ECOSYSTEMS AND BIODIVERSITY OF THE ARABIAN GULF

SAUDI ARABIAN WATERS

Fifty Years of Scientific Research

A Publication by Saudi Aramco and King Fahd University of Petroleum & Minerals

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جامعة الملك فهد للبترول والمعادن
King Fahd University of Petroleum & Minerals

أرامكو السعودية
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Preface

For nearly five decades, the King Fahd University of Petroleum and Minerals (KFUPM) has partnered with Saudi Aramco to document and explore the wondrous ecosystem that exists in the Arabian Gulf. The book before you offers a comprehensive and up to date guide on the fruits of that work and its findings.

Through its pages, marine scientists, decision makers, students and indeed anyone with an interest in marine environmental protection, will have access to a wealth of scientific information.

The Arabian Gulf is environmentally challenged because of the natural stressors of salinity and temperature fluctuations. Rapid population growth and associated developmental activities along its coasts, particularly those related to the urban and industrial development, are adding additional stress on the Arabian Gulf's fragile environment.

The partnership between KFUPM and Saudi Aramco, has resulted in a greater understanding of the Arabian Gulf's natural ecosystems, ensuring greater protection of biodiversity and natural resources. The backbone of this partnership has been the Marine Environmental Sustaining Research Program, which has produced fundamental knowledge on the Arabian Gulf's marine environment. In addition, detailed and in-depth environmental impact assessments have been systematically conducted for proposed development projects as well as environmental monitoring during construction and commencement of operations, all contributing to our knowledge of the ecosystems. This information has contributed to the protection of the ecosystems and the development of a fisheries management framework in the Arabian Gulf.

We are grateful for the collaboration and efforts of the interdisciplinary teams of the Environmental Protection Department of Saudi Aramco and the Marine Studies Section of KFUPM in preparation of this book. A deep and sincere appreciation is extended to each and every person who, for nearly five decades, has played a part in this partnership in marine environment protection. This book is a testament to your hard work and our collective desire to preserve the beautiful ecosystem that flourishes in the Arabian Gulf.

AMIN H. NASSER
Saudi Aramco President & CEO

Foreword

The Arabian Gulf has always been a special component of the Kingdom's economy and culture. Aside from its rich oil and gas resources, it is also an important source of food and water, and is a major transportation point. But not to be undermined or forgotten is the fact that it also supports vital and thriving ecosystems. In its waters are seagrass, coral reefs, salt marshes, and mangroves, as well as intertidal and subtidal sediments and deeper water areas. These interacting habitats provide the essential components for a vibrant and productive marine ecosystem. However impressive this may sound, the Arabian Gulf is also facing natural and human-induced stress, such as elevated seawater temperature and salinity; coupled with coastal urbanization and rapid industrialization. These stresses, if not managed, can impact the long-term ecosystem services currently provided by the Arabian Gulf.

Scientific research on its marine environment is the result of collaboration between industry and academia. It was in 1982 that the Environmental Protection Department of Saudi Aramco and the Marine Studies Section of the King Fahd University of Petroleum and Minerals began joint research into the Arabian Gulf's ecosystem. This partnership involved the development of research programs to study the Arabian Gulf's ecosystem values, interactions, and reduce the impact of stress. Currently, the sixth phase of this sustaining research program is focusing on the biodiversity status across the Arabian Gulf's ecosystems. This book gathers the results and the major scientific findings of this long-term collaborative program and provides a detailed, updated review on the state of the marine ecosystems and biodiversity of the Western Arabian Gulf. For anyone who has an interest in the topic, it serves as the current definitive work, and is a reminder of the importance of marine ecosystems.

Prof. Sahel N. Abduljauwad
Rector of King Fahd University
of Petroleum & Minerals

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Seagrass

Mohammed A. Qurban[1], Thadickal V. Joydas[1], Karuppasamy P. Manikandan[1], Jeff Bogart R. Abroguena[1], and Carlos M. Duarte[2]

Introduction

Seagrasses are the only flowering plants (angiosperms) that have fully colonized the oceans, being able to grow submerged in full strength seawater (Hemminga and Duarte, 2000). These unusual marine plants are called seagrasses because in many species the leaves are long and narrow, grow by rhizome extension, and often grow in large "meadows," which resemble grassland. Despite their superficial resemblance to terrestrial grasses, they do not belong to the *Poaceae*, where terrestrial grasses belong, but to *Alismatacea*. Seagrasses are flowering monocotyledon plant species that live in coastal and estuarine areas of the world. Like all flowering plants, seagrasses develop fruits and produce seeds, have true roots and nutrient transport systems (Ackerman, 2006; Kuo and den Hartog, 2006). Their root system allows them to anchor in sandy or muddy substratum, and some species, in rocky substrate.

Seagrasses have also developed unique genomic, ecological, physiological, and morphological adaptations for a completely submersed existence, including internal gas transport, epidermal chloroplasts, submarine pollination, and marine dispersal (den Hartog, 1970; Les, et al., 1997; Olsen, et al., 2015). Seagrasses require much higher light levels to grow than macroalgae do (Gattuso, et al., 2006), as they must provide oxygen and carbon to their roots and rhyzomes through photosynthesis to develop large amounts of non-photosynthetic tissue and support their metabolic requirements (Dennison, et al., 1993; Terrados, et al., 1999). This means that seagrasses are very sensitive to environmental changes, especially those that alter water clarity (Orth, et al., 2006). The concerted growth, mostly through clonal expansion, of many individuals in a defined area leads to formation of seagrass meadows. Such beds are mostly monospecific but may occasionally be multi-specific, particularly so in the tropics (Hemminga and Duarte, 2000). Seagrass meadows rank among the most productive ecosystems in the world (Duarte and Chiscano, 1999) and support high biodiversity in marine food webs, including endangered species such as green turtles, dugongs and sea horses (Hemminga and Duarte, 2000).

Seagrass beds are cosmopolitan in distribution, from equator to high temperate latitudes and from intertidal zones to sublittoral waters defined by the extent of penetration of about 11% of surface incident solar radiation. In temperate waters, seagrass beds are dominated by one or a few species, while in tropical seas, the beds are usually diverse. In the tropics they are often found associated with mangroves and/or on soft sand or mud.

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Seagrass meadows have an estimated coverage of about 600,000 km^2 across the coastal ocean and occur in abundance on every continent except Antarctica (Duarte, et al., 2010). Although, unlike other taxonomic groups with worldwide distribution, they exhibit low taxonomic diversity. There are approximately 65 species of seagrass, compared with approximately 250,000 terrestrial angiosperms (Orth, et al., 2006; Cullen-Unsworth and Unsworth, 2013). Among the existing seagrass species, three species are endangered and 10 species are at an elevated risk of extinction (Short, et al., 2011).

Seagrass beds are highly productive ecosystems, and can harbor hundreds of associated species from many phyla, (e.g., juvenile and adult fish, epiphytic and free-living macroalgae and microalgae, and hundreds of macrobenthic species) (Basson, et al., 1977; Coles and McCain, 1990; KFUPM/RI, 2003, 2010a and 2014). Few species are considered to feed directly on seagrass leaves partly because of their low nutritional content like green turtles, dugongs, manatees, fish, geese, swans, sea urchins and crabs, some of which are endangered and targets of important conservation efforts.

Their importance to associated species is a result of the shelter they provide through their three-dimensional structure in the water column and their extraordinarily high rate of primary production. As a result, seagrasses provide coastal zones with a number of ecosystem goods and services, such as their role in food web dynamics, nursery habitat, seascape interactions, and ecological resilience potential (Hemminga and Duarte, 2000; Gunderson, 2001; Valentine, et al., 2002; Moberg and Ronnback, 2003; Unsworth and Cullen, 2010). Seagrasses are sometimes labeled ecosystem engineers, because they partly create their own habitat; the leaves slow down water currents, increasing sedimentation, and the seagrass roots and rhizomes stabilize the seabed (Gutierrez, et al., 2011).

Worldwide, environmental, biological, and extreme climatological events have been identified as causes of seagrass losses. Threats from global climate change, regional shifts in water quality and more localized impacts due to increased loading of sediment, contaminants and nutrients impact the health of seagrass ecosystems (Kemp, et al., 2005; Walker, et al., 2006).

