove forests between countries of study area belongs to Qatar. Area of Qatar's mangrove forests in 1989 was about 183 ha (1.83 km^2), while in 1977 we detect just 16 ha and shows 168 ha (1052%) increase in mangrove forests in this country especially in Al Dhakira Bay (Fig. 3.13a).

Mangrove forests decrease from 31 ha in 1977 to 25 ha from 1977 to 1989 in this country especially in Tubli Bay. In Saudi Arabia (Tarut Bay) mangrove forest in 1989 reach to 107 ha (1.07 km^2) and shows increase about 10 ha during this time (Fig. 3.14a).

Mangrove Forest in 2000

At this time, same as early period (1977–1989), ETM satellite images processing indicate increasing mangrove forests in the Persian Gulf and the Gulf of Oman in all countries mentioned. Mangrove forests increased during this time about 4692 ha (46.92 km^2) and reached an overall area of 13,432 ha (134.3 km^2), which showed about 59% increase compared to before 1989 (Table 3.2, Fig. 3.9).

Area of Mangrove forests in Iran rose about 1962 ha (19.62km^2) between 1989 and 2000 and reached 8015 ha (80.15 km^2). All mangrove forests zones showed increases in Iran especially in Zone 6 (north of Striate of Hormoz and Govatre Bay) and Zones 11 and 12 (Pakistan Border) (Fig. 3.6a).

NDVI analysis in Oman showed about a 10% increase (16 ha) in mangrove forests compared to before 1989. The area of mangrove forests in 2000 was about 168 ha (1.68 km^2) and the maximum concentration of mangrove forests was located in the Quriyat area (Table 3.2, Fig. 3.7a).

Maximum increase in mangrove forests between all countries in the study area belongs to Emirates. Area of these forests increased about 2828 ha (28.28 km^2) between 1989 and 2000, about 145% increase when compared to before 1989. During this time, mangrove forests in the Emirates was about 4747 ha (47.47 km^2). Mangrove forests increases were about 39 ha in Saudi Arabia's Tarut and Aldaid regions (South of Qatar; Total Area 146 ha), 17 ha in Bahrain (Tubli bay and Howar Island; Total Area 43 ha), and 100 ha in Qatar, especially in Al Dhakira (Total Area 283 ha) (Table 3.2, Figs. 3.7b and 3.8a, b).

Mangrove Forest in 2017

According to NDVI analysis on OLI8 Landsat images for mangrove forest distribution and area in the Persian Gulf and the Gulf of Oman in April 2017, area of this forest increased from 2000 to 2017. Mangrove forest area in this year in study area was about 19,746 ha (197.46 km^2), which indicated a 6314 ha (64.14 km^2) increase from 17 years ago.

Mangrove forests in Iran at this time are about 9402 ha (94.02 km^2) and increased about 1388 ha (13.88 km^2) (Fig. 3.6a). Maximum increase in mangrove forest of Iran during this time belongs to Qeshm Island (Fig. 3.10b).

Mangrove forests in Oman also increased about 362 ha (3.62 km^2) and in 2017, the area of mangrove forests in this country was about 530 ha (5.30 km^2) (Fig. 3.7a). Qurm Bay is an example of this increase (Fig. 3.11b).

The maximum increase in mangrove forest area between countries of the Persian Gulf and the Gulf of Oman from 2000 to 2017 belongs to Emirates with 3149 ha (31.49 km^2). The area of mangrove forests in the Emirates in 2017 reached about 7926 ha (79.26 km^2) (Table 3.2, Figs. 3.6b and 3.12b).