Western Arabian Gulf Seagrass Ecosystem

The western Arabian Gulf has vast areas with shallow water less than 15 m depth suitable for seagrass growth. Three species of seagrass occur in the western Arabian Gulf: (1) *Halodule uninervis* (most widely distributed), (2) *Halophila stipulacea* (less common, but forming dense meadows in some areas), and (3) *Halophila ovalis* (rarely forming dense monospecific meadows) (Den Hartog, 1970; Basson, et al., 1977). A fourth species has been recorded from the adjacent Gulf of Oman waters (Wilson, 2000), however, it has not yet been reported from the Arabian Gulf.

The seagrass beds in the western Arabian Gulf are known to play a major role in the overall functioning of the marine ecosystem of this region (Sheppard, et al., 1992; Price, 1998; Jones, et al., 2002; Erftemeijer and Shuail, 2012). The seagrass beds in this region support a rich benthic fauna (Basson, et al., 1977; KFUPM/RI, 1988; Coles and McCain, 1990). They are home to the world's second largest assemblage of endangered dugongs *Dugong dugon*. Dugongs are some of the few animals that feed directly on the seagrass, including also a sizeable population of herbivorous green turtle *Chelonia mydas* that utilizes the seagrass beds of the western Arabian Gulf. Seagrass beds support shrimp fishery in this region by providing habitat for juvenile shrimp *Penaeus semisulcatus*. Pearl oysters, several fishes, and sea snakes are also associated with the seagrass beds of the Arabian Gulf.

The seagrass beds in this region survive in some of the harshest environmental conditions in the world as the Arabian Gulf experiences extreme oscillations in key environmental properties. Seagrass in the Arabian Gulf are subject to extreme temperature variations 4 °C to 39 °C hypersaline conditions salinity 38 psu to 70 psu and waters with relatively higher turbidity 1 to 2 NTU compared to other parts of their biogeographical range in the Indian Ocean (Shinn, 1976; Sheppard, et al., 1992; KFUPM/RI, 2014; Krishnakumar, et al., in this book).

The seagrass beds in the Arabian Gulf suffer the consequences of the large-scale oil-related activities, and increasing coastal and urban development. The seagrass beds of the region also were influenced by the largest oil spill in history, the 1991 Gulf oil spill.

The purpose of this chapter is to review their current status, in the NW Arabian Gulf in terms of species composition, productivity, faunal and floral diversity associated with them, and threats to their survival at present, and propose measures needed to reverse the impacts of threats and enhance their sustainability. The purpose is also to analyze data and research that conducted by KFUPM during the last four decades that may lead to improved understanding of the long-term trends of the survival and distribution of seagrass in the Arabian Gulf.

Methods of Obtaining Data

Most of the data used for this chapter were obtained from approximately 40 years of field studies conducted by King Fahd University of Petroleum and Minerals (KFUPM) and Saudi Aramco in the Saudi waters of the Arabian Gulf. Available literature was used to cover other parts of the Arabian Gulf.

Multiple methods were used for seagrass surveys, including conventional visual observations and photographic documentation by SCUBA divers and snorkelers, submersible cameras, and remotely operated vehicles (ROV). For the quantitative studies quadrat surveys were employed.

Grab samples (normally a van Veen grab of 0.1 m^2 bite area) were used to obtain macrobenthic samples from the seagrass beds. During the 1970s and 1980s, diver operated scoops (0.1 m^2) were used for collecting sediment samples. Divers used to push this device through the sediment so that the upper 10 cm of the sediment would be brought into the scoop.

Abiotic Characteristics

The shallow coastal environment where the seagrass community thrives is under constant and sporadic episodes of disturbances, both natural (waves or turbulence associated with storms) and man-made (human usage and development of coastal zones). These disturbances have a huge influence on the dynamics of this ecosystem. Any disturbance that hinders or modifies adequate light, transparency of the water layer and the sediment conditions affects the abundance and distribution of seagrasses (Short and Wyllie-Echeverria, 1996). The prime factors that are of vital importance in supporting seagrass communities could be categorized as physical and chemical factors.

Physical Factors

Light

The underwater light regime is the primary physical factor affecting seagrass performance as it influences photosynthesis, and therefore growth and depth distribution of seagrasses. Incoming solar radiation at the sea surface reaches a daily maximum amount of over 1,000 W/m^2 in the Arabian Gulf during summer, from May to September (Aksakal and Rehman, 1999) with a monthly mean of 328 W/m^2. Of this, the radiation in the visible spectrum (400 nm to 700 nm), also referred to as photosynthetically active radiation (PAR) is of prime importance. Typically, in the Arabian Gulf the PAR (Figure 3.60) ranges from 20 to 60 mol quanta m^2/day (92 to 276 micromol quanta/m^2/sec) with the lowest in January and highest in May, which corresponds to the winter and summer seasons. Seagrass requires a minimum submarine PAR of about 5 mol quanta m^{-2} day^{-1}, although *H. stipulacea* has been reported to grow at light levels as low as 0.2 mol quanta m^{-2} day^{-1} (Gattuso, et al., 2006).

The driving force of photosynthesis, leading to the production of oxygen and carbohydrates is light. For photosynthesis to occur in seagrasses, light must penetrate the water column, enter the canopy of leaf blades, pass through a layer of epiphytes on the surface of the leaf and finally enter the leaf epidermis to reach the photosynthetic apparatus (Dalla Via, et al., 1998). As the depth of water increases the underwater light intensity attenuates exponentially due to the absorption and scattering process of dissolved substances, phytoplankton, and particulate matter (Roesler, et al., 1989; Gallegos, et al., 1990) and this limits the growth and sustenance of seagrasses. In clear water, seagrasses reach depths of up to 17 m, while in very turbid waters the seagrass beds may only reach depths of 5 m to 8 m. The minimum percentage of light required is 4.4 for the seagrasses belonging to the genera *Halophila* (Dennison, et al., 1993) and for *Halodule* it ranges from 15 to 20 (Burd and Dunton, 2001). In the Indian Ocean, the average PAR value in seagrass bed was 17.70 ± 0.20% of the solar radiation incident in the surface (Camp, et al., 2016). Longstaff and Dennison (1999) have demonstrated that under full shade, *H. ovalis* can survive for more than 30 days. Therefore, *H. ovalis* is well adapted to the variable light environments in the Arabian Gulf. *Halophila* spp. have very thin leaves as they are more efficient at harvesting light than linear leaves, and therefore, have the greatest depth limit, and consequently the lowest minimum light requirement (Enriquez, et al., 1994).

Temperature

The sea surface temperature is projected to warm between 2 °C and 4 °C by 2100, mostly due to human activity (IPCC, 2007). Similar increases have been predicted for marine systems (Sheppard and Rioja-Nieto, 2005). High temperatures are one of the major stressors in the marine environment. The response of seagrasses to increased water temperatures will depend on the thermal tolerance of the different species and their optimum temperature for photosynthesis, respiration and growth (Short and Neckles, 1998). For tropical seagrasses, it was suggested that the photosynthetic mechanism becomes irreversibly damaged at temperatures of 40 °C to 45 °C (Campbell, et al., 2005). Also, increased temperatures may