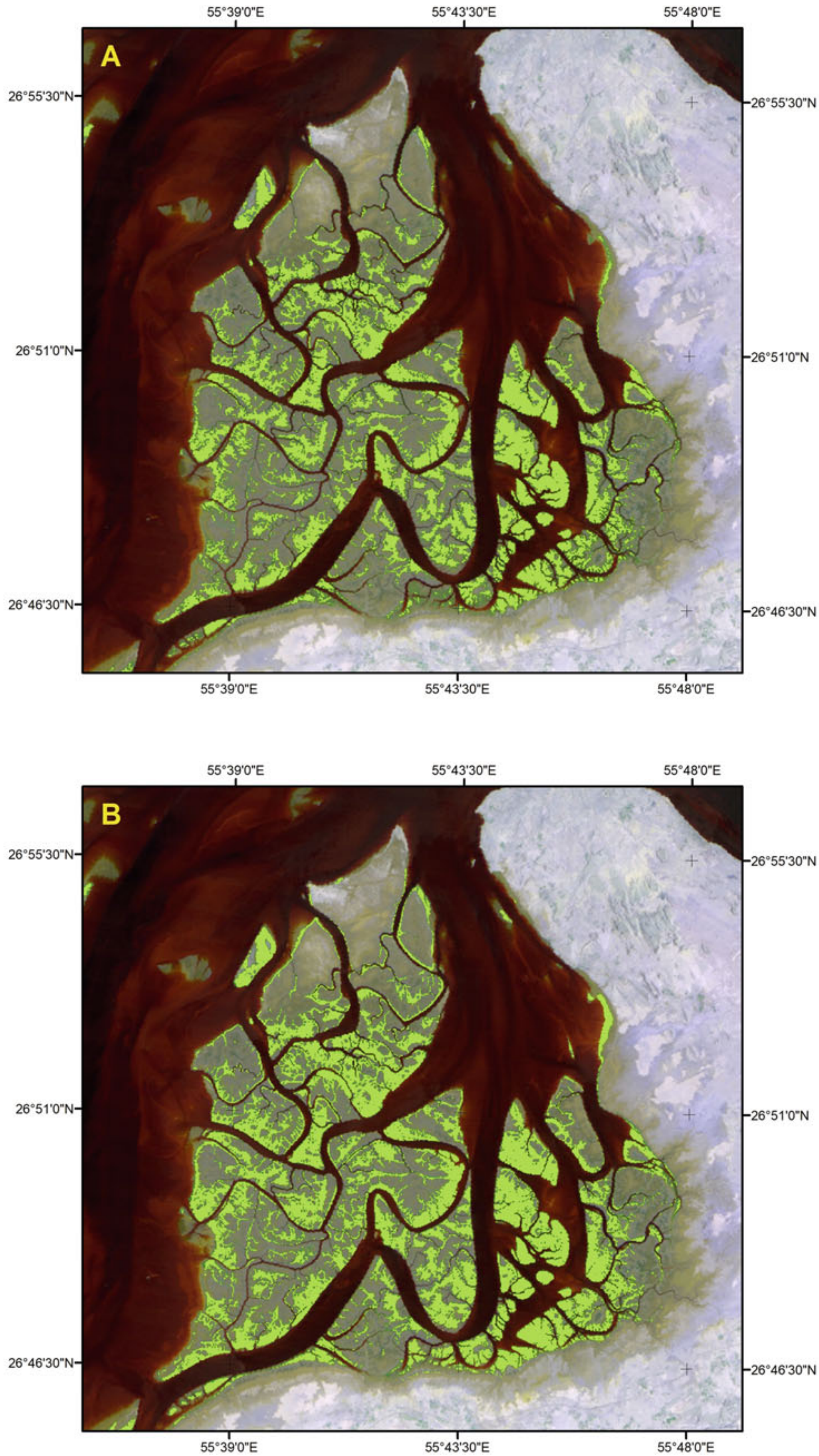
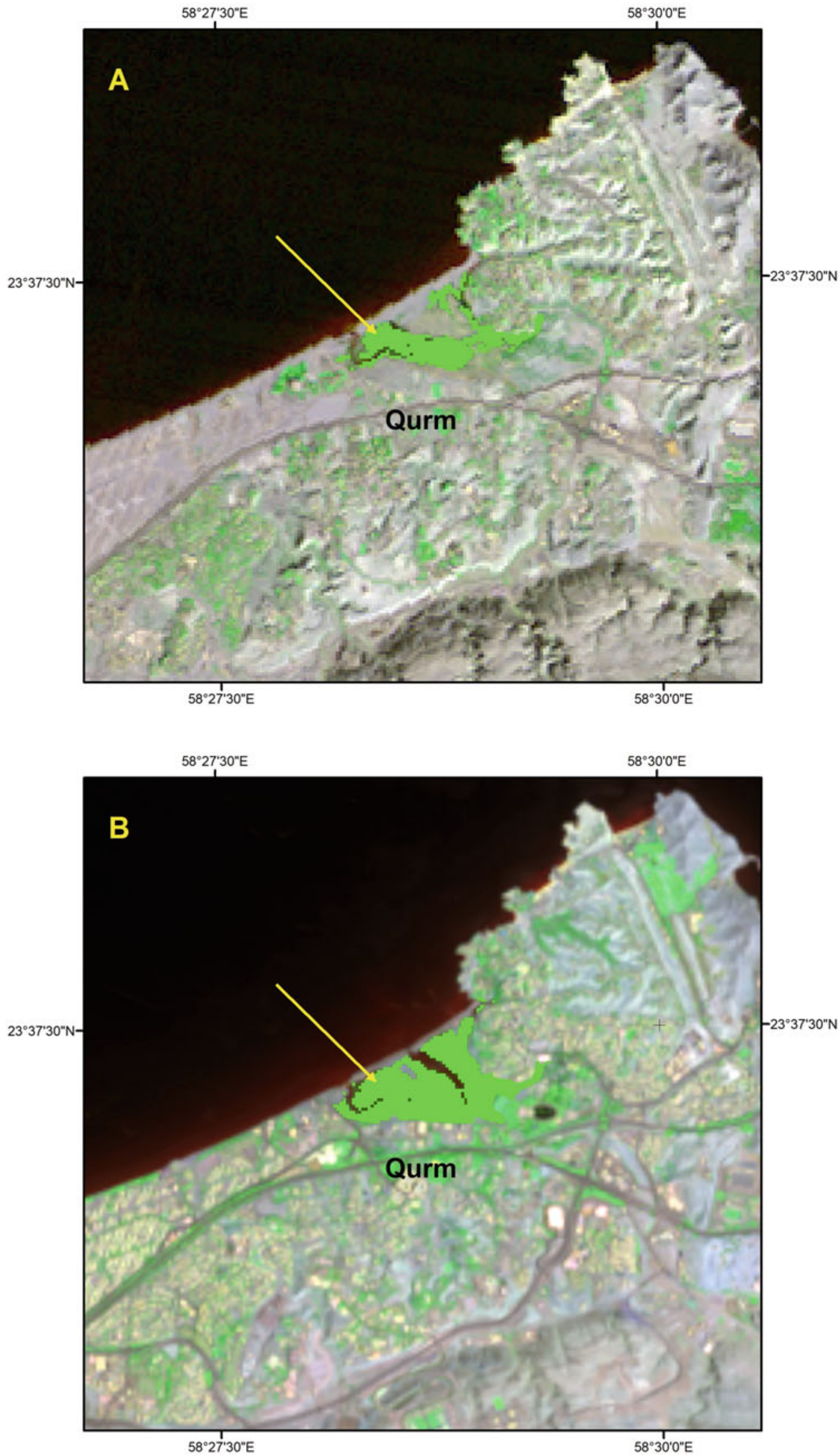


Fig. 3.10 Mangrove forests changes in Qesham Island in Iran, (**a**) 1989, (**b**) 2017

Fig. 3.11 Mangrove forests changes in Qurm region in Oman, (**a**) 1989, (**b**) 2017