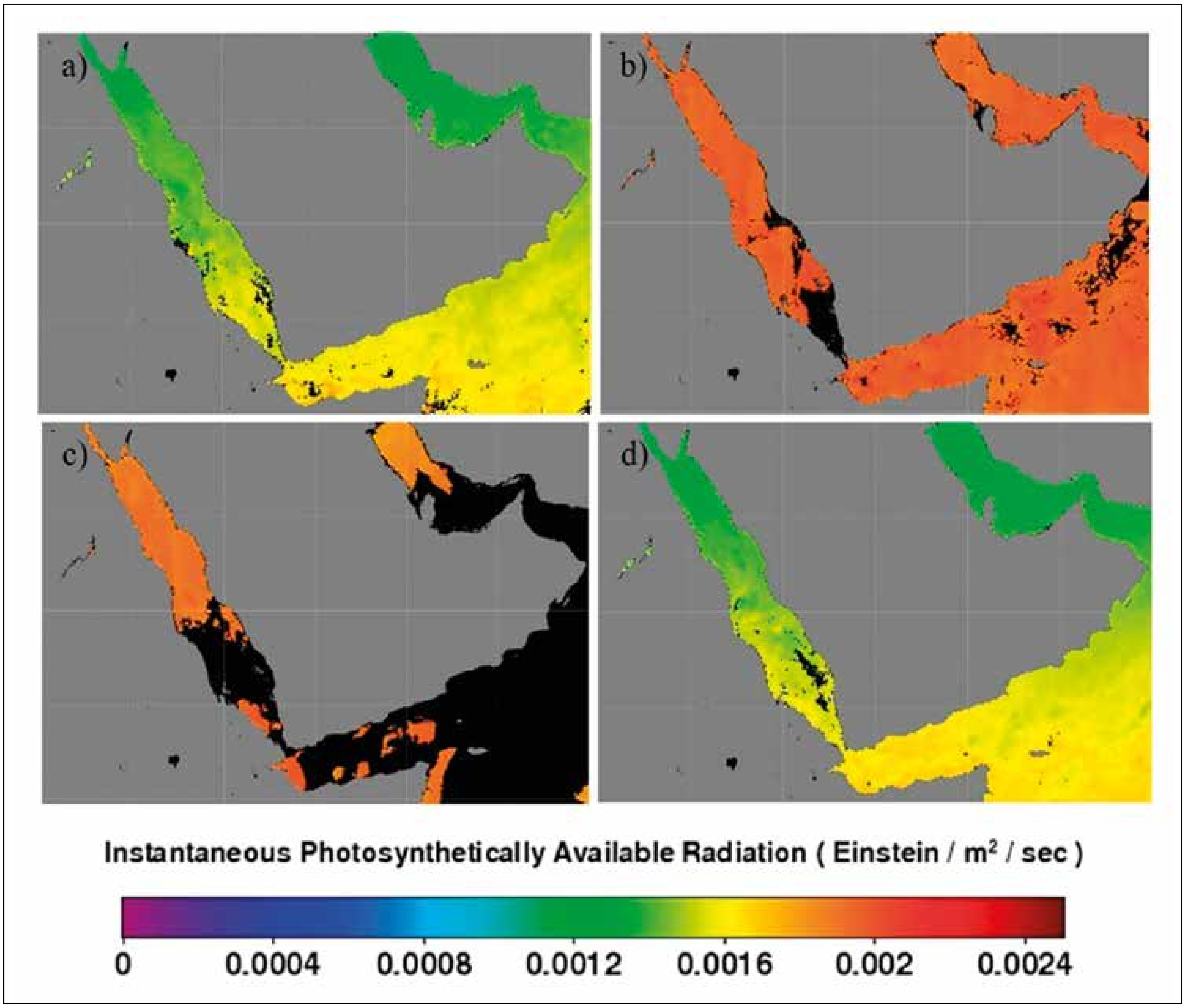

FIGURE 3.60. *Averaged monthly Aqua MODIS PAR in: (a) January, (b) May, (c) August, and (d) December 2009 (Data courtesy NOAA).*

proliferate the competitive algae and epiphytes, which outgrow and reduce the availability of sunlight for photosynthesis. In addition, low temperatures may be harmful to tropical seagrass species, as those growing in the Arabian Gulf.

In the Arabian Gulf, seagrasses are subject to extreme natural variations in water temperature from 10 °C to 39 °C (Price, et al., 1993) and water temperature differences between monthly averages of 21 °C in the northern Gulf (Figure 3.61), and therefore, temperature plays a major stressor in the seagrass productivity. Interestingly, *Halodule uninervous* sp. shows the highest tolerance and *H. stipulacea* sp. shows an intermediary tolerance. Among them, the narrow-leaved plants (i.e., *H. uninervous*) showed higher resistance when compared to the broader leaved plants (Ballorain, et al., 2010).

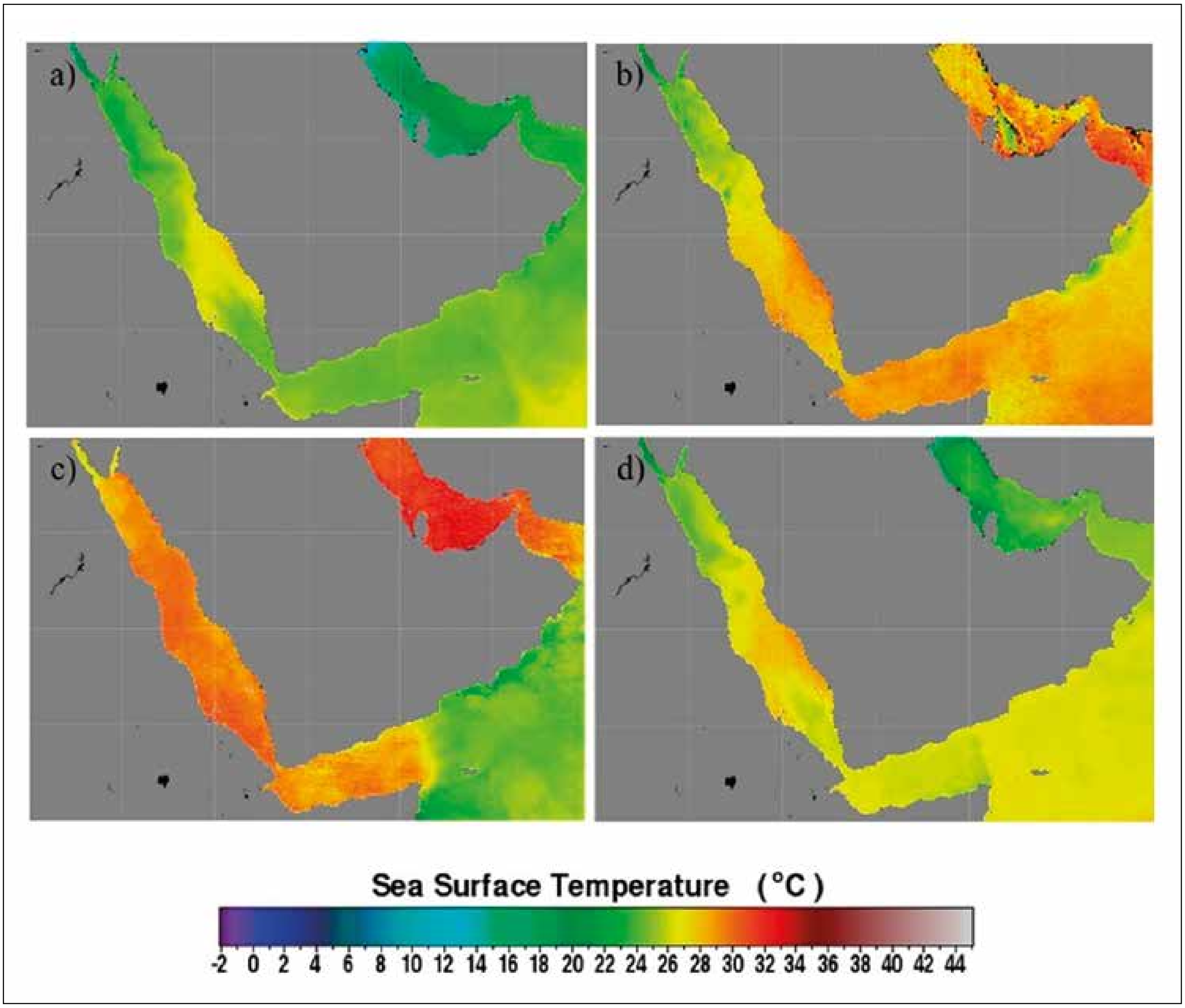

FIGURE 3.61. *Averaged monthly pathfinder sea surface temperature in: (a) January, (b) May, (c) August, and (d) December 2009. Maximum water temperature differences between monthly averages were 21 °C in the northern Gulf, and ~17 °C in the southeast Gulf (Data courtesy NOAA).*

Growth rates in seagrasses exhibit clear seasonal trends, with increasing growth during spring and summer, and decreasing growth during fall and winter (Orth and Moore, 1986; Vermaat, et al., 1987; Macauley, et al., 1988; Dunton, 1990; Thom, 1990; Lee and Dunton, 1996). Several studies consider temperature a primary factor controlling seasonal growth (Setchell, 1929; Tutin, 1942; Phillips, et al., 1983, 2002 and 2004; Bulthuis, 1987; Lee and Dunton, 1996). Elevated temperatures during fall and spring may enhance seagrass productivities (e.g., *Syringodium filiforme* and *T. testudinum*), but high temperatures during summer can reduce seagrass productivity (Barber and Behrens, 1985). In the Arabian Gulf, growth of the seagrass beds is seasonal with the vegetative part above the substrata reduced by the end of winter (mid-February). New growth begins in March and reaches maximum levels by June with continued growth throughout the summer. Sediments are removed from the bed areas during the winter period when vegetative leaves are reduced and resuspension due to winter wave surges is greatest.