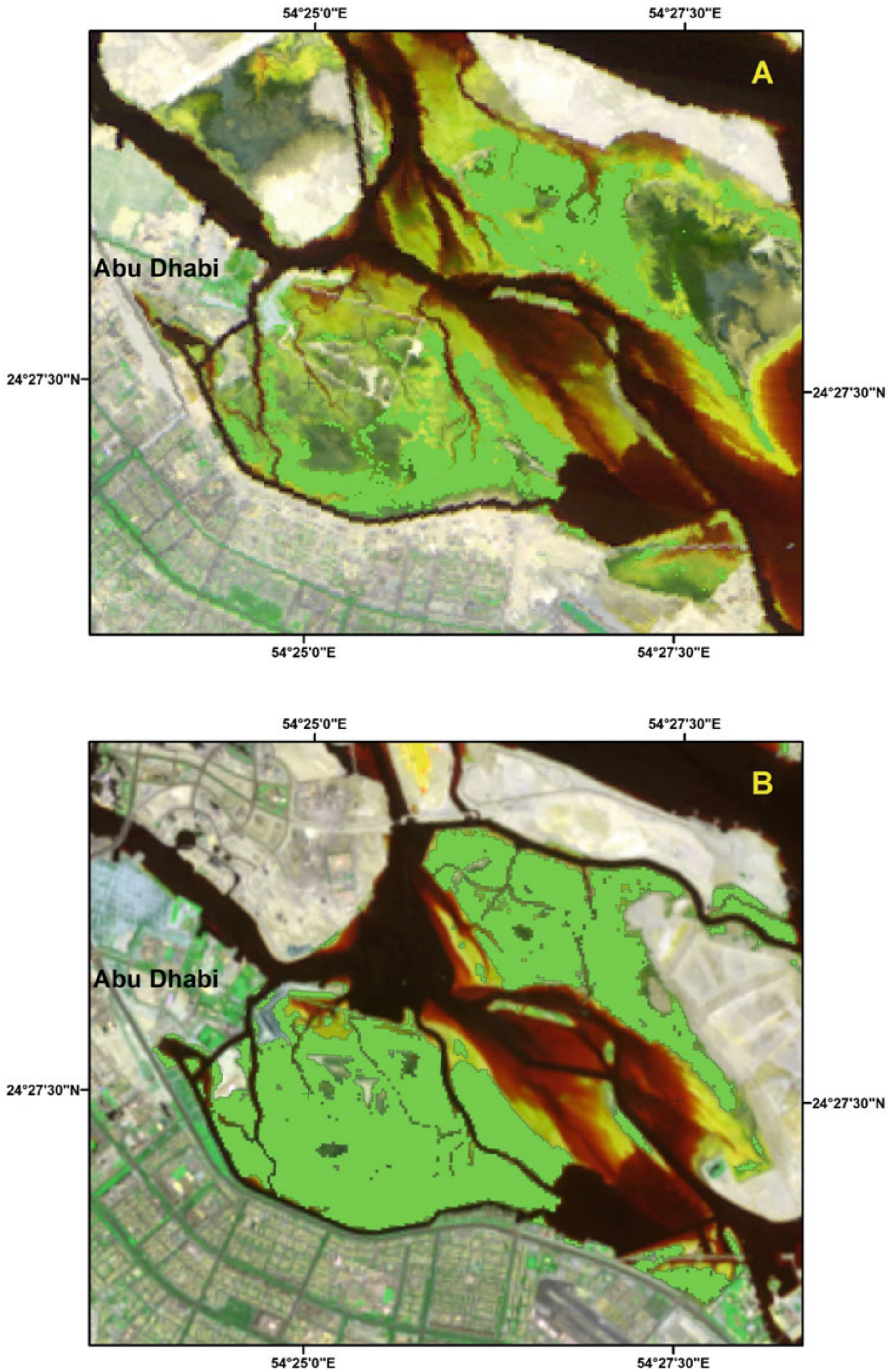


Fig. 3.12 Mangrove forests changes in Abu Dhabi, Emirates (**a**) 1989, (**b**) 2017

However, we can also see increasing mangrove forests in other countries. In Qatar, the area of mangrove forests increased about 719 ha (7.19 km^2) and reached about 1002 ha (10 km^2) (Table 3.2, Figs. 3.8a and 3.13b). Mangrove forests in Bahrain in 2017 was about 48 ha (0.48 km^2) and increased about 5 ha from 2000 to 2017 (Table 3.2, Fig. 3.8b). In Saudi Arabia, Tarut and Aldaid (South of Qatar) recorded total mangrove forests in 2017 of about 837 ha (8.37 km^2), an increase of about 691 ha (6.91 km^2) during this time (Table 3.2, Figs. 3.7b and 3.14b).

Table 3.2 and Fig. 3.9 indicate mangrove forest and their changes in the Persian Gulf and the Gulf of Oman between

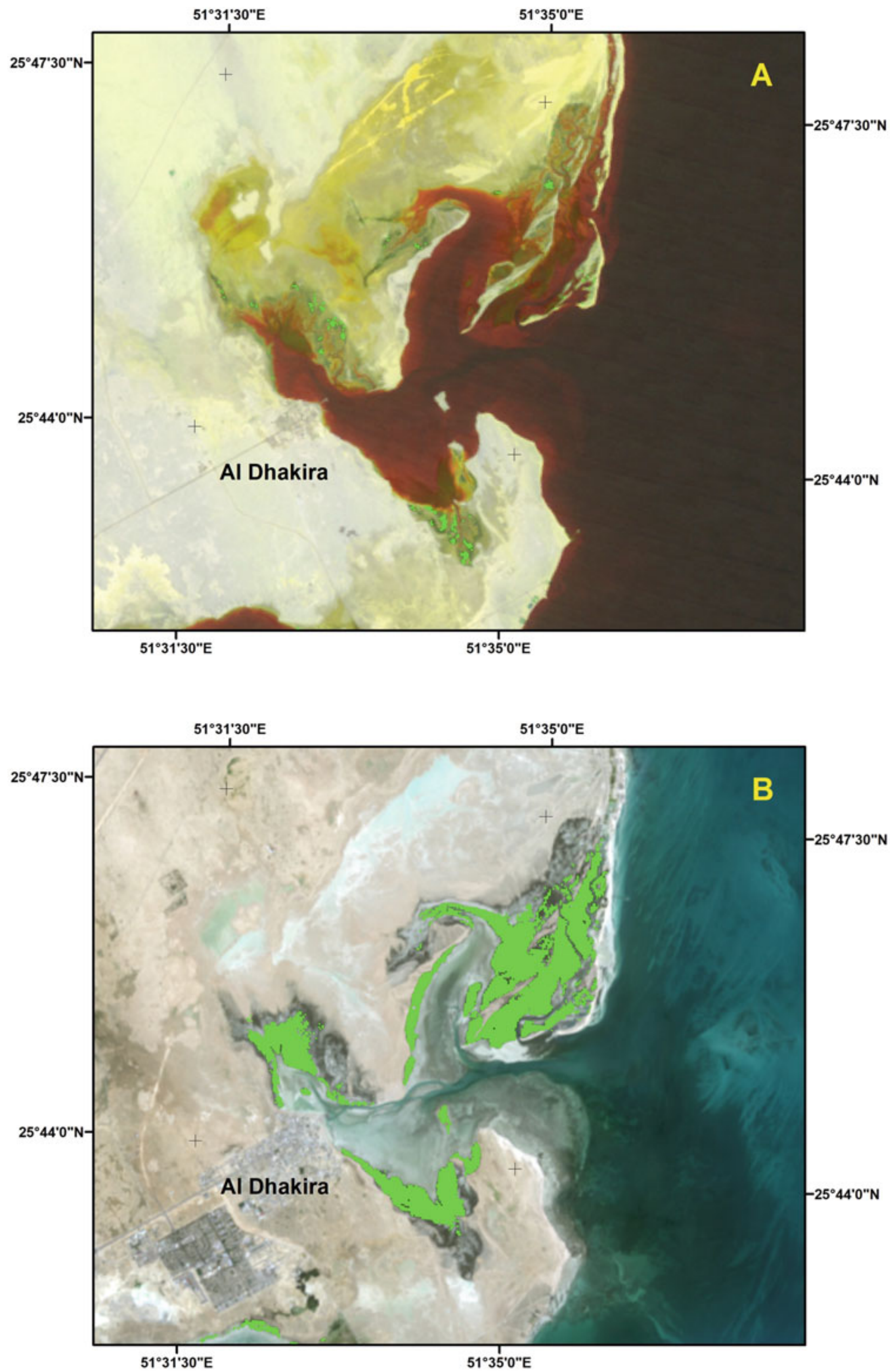


Fig. 3.13 Mangrove forests changes Al Dhakira, Qatar. (**a**) 1989, (**b**) 2017

1977 and 2017. Mangrove forests in developed and increased during the time. While in some region and some years we are faced to decrease mangrove forest, but dominate trend are increasing. In 1977, the area of mangrove forest within the study area was about 6411 ha (64.1 km^2) and about 40 years later this area increased about 13,334 ha (133.34 km^2) to approximately 19,746 ha (197.5 km^2). This study indicates mangrove forests in the study area increase about 203% from 1977 to 2017 (Table 3.2 and Fig. 3.9).

Maximum increase in mangrove forests area from 1977 to 2017 belongs to Emirates (6599 ha), followed by Iran (46.67 ha). However, we should also answer this question:

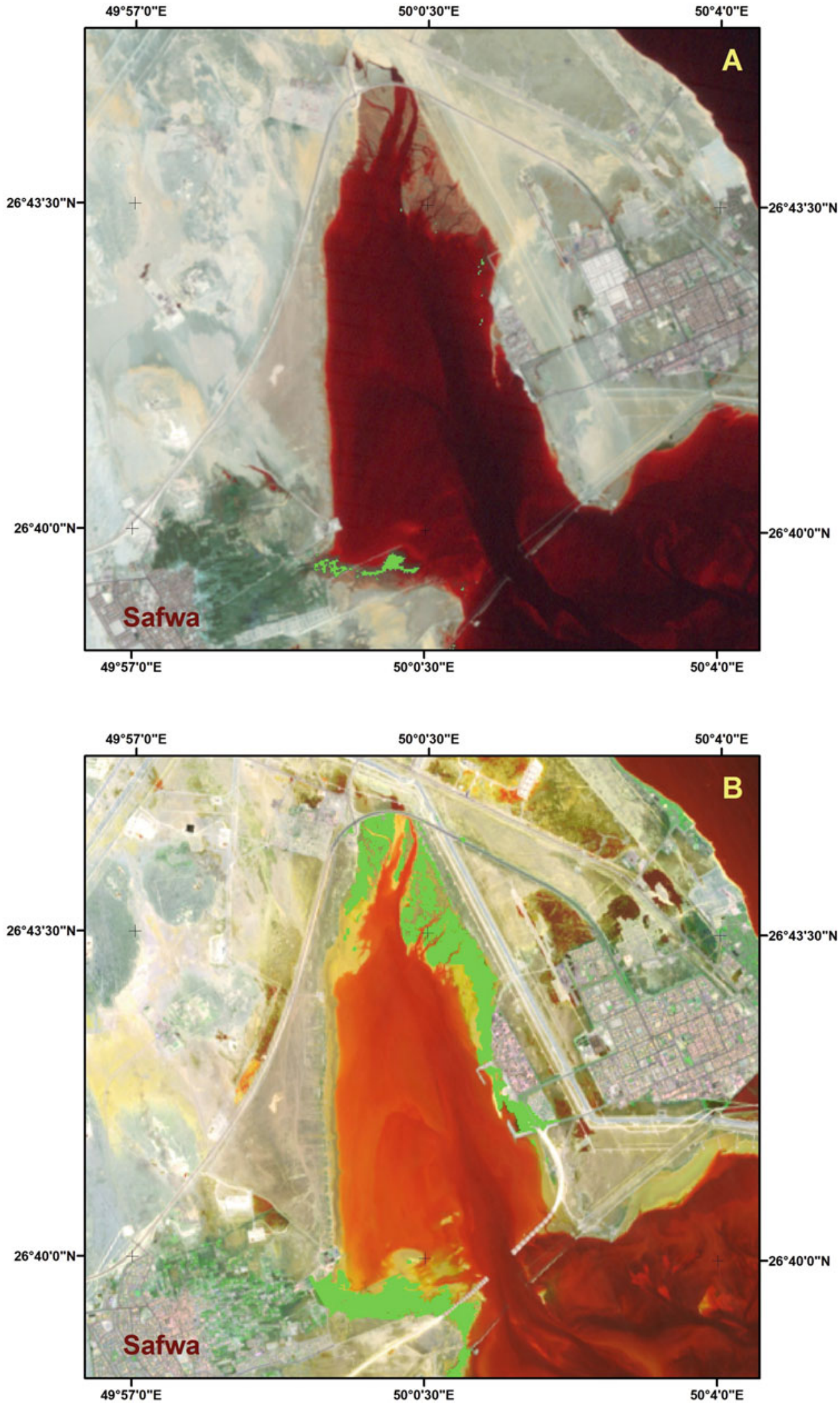


Fig. 3.14 Mangrove forests changes in North part of Tarut Bay, Saudi Arabia. (**a**) 1989, (**b**) 2017

What is the reason of this increase in mangrove forest area in the Persian Gulf and the Gulf of Oman? One of the main reasons for the positive development of mangrove forests in study area could be extensive forest management and conservation programs launched in these regions.

3.2.5 Mangrove Forest Management and Conservation Programs in the Persian Gulf and the Gulf of Oman Countries

3.2.5.1 Iran

Iran has areas of mangrove forest in the Persian Gulf and the Gulf of Oman. Mangrove forest plantation and developments in Iran started in 1914. Afforestation in Iran has its roots in traditional and national customs, and in the religious beliefs of Iran's people. With the growth of civilization in Iran, people began to plant trees for different purposes. Therefore, tree planting has a long history in Iran. The first modern afforestation was conducted with the planting of a mangrove species, *Rhizophora mucronata*, on the southern coasts in 1914–1918 during World War (Ajorlo 2003).

Developments of mangrove forests in southern Iran is one of the goals of the forests service. Recently, conservation of fragile ecosystems in dry, sub-dry and sub-humid areas is specifically taken into consideration and restoration of these ecosystems is given high priority in executive programs. For instance, some degraded mangrove forests are rehabilitated in recent years. Forests, rangelands and watershed organization of Iran have improved the mangrove plantation in south coasts of Iran in Bushehr, Hormozgan and Sistan and Baluchistan provinces to increase the socio-eco-environmental products of mangrove habitat. For example, the mangrove plantation around Qeshm Island has been established to develop those above-mentioned objectives. There is large area with potential for expansion of mangrove forests stands, for example total area of present mangrove in Hormozgan provinces is almost 12,500 ha, but swamps and tidal flat in this province amount to 28,000 ha. Within 3 years (2005–2007), more than three million seedlings of *Avicennia marina* trees have been produces and planted in Hormozgan Provinces only (Safiari and Nasouri 2009).