Salinity

Salinity tolerances in seagrasses vary from species to species (Lirman and Crooper, 2003). Experimental results show that a wide range of salinities may be tolerated by seagrasses for short periods, but long-term tolerances are narrower (Hillman, et al., 1989). In the Arabian Gulf seagrasses are subject to extreme salinity fluctuations ranging from 38 psu to 70 psu (Price, et al., 1993). In studies conducted in the Arabian Gulf, Price and Coles (1992) found no correlation between seagrass cover and salinity. Being euryhaline, *H. uninervis* was found in the shallow areas subject to extreme salinity ranges (Hillman, et al., 1989) and was even found thriving in Dawhat Zalum and parts of the Gulf of Salwah where recorded salinities reached 60 psu to 62 psu (Basson, et al., 1977). Also, in the coastal lagoon of Al Qair, healthy beds dominated by *H. uninervis* and *H. stipulacea* were found at salinities of 55 psu to 59 psu (Wijsman and Riegl, 2001). In 2003, during surveys of coastal lagoons within Ras Abu Khamese (UAE), salinities of 60 psu were recorded in water covering dense beds of *H. uninervis*. Even though some EIA studies report that salinities greater than 58 psu reduces growth of seagrasses, the thresholds of salinity for seagrasses in the Arabian Gulf need be revisited.

Waves and Currents

High energy waves determine landscape patterns in seagrass habitats. In areas dominated by high energy waves, either seagrasses will not exist or the distribution may be patchy and restricted to deeper areas below the maximum wave penetration depth. In the Arabian Gulf, seagrass habitats occur at 46% of the coastal and 30% of the offshore sites surveyed along the Saudi Arabian coastline (Price and Coles, 1992). The total extent of seagrasses in the Gulf is estimated to range between 6,790 km^2 and 7,320 km^2 (Erftemeijer and Shuail, 2012).

Seagrasses in high energy environments have longer blades and exist as patches to avoid being removed from the seabed. In addition, high currents and waves result in course sediments, loss of fine sediment and the associated organic material, and diffusive advection of pore water nutrients into the water column. In the Arabian Gulf, seagrass beds are abundant in naturally protected areas such as inner bays and tidal flats (e.g., Tarut Bay and areas adjacent to Ras Tanura). Erosional features along the open coast consist of rip current channels and sand strips, which break up the seagrass bed. The erosional patterns in bays with very high energy tidal exchange consist of bare sand depressions 5 m to 10 m wide, 0.5 m to 1 m deep that occur in lines along the path of tidal currents. The depressions act as depositional basins for coarse sand and larger fragments of shell and coral debris. In tidal channels with very high current velocities, no seagrass beds occur and the sediment is eroded down, exposing the bedrock. The maximum depth at which the seagrass beds occur is controlled by turbidity and the intensity of light penetration.

Nature of Seabed

The type of substratum plays a major role in the distribution of seagrasses. For the rhizomes to grow and for the anchoring of roots, seagrasses typically require a soft substrate of gravel, sand or mud (Greve and Binzer, 2004). Sediment grain size distribution and organic content seem to be particularly important factors due to their effects on dissolved oxygen levels and concentrations of sulfide and other phytotoxins in pore water (Koch, 2001).

Chemical Factors

Nutrients

Excessive nutrient concentrations may hinder seagrass survival. Nitrogen and phosphorus are the most quantitatively important inorganic nutrients, with the ratio of nitrogen to phosphorus determining the dominant plant community. Seagrasses have very low nutrient requirements when compared to other macroalgae and phytoplankton, and it is estimated that seagrasses requires about four times less nitrogen and phosphorous per unit of carbon than phytoplankton cells (Duarte, 1990, 1992). The competitive advantage results from the capacity of seagrasses to take up nutrients from sediments in addition to the water column, whereas once the water column nutrient concentrations are high, blooms of phytoplankton and macroalgae shade seagrass meadows, eventually leading to their exclusion (Duarte, 1995). This gives an added advantage for the sustenance of seagrasses in oligotrophic environments such as the Arabian Gulf compared with other primary producers.

Sulfide

Sulfide in sediments can be toxic to seagrasses at concentrations > 1 mM, which commonly occurs in anoxic sediments as a byproduct of bacterial nutrient remineralization (Carlson, et al., 2002). The toxicity, due to sulfide, increases when light availability is reduced as photosynthesis rates would not be adequate to produce oxygen to maintain an oxidized zone adjacent to plant roots (Calleja, et al., 2006).

Seagrass Species in the Western Arabian Gulf

Species Occurrence

Three seagrass species have been reported in the Arabian Gulf (Erftemeijer and Shuail, 2012). Efforts of KFUPM/RI to map seagrass biotopes in the Arabian Gulf for the past three decades confirm the presence of only three dominant species of seagrasses, i.e., *H. uninervis*, *H. stipulacea* and *H. ovalis*. Phillips (2003) reports three seagrass species *H. uninervis*, *H. stipulacea* and *H. ovalis* in Saudi Arabia, Bahrain, Qatar and the UAE, two species *H. uninervis* and *H. ovalis* in Kuwait, but one species in Iran *H. uninervis* and the absence of seagrasses in Iraq.

As indicated above, the total extent of mapped seagrass habitats in the Arabian Gulf is estimated to be from 6,790 km^2 to 7,320 km^2, of which 565 km^2 exists in the Saudi waters of the Arabian Gulf (Phillips, 2003). This is an underestimate because large areas have not yet been surveyed. Green and Short (2003) estimated the extent of seagrasses in the Arabian Gulf to be approximately 10,000 km^2, which is around 6% of the global total. Price (1990) provided the first comprehensive overview of seagrass extent in the Arabian Gulf, surveying 53 discrete sites at approximately 10 km intervals spanning the entire 450 km of the Saudi Arabian Gulf shoreline where the abundance of mangroves, seagrasses, halophytes and macroalgae was assessed. From his assessment, he found seagrasses only at 15 sites with the largest beds occurring in the north between Safaniyah and Manifa, in Al-Mussallamiyah, south of Abu 'Ali, Tarut Bay, Half Moon Bay, Al Uqayr and the Gulf of Salwa. KFUPM/RI's data shows that the percentage coverage of seagrasses along the Saudi coast of the Arabian Gulf ranges from 12.7% to 71.6% (Figure 3.62). The lowest coverage was found north of Abu 'Ali and the highest coverage was found in Tarut Bay.

Spatial Pattern and Zonation

In the Arabian Gulf, seagrass beds are confined to sandy and muddy substrates in the nearshore waters shallower than 10 m. Even though the maximum depth penetration of seagrasses has not been thoroughly assessed, Erftemeijer and Shuail (2012) observed seagrasses down to a depth of 22 m. The percentage composition of the three most abundant seagrass species in the Saudi coastal area of the Arabian Gulf,