3.2.5.2 Oman

In Oman, mangrove forest area decreased from 206 to 153 ha (53 ha, 26%) from 1977 to 1989. The area of mangrove forest has been decreased due to the damages by the inhabitant to be used as fuel wood and overgrazing during long period of time. However, Mangrove was planted in Oman at various times from 1983 to 1985, however they did not produce concrete results. The reason they did not succeed is the lack of experience on technical knowledge and skill for mangrove afforestation (MRMEWR 2004). However extensive program called 'mangrove afforestation' have launched (MECA 2010). According to this program was undertaken on local use of mangroves and threat to the ecosystems. This program provided the basis for development of a conservation strategy and detailed information along with site-specific management measures, including protection, development of mangrove nursery and the provision of facilities for recreation as well as environmental education. Based on this program, considering the special value of mangroves in coastal environments in Oman, the Ministry of Regional Municipalities and Water Resources (MRMWR) and Ministry of Environment and Climate Affairs (MECA) have launched 'mangrove afforestation' program (MECA 2010). Nowadays there are 12 existing marine protected areas covering a range of environment, species which provide great opportunities for research as well as management. According to IUCN (1986, 1989) these marine protected areas are studied with interest on mangroves at Qurm Nature Reserve, Ras al Hadd Turtle Reserve for turtle conservation, Dimaniyat Islands Nature Reserves for the protection of coral reefs, hawksbill turtles and nesting birds along the Salalah coast, nine Khawrs (coastal lagoons) for mangroves and migratory birds. The mangrove transplantation project was initiated by MECA in collaboration with JICA in 2000. Four nursery establishments in Qurum Nature Reserve (QNR), Sur and Salalah were sources of seedlings which were distributed in various areas of the country. The project was envisioned to produce seedling in the nurseries and transplant them in khwars to enhance existing mangrove vegetation or reforest bare lagoons. QNR nursery in Muscat was the first pump irrigated nursery in the country and is currently producing 24,000 seedlings annually with about 85% survival. Participation in transplanting of seedlings to the site by local resident volunteers especially women and school children had been very encouraging. To date, less than half a million *Avicennia marina* seedlings had been successfully transplanted in various coastal locations of the country. Signs of mangrove regeneration are evident in many areas (Choudri et al. 2016). Results of this efforts caused increase mangrove forests morae than 2.5 times (250%) from 1977 to 2017).

3.2.5.3 United Arab Emirates

The maximum increase in mangrove forest area in the Persian Gulf and the Gulf of Oman belongs to the Emirates from 1977 to 2017. In the Emirates, despite numerous threats, mangrove extent has been increasing over the last 20 years due to natural growth and successful afforestation program activities, which were started by the Ministry of Agriculture and Fisheries in 1972 in Abu Dhabi (Anwahi 2005: Böer 2002; Khan 1982; Scott 1995; Spalding et al. 1997).

In United Arab Emirates, mangrove plantation NOC projects were launched. A No Objection Certificate (NOC) for planting mangroves is required for any mangrove planting project in Abu Dhabi Emirate. NOCs for mangrove planting are issued by the Environment Agency-Abu Dhabi (EAD). EAD's goal, in line with the targets outlined in the Emirate of Abu Dhabi Biodiversity Strategy (2015–2019), is to protect existing mangrove ecosystems, and ensure that environmental impacts due to development are avoided, minimized and adequately mitigate Excessive human activities have adversely affected the mangrove ecosystem, (EAD) urges developers to rehabilitate the affected areas through large-scale cultivation programs. A case in point is Saadiyat Island in Emirate where (EAD) partnered with the Tourism Development and Investment Company (TDIC) to plant 750,000 saplings of mangroves on 25% of the island, which is currently being developed as a cultural hub of Abu Dhabi. The move is aimed at mitigating the environmental damages caused by the massive development on the island. Property developers are also urged to protect this endangered natural treasure by giving the environment proper consideration from the early planning stages of their development. (EAD) has also urged the public not to litter around mangroves, especially as plastic bags can prevent the growth of mangrove trees and release pollutants that could be harmful for their health. (EAD) works to rehabilitate and protect mangrove forests in seven key sites in the Emirate: Saadiyat Island, Jubail Island, Marawah Marine Biosphere Reserve (which also comprises of Bu Tinah Island), Bu Syayeef Protected Area, Ras Gharab, the Mangrove National Park and Ras Ghanada (Environmental Agency Abu Dhabi 2015).

3.2.5.4 Qatar

Qatar is gradually increasing the level of protection of the country's mangroves, with 40% of the country's coastline now protected. Organizations such as Conservation International have begun mapping out the mangroves locations and data in Qatar and around the globe in order to assess the population distribution and threatened areas. With further enforcement and data tools, the mangrove forests of Qatar can be restored, and continue to provide immense benefits to this harsh desert environment. The management of Ras Laffan Industrial City initiated a mangrove conservation program which includes the protection of the existing plants and planting and sowing of additional seedlings and seeds respectively. Currently the mangrove population has increased 10,000 in numbers (Ras Luffan Industrial City 2005). As of November 2007, FEC, with the aid of representatives of Birdlife International, completed an extensive survey confirming three of the five suggested IBAs as indeed being prime bird conservation sites in Qatar. Those sites include Al Thakira mangroves, Khor Al Udaid, and Alshat Island. The two remaining sites have yet to be surveyed. In addition, five other sites were recommended for IBA consideration. These include Um Tais, Ras Rukon, Abu Nakhla pond, Ashat Island, and Shahanniya (Richer 2009). this activity lead to conservation of mangrove habitat and increasing area of mangrove forests in Qatar from 15 h in 1977 to 1002 ha in 2017. This increase in mangrove forest area indicates successful programs in this countries during the times.

3.2.5.5 Bahrain

Tubli Bay is an inshore coastal area situated in the northeast of Bahrain and mangrove forest in Bahrain concentrated in this region (Besides Howar Bay). For the past 40 or so years, Bahrain coasts especially the Tubli Bay in Bahrain (maximum concentration of mangrove forest in Bahrain) has been under threat from human activity. Infilling the coast for development has caused the size of the Bay to decrease from 23.5 km^2 in 1956 to 16.1 km^2 in 1996 (Environmental Affairs 1996). This on-going activity is causing even more degradation/destruction to the Bay's vulnerable ecology. Tubli Water Pollution Control Centre discharges 160,000 m^3 (Personal Communication 1996) into the Bay every day. Sand washing plants continue to discharge silt into the Bay daily, and the dumping of rubble and litter within its surroundings still remain a point of concern. In 1988 The Mangrove Stand, protected by the Environmental Affairs of Bahrain, is situated at Ras Sanad in the south-western part of the Tubli Bay. Fishing activities are carried out in the Bay, even though it represents a nursery ground for commercially important species. According to this programs mangrove forests area from 1989 to 2017 from 31 to 48 ha. The area is also RAMSAR listed internationally (Convention on the Conservation of Wetlands of International Importance especially as Waterfowl Habitat). It is characterized by its unique ecology as it provides a habitat for important coastal ecosystems, such as mangroves and seagrass. It is the only place in Bahrain with an ecological interaction between mangroves, seagrass and corals. These three systems are important for productivity of coastal fisheries that society depends on.