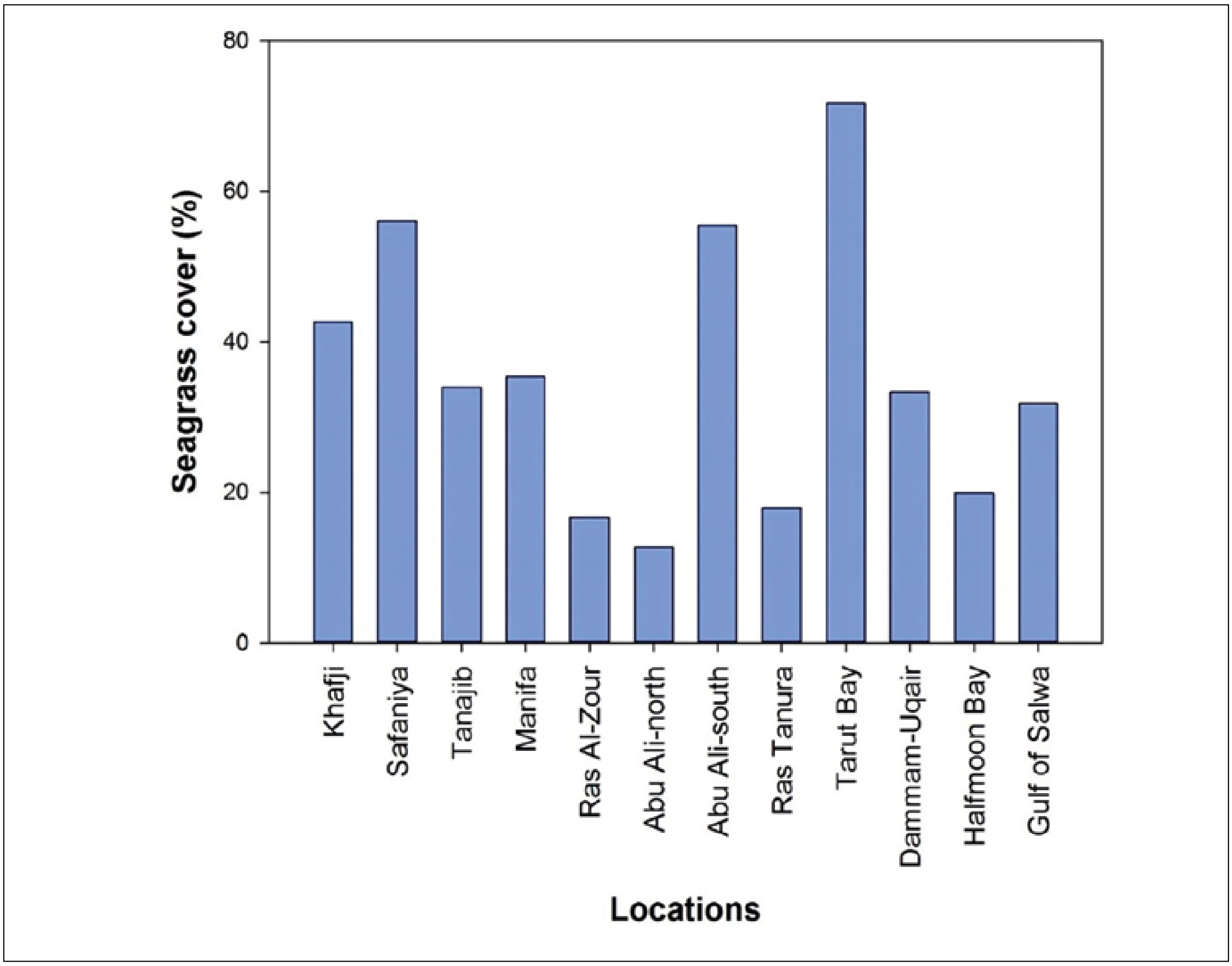

FIGURE 3.62. *Seagrass coverage (%) along the Arabian Gulf coast of Saudi Arabia (KFUPM/RI, 2015a).*

such as Khafji, Safaniyah, Tanajib, Manifa, Ras Tanura, Half Moon Bay and the Gulf of Salwa, reveals that seagrasses exist as mixed species meadows (Figure 3.63). Monospecific meadows of *H. uninervis* are found at Ras al-Khair and Abu 'Ali while meadows of *H. stipulacea* were found in the Dammam and Al Uqair regions. This is the favorite food for dugong and may correlate with dugong distribution, which is mostly south of Dammam.

Factors Favoring Seagrass Abundance

Price and Coles (1992) found no significant correlation between salinity and the seagrass cover and biomass along the Saudi Arabian coastline.

H. ovalis has been found to be the most broadly euryhaline of the three seagrass species in the Gulf and because of its tolerance to salinity, it is always found occupying the shallow areas subject to extreme salinity ranges as in Al Uqair and parts of the Gulf of Salwah (Figure 3.64). Sheltered inner bays such as Manifa, Tarut and Abu 'Ali favor *H. uninervis* while the unsheltered open coasts such as Khafji, Safaniyah and Tanajib favors *H. ovalis*, in addition to *H. uninervis* (Figure 3.65). The scatterplot of seagrass cover (%) with depth (Figure 3.66) shows that *H. stipulacea* has the highest depth tolerance followed by *H. ovalis* and *H. uninervis*. This is also evident from the distribution of *H. uninervis* (Figure 3.64) along the shallow coastline of Saudi Arabia.

The abundance of seagrasses clearly shows that sand is the most preferred substratum followed by mixed, and mud types with the least preference for rocks (Figure 3.67).

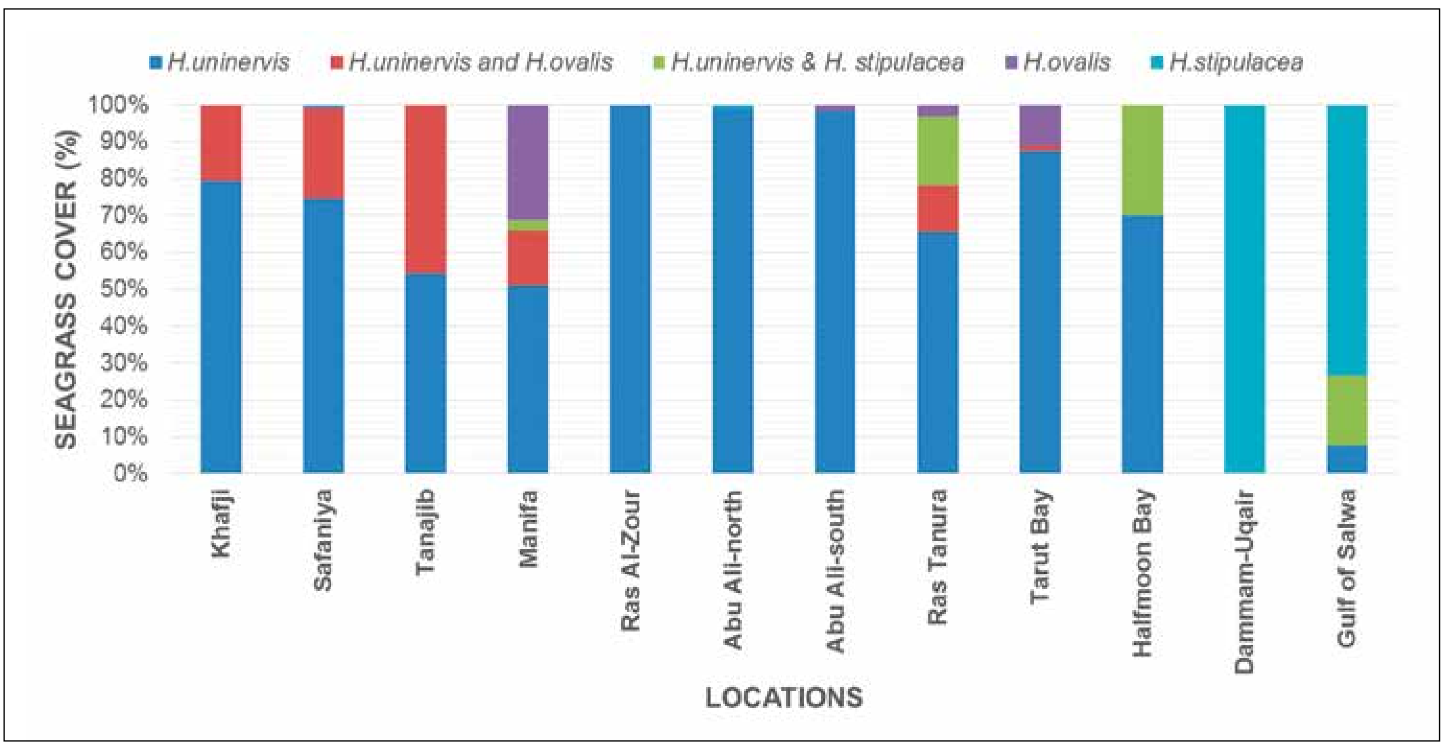

FIGURE 3.63. *Seagrass coverage (%) of different species of seagrasses along the Arabian Gulf coast of Saudi Arabia (KFUPM/RI, 2015a).*

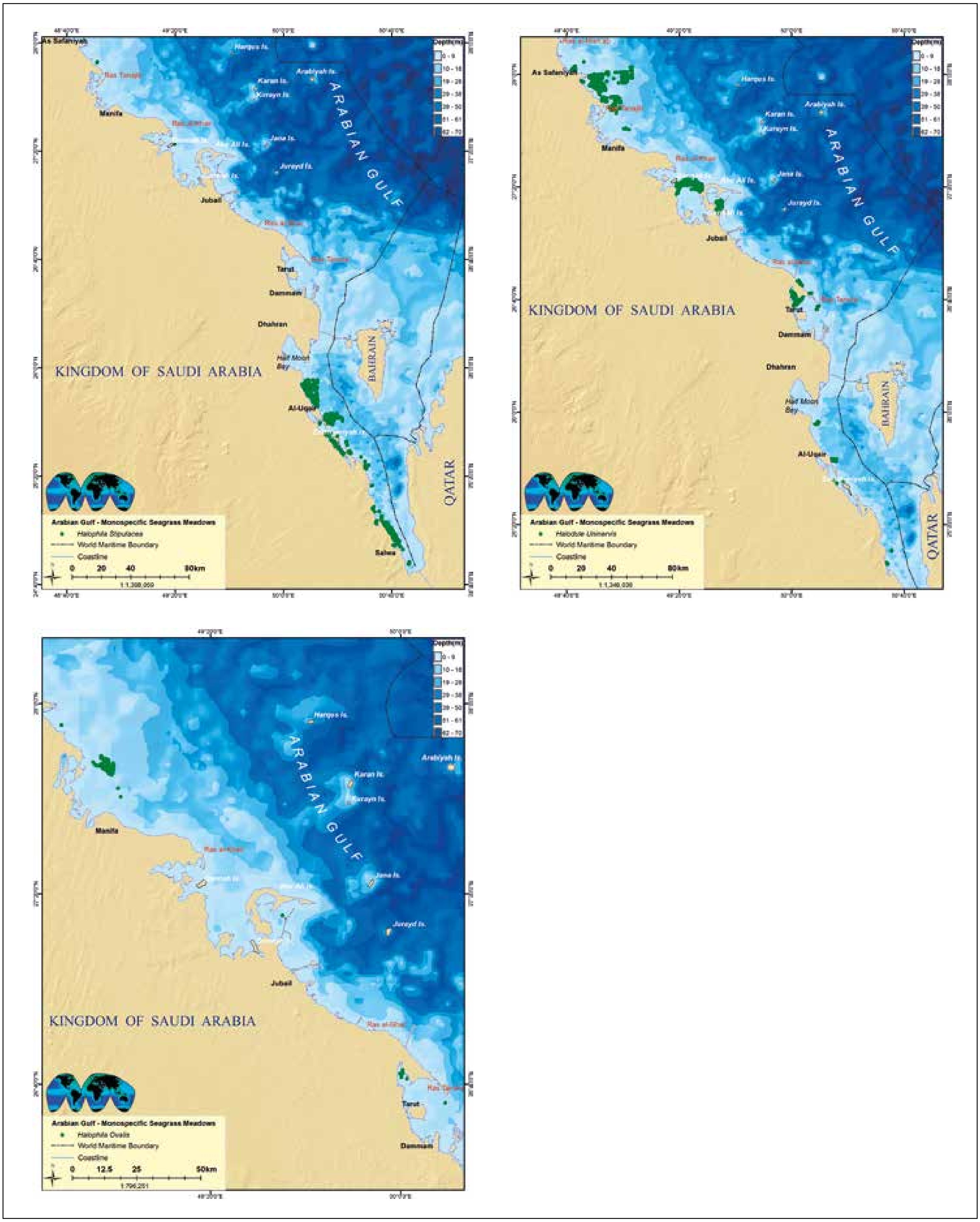

FIGURE 3.64. *Distribution of monospecific seagrass meadows along the Arabian Gulf coast of Saudi Arabia (KFUPM/RI, 2015a).*

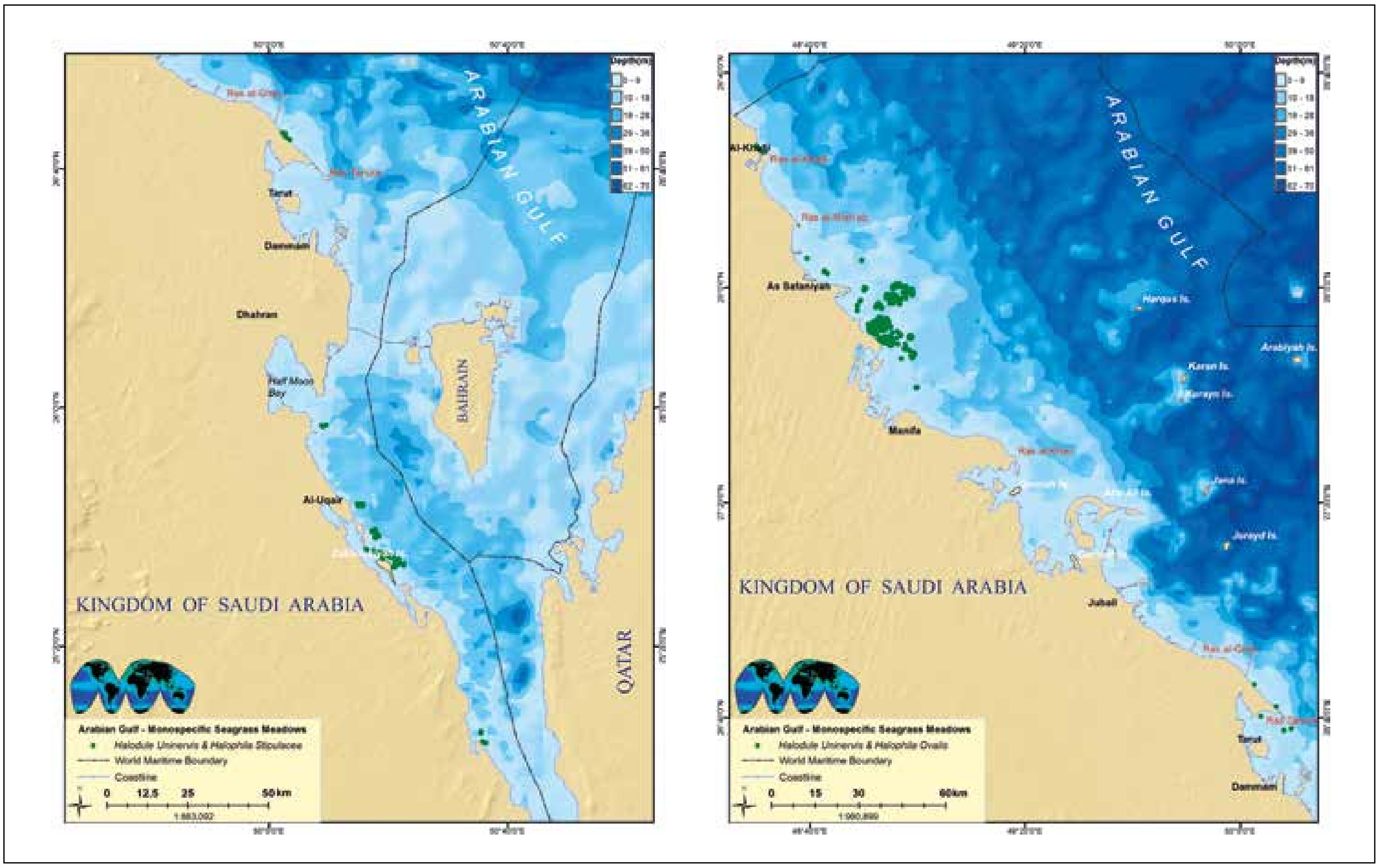

FIGURE 3.65. *Distribution of mixed species seagrass meadows along the Arabian Gulf coast of Saudi Arabia (KFUPM/RI, 2015a).*