3.2.5.6 Saudi Arabia

Mangrove forests along Saudi Arabia coasts in the Persian Gulf increased from 97 ha in 1977 to 838 ha in 2017. In Saudi Arabia, shrimp aquaculture represents one of the emerging threats to this ecosystem. Farming first started in Al-Lith in 1983 on a small area of 20 ha, which has increased up to 1000 ha in 1998. Additionally, other shrimp farms are now being planned at Shuqaiq mangrove areas.

In Tarut Bay in Saudi Arabia Saudi Aramco, the ministry of agriculture and NCWCD have established several mangrove plantations since 1996 and this stand are thriving (Allen 1998). Some of this plantation are probably established too far landward too obtain maximal growth, but they are never less in good condition. The ecosystem of

Tarut Bay in Saudi Arabia is exposed to many environmental pressures and if the pollution and Urban utilization continues will lead to erosion of the Bay and near in the future will be burden on the environment and not the source of the wealth of fish and the most important site for the passage of winter birds in the Saudi sector on the coast of The Persian Gulf.

3.3 Conclusion

Mangroves were once recognized as worthless wastelands. This attitude made it acceptable for people to exploit mangroves as a source of land for constructing ports, condos, hotels, aquaculture ponds, and expansive infrastructure for the tourism and fisheries industries.

If improvements to mangrove management and restoration programs were not made soon, there would have been great losses in commercial fisheries and local economies, as well as increased erosion and shoreline instability in countless coastal communities.

The rate of loss of mangrove forests remains substantially higher than that of other terrestrial forests, even as management and conservation programs have become widespread (FAO 2007: Lal 2003). Humans are greedy for coastal land and the profits that coincide with its development. Increasing population pressure in the coastal zone and growing demand for development appear to be the key drivers of mangrove forest destruction. Where legislation and management are absent, the problem of mangrove overuse becomes more prominent (ISME 2004). Mangrove health, as well as that of all marine and terrestrial ecosystems, is directly influenced by the effectiveness of their management and conservation (FAO 2007).

Mangrove forests are unique wetland ecosystems that are established directly in the intertidal zone in the Persian Gulf and the Gulf of Oman. High population pressure in coastal areas could led to the conversion of many mangrove areas to other uses and numerous case studies describe mangrove losses over time. However, information on status and trends of area and distributions in the mangrove forests in the study area is necessary. While some studies had been done for mangrove forests in each country in the Persian Gulf and the Gulf of Oman, most obtained data are scattered and didn't normalize properly.

This research is first attempt at estimating the total mangrove area and their changes in the study area with the one of the powerful method for mangrove forests detection during same periods of tomes for 40 years from 1977 to April 2017. In this study emphasis is given over the NDVI technique, which has been applied to classify satellite images. Basically, through NDVI technique mangrove vegetation can easily be differentiated from other forest due to its different reflectance value. Landsat satellite images form 1977 and 2017 have been applied to assess the decadal land use/land cover changes in the study area. The results of this research show that Landsat data are very useful in monitoring changes in forest cover over moderate time intervals (40 years in this study) at a broad level of classification such as forest/non-forest for a regional area or state. However, the NDVI difference produced fewer visually identifiable errors of omission and commission than the maps of deforestation and reforestation, classification of the vegetation change map into forest change is required.

Results indicate that in 1977, the area of mangrove forest in the study area was about 6412 ha (6.91 km^2). About 40 years later, this same area increased to 13,334 ha (133.34 km^2) and reached a total of about 19,746 ha (197.5 km^2). This increase in mangrove forests in the Persian Gulf and the Gulf of Oman represent sustainable development and management in mangrove ecosystems for all countries in this region.

These successful programs will ultimately rely on the cooperation of numerous governmental bodies as well as local stakeholders striving for a common goal: the protection and restoration of all remaining mangrove habitats. Finally, mangrove forest management and development in the Persian Gulf and the Gulf of Oman could be a pattern for mangrove ecosystems in the world.

Acknowledgement This project was funded by Faculty of Earth Science in Shahid Beheshti University, Iran. We would like to express our appreciation to all colleagues who provided us with their valuable support and comments.

References

Ajorlo M (2003) The history of afforestation in Iran. XII forestry congress, Québec, Canada

Al Mamoon A, Noor S, Rahman A, Almasri S (2016) National sea outfall assessment in Qatar: opportunities and challenges. 37th Hydrology & Water Resources Symposium 2016: Water, Infrastructure and the Environment:295

Alkathiri AMM (2004) Information provided for the Global Forest Resources Assessment (FRA) 2005 thematic study on mangroves. Unpublished

Alongi DM (2002) Present state and future of the world's mangrove forests. Environ Conserv 29:331–349

Allen JA (1998) Mangroves as Alien species: the case of Hawaii. Glob Ecol Biogeogr Lett 7(1):61

Anwahi AA (2005). Information provided for the Global Forest Resources Assessment (GFRA) 2005 thematic study on mangroves. Unpublished

Arturo RL, Aimeé Cervantes E, César B (2010) Assessing distribution patterns, extent, and current condition of Northwest Mexico mangroves. Wetlands 12., 2010:717–723

Aschbacher J, Ofren R, Delsol JP, Suselo TB (1995) An integrated comparative approach to mangrove vegetation mapping using advanced remote sensing and GIS technologies: preliminary results. Hydrobiologia 295., 1995:285–294

Badola R, Hussain SA (2005) Valuing ecosystem functions; an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem India. Environ Conserv 32:85–92
Bannari A, Morin D, Bonn F, Huete AR (1995) A review of vegetation indices. Remote Sens Rev 13(1–2):95–120
Baret F, Guyot G, Major DJ (1989) TSAVI: a vegetation index which minimizes soil brightness effects on LAI and APAR estimation. Geoscience and remote sensing symposium, 1989. IGARSS'89. 12th Canadian Symposium on Remote Sensing. 1989 International, pp 1355–1358
Barnes EM, Clarke T, Richards SE, Colaizzi PD, Haberland J, Kostrzewski M, Waller P, Choi C, Riley E, Thompson T, Lascano RJ, Li H, Moran MS (2000) Coincident detection of crop water stress, nitrogen status and canopy density using ground-based multispectral data. In: Robert PC et al (eds) Proceeding of the International conference on Precision Agriculture, 5th, Bloomington, MN. 16–19 July 2000. ASA, CSSA, and SSSA, Madison
Barth H (2001) Preliminary report on: the coastal ecosystems 10 years after the 1991 Gulf Waroilspill. http://www.uniregensburg.de/Fakultaeten/phil_Fak_III/Geographie/phygeo/downloads/barthcoast.pdf
Behrouzi RB (1996) Gandoo protected area. Environ Sci Q J 8:28–35
Böer B (2002) The coastal and sabkha flora of the United Arab Emirates. In: Sabkha ecosystems, pp 303–309
Böer B (2005) Information provided for the global forest resources assessment (FRA) 2005 thematic study on mangroves. Unpublished
Choudri BS, Said BM, Mushtaque A (2016) An overview of coastal and marine resources and their management in sultanate of Oman. J Environ Manage Tour 1:21
Czudek R (2006) Wildlife issues and development prospects in West and Central Asia Thematic study for the Forestry Outlook Study for Africa. The wildlife management working paper 9, of Food and Agriculture Organization of the United Nations, 71 pp
Dahdouh-Guebas FM (2005) How effective were mangroves as a defense against the recent tsunami? Curr Biol 15(12.), 2005):443–447
Danehkar A (1994) Study on Sirik region mangroves. MS Thesis, Faculty of Natural Resources-Tarbiat Modares University, Noor
Danehkar A (1996) Iranian mangroves forests. Environ Sci Q J:8–22
Danehkar A (1998) Marine sensitive areas of Iran. Environ Sci Q J 24:28–38
Danehkar A (2001) Mangroves forests zonation in Gaz and Harra international wetlands. Environ Sci Q J 34:43–49
Darvishsefat A, Zobeiri M (2007) Potentiality of Aster images for forest density mapping in Zagros forests of Iran. Geomatica Barselona, Barcelona, February pp 20–23
Directorate-General of Nature Conservation (2010) Fourth national report to the convention on biological diversity. Ministry of Environment and Climate Affairs Sultanate of Oman
Duke NC, Meynecke J-O, Dittmann S, Ellison AM, Anger K, Berger U, Cannicci S, Diele K, Ewel KC, Field CD, Koedam N, Lee SY, Marchand C, Nordhaus I, Dahdouh-Guebas F (2007) A world without mangroves? Science 317(5834):41–42
Emch ME, Peterson M (2006) Mangrove forest cover change in the Bangladesh sundarbans from 1989–2000. A remote sensing approach. Geocarto Int 21(1):5–12
Environmental Agency Abu Dhabi (2015) Technical guidance document for mangrove planting permitting and management plan
Ewel KC, Ong JE, Twilley RR (1998) Different kinds of mangrove swamps provide different goods and services. Glob Ecol Biogeogr Lett 7:83–94
FAO (2005) Global forest resources assessment 2005 thematic study on mangroves (Saudi Arabia)
Field CB, Osborn JG, Hoffman LL, Polseaberg JF, Ackerly DD, Berry JA, Biorkman O, Held A, Matson PA, Mooney HA (1998) Mangrove biodiversity and ecosystem function. Glob Ecol Biogeogr Lett 7:3–14
Fluor Cam PAR (2014) Absorptivity module & NDVI measurement instruction manual, product .PSI, spol. s r. o., Drásov 470, 664 24 Drásov, Czech Republic
Food and Agriculture Organization of the United Nations (2007) The world's mangroves 1980–2005, FAO Forestry Paper No. 153. FAO Forestry Department, Rome, p 77
Gao B-C (1996) NDWI – a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sens Environ 58:257–266
Gao J (1999) A comparatives study on spatial and spectral resolutions of satellite data in mapping mangrove forests. Intern J Remote Sens 20:2823–2833
Gilman E, Ellison J, Duke NC, Field C (2008) Threats to mangroves from climate change and adaptation options: a review. Aquat Bot 89 (2):237–250
Giri C, Zhu Z, Tieszen LL, Singh A, Gillette S, Kelmelis JA (2008) Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. J Biogeogr 35:519–528
Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek Jand Duke N (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. Glob Ecol Biogeogr 20(1):154–159
Green ER, Mumb PJ, Edwards AJ, Clark CD, Ellis AC (1998) The assessment of mangrove areas using high resolution multispectral airborne imagery. J Coast Res 14:433–443
Green EP, Clark CD, Edwards AJ (2000) Image classification and habitat mapping. In: Edwards AJ (ed) Remote sensing handbook for tropical coastal management. UNESCO, Paris, pp 141–154
Hend K (2015) Mangroves in Qatar: perspectives. https://www.ecomena.org/mangroves-in-qatar/
Heumann BW (2011) An object based classification of mangroves using a hybrid decision tree – support vector machine approach. Remote Sens 3:2440–2460
Huete AR (1988) A soil-adjusted vegetation index (SAVI). Remote Sens Environ 25:295–309
Huete A, Didan K, Miura T, Rodriquez EP, Gao X, Ferreria LG (2000) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sens Environ 83:195–213
International Society for Mangrove Ecosystems and International Tropical Timber Organization. ISME (2004) Mangrove action plan for the sustainable management of mangroves 2004–2009. ISME, Okinawa
International Union for Conservation of Nature (IUCN) (1986) Sultanate of Oman. Proposals for a system of nature conservation areas. Report to Diwan of Royal Court, Sultanate of Oman. IUCN, Gland
International Union for Conservation of Nature (IUCN) (1986–89) Coastal Zone Management Plan. Reports to the Ministry of Commerce and Industry, Oman
IPCC (2007) Summary for policymakers. Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change (ed by Parry ML, Can-ziani OF, Palutikof JP, van der Linden PJ, Hanson CE) Cambridge University Press, Cambridge, pp 7–22
Jensen JR, Lin H, Yang Y, Ramsey E, Davis BA, Thoemke CW (1991) The measurement of mangrove characteristics in Southwest Florida using SPOT multispectral data. Geocarto Int 2:13–21
Kairo JG, Kivyatu B, Koedam N (2002) Application of remote sensing and GIS in the management of mangroves forests within and adjacent to Kiunga Marine Protected Area. Lamu Kebya. Environ Dev Sustain 4:153–166
Khan MIR (1982) Mangrove forest of the United Arab Emirates. Pak J For 32(2):36–39
Khosravi M (1992) Ecological studies plan of Iranian mangrove forests. Report of mangrove forests identification phase. Department of the Environment, Tehran