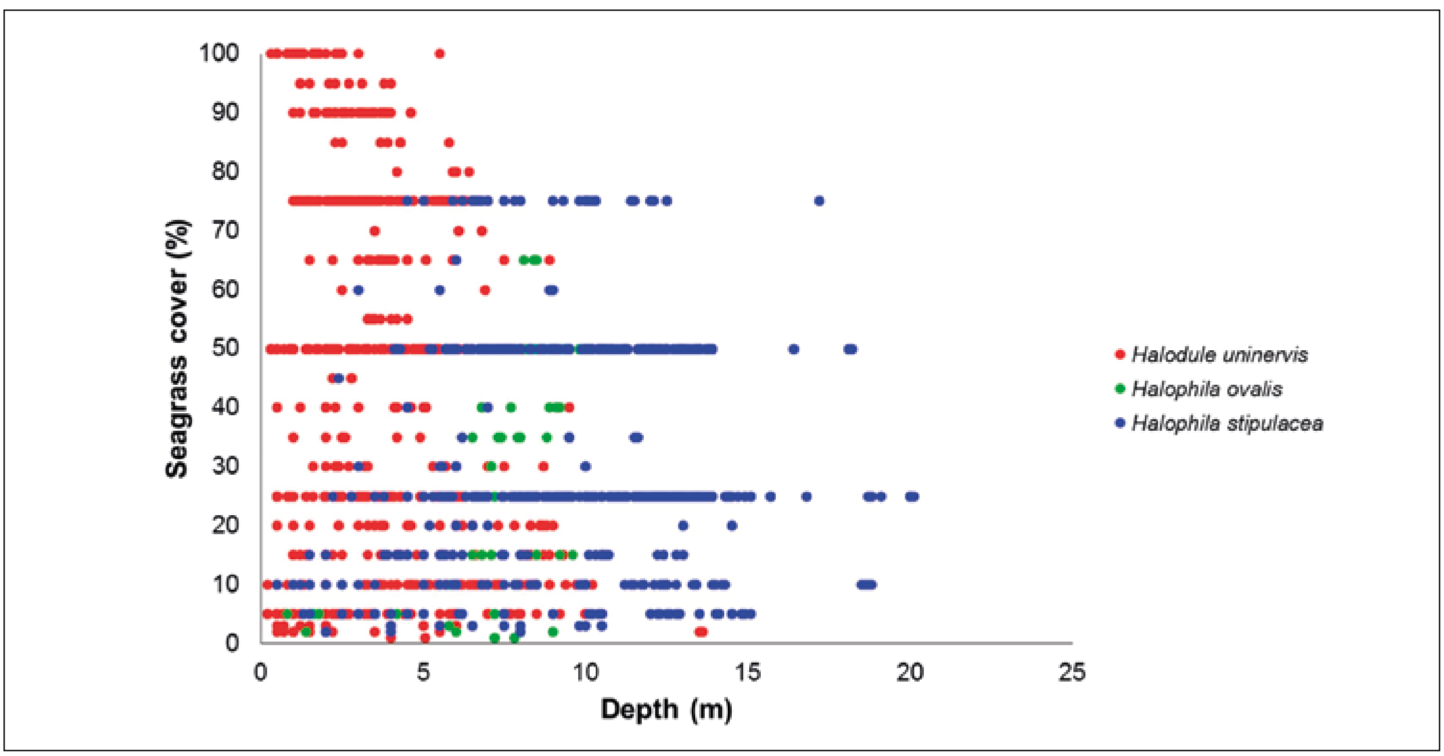

FIGURE 3.66. *Scatterplot of seagrass coverage (%) with depth (KFUPM/RI, 2015a).*

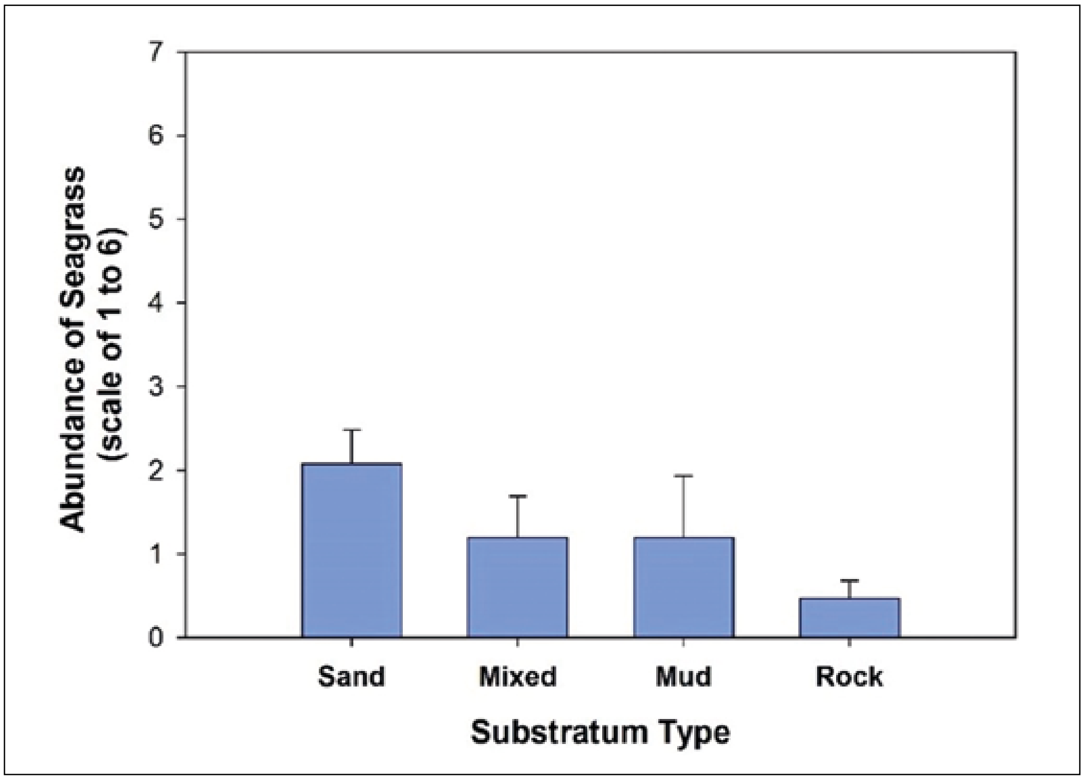

FIGURE 3.67. *Abundance of seagrass with substratum type (Price and Coles, 1992).*

Extent of Seagrass Habitats

The digitized biotope map of the Arabian Gulf coast of Saudi Arabia prepared by KFUPM/RI was utilized in the estimation of seagrass cover. The extent of coverage of seagrass meadows along the Saudi coast of the Arabian Gulf was estimated to be around 88,837 ha (Table 3.20 and Figure 3.68) (KFUPM/RI, 2015a). Half Moon Bay had the highest seagrass cover with a total area of 36,410 ha and Manifa had the least coverage with an area of only 47.82 ha.

Reclamation of Tarut Bay from 1973 to 1985 resulted in the loss of around 1,050 ha of seagrass habitats (Al-Thukair, et al., 1995). In addition, construction of the Bahrain-Saudi Arabia (King Fahd) Causeway (direct footprint 2 km^2 involving several million m^3 of fill) has had major impacts on the marine ecology of the region, including seagrass beds (Price, et al., 1984). Similarly, sediment spill from dredging and reclamation during the construction of the new Qatar-Bahrain causeway is expected to affect some 4 km^2 to 5 km^2 of seagrass beds (COWI, 2008). Seagrasses in the Arabian Gulf are well adapted to the harsh environmental conditions in the Gulf, characterized by extreme natural fluctuations in temperature and salinity. Subsequently, a recent and unprecedented increase in the threats to seagrass habitats in the Gulf, particularly from large-scale dredge and fill operations, desalination plants, and other industrial developments (Sheppard, et al., 2010), are challenging the resilience of seagrass in the Arabian Gulf. This issue must be addressed in a concerted manner within and between the various Gulf states for the successful management of seagrass habitats, which are key habitats for shared resources, such as dugong and turtle populations and various fish and shrimp species.