Kovacs JM, Wang J, Verdugo F (2005) Mapping mangrove leaf area index at the species level using IKONOS and LAI-2000 sensor for the Agua Brava Lagoon, Mexican Pacific. Estuar Coast Shelf Sci 62:377–384

Kumar R, Silva L (1973) Light ray tracing through a leaf cross- section. Appl Opt 12:2950–2954

Lal P (2003) Economic valuation of mangroves and decision-making in the Pacific. Ocean Coast Manag 46(9-10):823–844

MA (Millennium Ecosystem Assessment) (2005) Mille ecosystem and human well-being: synthesis. Island Press, Washington, DC

Ma BL, Dwyer LM, Costa C, Cober ER, Morrison MJ (2001) Early prediction of soybean yield from canopy reflectance measurements. Argon J 93:1227–1234

Mahdavi A (2001) Investigation on quantitative and qualitative alterations of mangrove forests in Gheshm area by using of 1967 and 1994 aerial photos. University of Tehran

Manandhar R, Odeh IOA, Ancev T (2009) Improving the accuracy of land use and land cover classification of landsat data using post-classification enhancement. Remote Sens 1(3):330–344

Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR)(2004a)

Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR) (2004b) The master plan study on restoration, conservation and management of mangrove in the sultanate of Oman

Ministry of Environment and Climate Affairs (MECA) (2010) Fourth National report to the Convention on International Union for Conservation of Nature (IUCN) (1986) Sultanate of Oman. Proposals for a System of Nature Conservation Areas. Report to Diwan of Royal Court, Sultanate of Oman. IUCN, Gland, Switzerland

Nizwa Net (2014) Turtle species of Oman. http://www.nizwa.net/env/turtles/turtles.html. Accessed 3 Sept 2014

O'Grady AP, McGuinness KA, Eamus D (1996) The abundance and growth of Avicenia marina and Rhizophora stylosa in the low shore zone of Darwin Harbor, Northern Territory. Aust J Ecol 21:272–279

Peñuelas J, Gamon J, Fredeen A, Merino J, Field C (1994) Reflectance indices associated with physiological changes in nitrogen- and water-limited sunflower leaves. Remote Sens Environ 48:135–146

PERSGA/GEF (2004) Status of mangroves in the Red Sea and Gulf of Aden, PERSGA Technical Series No 11. PERSGA, Jeddah

Qi J, Chehbouni A, Huete AR, Kerr YH, Sorooshian S (1994) A modified soil adjusted vegetation index (MSAVI). Remote Sens Environ 48:119–126

Quarto A (2005) Mangrove restoration-natural protection from natural disasters. Biodiversity (Ottawa) 6:3–12

Ramsey E, Jensen JR (1996) Remote sensing of mangrove wetlands: relating canopy spectra to site-specific data. Photogramm Eng Remote Sens 62:939–948

Ras Luffan Industrial City (2005) Mangrove conservation program

Rasolofoharinoro R, Blaso F, Bellan MF, Aizpuru M, Gauquelin T, Denis J (1998) A remote sensing based methodology for mangrove in Madagascar. Int J Remote Sens 19:1873–1886

Richardson AJ, Wiegand CL (1977) Distinguishing vegetation from soil background information. Photogramm Eng Remote Sens 43:1541–1552

Richer R (2009) Conservation in Qatar: impacts of increasing industrialization. Center for International and Regional Studies, Doha

Rodgers JC, Adam Murrah W, William H, Giri C, Bruce C (2009) monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multitemporal satellite data from 1973 to 2000. Estuar Coast Shelf Sci 73(1–2):91–100

Saenger P (1993) Management of mangroves in the Kingdom of Saudi Arabia. Saline Water Conversion Corporation and Ministry for Agriculture and Water, Riyadh

Safiari Sh, Nasouri M (2009) Mangrove forests development. Ministry of Jihad-e Agriculture, Forest, Range and Watershed

Samira O (2004) Information provided for the Global Forest Resources Assessment (FRA) 2005 thematic study on mangroves. Unpublished

Scott DA (1995) A directory of Wetlands in the Middle East. IUCN, Gland. Switzerland and IWRB, Slimbridge, U.K. xvii + 560pp, 13 maps

Shariatnegad S (2005) Information provided for the Forest Resources Assessment (FRA) thematic study on mangroves. Unpublished

Sherrod CL, McMillan C (1985) The distributional history and ecology of mangrove vegetation along the northern Gulf of Mexico coastal region. Contrib Mar Sci 28:129–140

Spalding M, Blasco F, Field CD (1997) World mangrove atlas. The International Society for Mangrove Ecosystems, Okinawa

Spooner M (1970) Oil spill in Tarut Bay, Saudi Arabia. Mar Pollut Bull 1(11):166–167

Sremongkontip S, Hussin YA, Groenindijk L (2000) Detecting changes in the mangrove forests of southern Thailand using remotely sensed data and GIS. Int Arch Photogramm Remote Sens 33:567–573

Stutzenbaker CD (1999) Aquatic and wetland plants of the western gulf coast. Texas Parks and Wildlife Press, Austin. 465 p

Supreme Council for the Environment & Natural Reserves (2004) A national biodiversity strategy and action plan – State of Qatar. Final National Biodiversity Strategy and Action Plan. www.biodiv.org/doc/world/qa/qanbsap-01-en.doc

Thiam S, Eastmen RJ (1999) Chapter on vegetation indices. In: Guide to GIS and image processing. 2; Idrisi Production. Clarke University, Worcester, pp 107–122

Tong PHS, Auda Y, Populus J, Aizpura M, Habshi AAL, Blasco F (2004) Assessment from space of mangrove s evolution in the Mekong Delta, in relation to extensive shrimp farming. Int J Remote Sens 25:4795–4812

Tsai-Ming L, Hui CY (2009) Applying remote sensing techniques to monitor shifting wetland vegetation: a case study of Danshui River estuary mangrove communities. Taiwan Ecol Eng 35 (4):487–496

UNEP (1999) Overview on land-based sources and activities affecting the marine environment in the ROPME Sea Area. UNEP Regional Seas Reports and Studies No. 168. 127 pp.

Vaiphasa C, Skidmore AK, de Boer WF (2006) A post-classifier for mangrove mapping using ecological data. ISPRS J Photogramm Remote Sens 61:1–10

Vits C, Tack J (1995) The use of remote sensing as information source for environmental accounting of coastal areas in Kenja, Feasibility Study Reference. University of Ghent No. T3/02/603, 1e45

Zahed A, Rouhani M, Mohajeri S, Bateni F (2010) An overview of Iranian mangrove ecosystems, northern part of the Persian Gulf and Oman Sea. Acta Ecol Sin 30:240–244