TABLE 3.20. *The extent of seagrass meadows along the Arabian Gulf coast of Saudi Arabia (KFUPM/RI, 2015a).*

Location	Seagrass Type	Area (Hectares)	Area (sq. km)
Khafji	Sparse Seagrass	498.89	4.99
	Dense Seagrass	1,715.18	17.15
	Subtotal	**2,214.07**	**22.14**
Safaniya	Sparse Seagrass	10,616.59	106.17
	Dense Seagrass	7,044.65	70.45
	Subtotal	**17,661.24**	**176.61**
Tanajib	Sparse Seagrass	10,205.24	102.05
	Dense Seagrass	2,200.46	22.00
	Subtotal	**12,405.70**	**124.06**
Manifa	Sparse Seagrass	26.30	0.26
	Dense Seagrass	21.52	0.22
	Subtotal	**47.82**	**0.48**
Ras Al-zour	Sparse Seagrass	2,516.18	25.16
	Dense Seagrass	709.32	7.09
	Subtotal	**3,225.50**	**32.26**
Abu ‘Ali	Sparse Seagrass	2,082.03	20.82
	Dense Seagrass	3,459.39	34.59
	Subtotal	**5,541.42**	**55.41**
Tarut Bay	Sparse Seagrass	4,032.56	40.33
Half Moon Bay	Sparse Seagrass	16,352.31	163.52
	Dense Seagrass	20,057.84	200.58
	Subtotal	**36,410.14**	**364.10**
Uqair and Salwa	Sparse Seagrass	5,499.33	54.99
	Dense Seagrass	1,799.28	17.99
	Subtotal	**7,298.61**	**72.99**
	Total	**88,837.06**	**888.37**

Inhabitants of Seagrass Beds

Flora

Although seagrass beds have a monotonous appearance, the superficial appearance of these uniform looking seagrass meadows masks a great diversity of other flora. The associated flora includes epiphytic algae that appear on the leaf blade and macroalgae that are attached to the substratum. Although the epiphytic components of seagrass beds have not been studied in detail in the western Arabian Gulf, whereas various qualitative studies (KFUPM/RI, 1987; KFUPM/RI, 2010a; Clerk and Coppejans, 1996) conducted in the northern part of the Saudi coast of the Arabian Gulf recorded 46 species of macroalgae associated to seagrass beds (Table 3.21). These species belonged to green algae (13 species), brown algae (eight species) and red algae (25 species). This list clearly proves the importance of the accompanying flora as structural elements, which add to the complexity of the seagrass community. A detailed description of macroalgae is presented in Chapter 3.5.

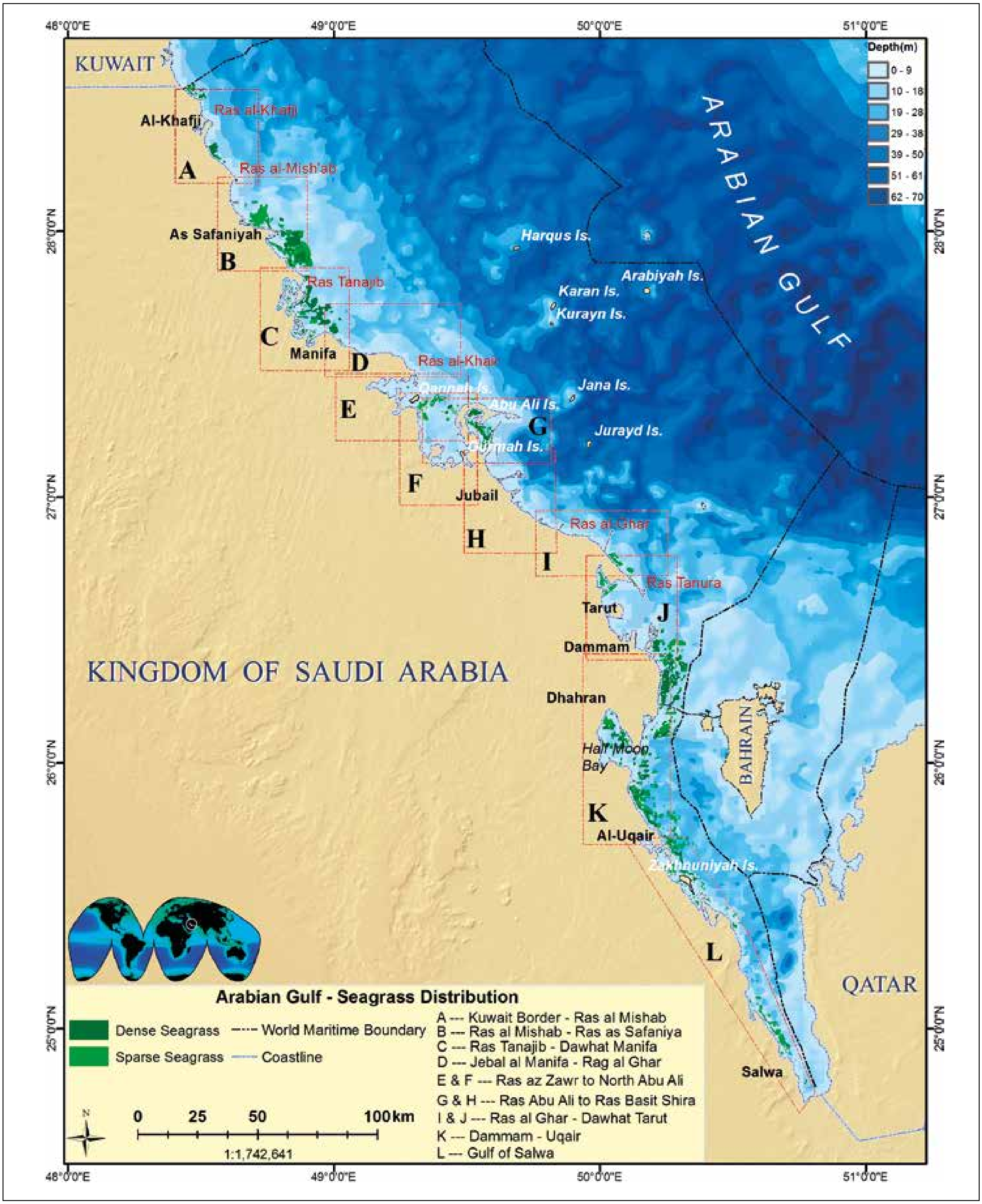

FIGURE 3.68. *Distribution of dense and sparse seagrass meadows along the Arabian Gulf coast of Saudi Arabia (KFUPM/RI, 2015a).*

TABLE 3.21. *A checklist of macroalgae recorded from the seagrass beds of the northern Saudi coast of the Arabian Gulf*.*

Sl No.	Species	Sl No.	Species	Sl No.	Species
	Phylum: Chlorophyta		**Phylum: Heterokontophyta**	29	*Dasya* sp.
	Class: Ulvophyceae		**Class: Phaeophyceae**	30	*Fosliella farinosa*
1	*Acetabularia calyculus*	14	*Colpomenia sinousa*	31	*Gelidium pusillum*
2	*Avrainvillea amadelpha*	15	*Dictyota divaricata*	32	*Gelidium* sp.
3	*Chaetomorpha* sp.	16	*Ectocarpus* sp.	33	*Griffithsia tenuis*
4	*Cladophora coelothrix*	17	*Iyengaria stellata*	34	*Heterosiphonia wurdemanni*
5	*Cladophora koei*	18	*Sphacelaria* sp.	35	*Hypnea cornuta*
6	*Cladophora nitellopsis*	19	*Hormophysa* sp.	36	*Jania rubens*
7	*Cladophora sericoides*	20	*Sargassum* sp.	37	*Laurencia* sp.
8	*Cladophora* sp.	21	*Padina* sp.	38	*Laurencia* sp. A
9	*Enteromorpha* sp.		**Phylum: Rhodophyta**	39	*Lithothamnion* sp.
10	*Rhizoclonium tortuosum*		**Class: Florideophyceae**	40	*Lophosiphonia subadunca*
11	*Spyridia filamentosa*	22	*Acanthophora spicifera*	41	*Lophosiphonia villum*
12	*Codium* sp.	23	*Centroceras clavulatum*	42	*Polysiphonia* sp.
13	*Udotea* sp.	24	*Ceramium cruciatum*	43	*Polysiphonia* sp. A
		25	*Ceramium maryae*	44	*Polysiphonia* sp. B
		26	*Champia* sp.	45	*Polysiphonia* sp. G
		27	*Chondria dasyphylla*	46	*Polysiphonia* sp. M
		28	*Chondria hypnoides*		

*Based on KFUPM/RI 1987, 2010, Clerk and Coppejans 1996.

Fauna

Except for coral reefs, the seagrass beds of the Arabian Gulf are richer, in both numbers and the variety of organisms than any other biotope occupying the same depth range (Basson, et al., 1977). According to Kikuchi and Peres (1977), three types of communities can be found in the seagrass beds: (1) epifaunal species living on leaves, including micro- and meiofauna, composed of sessile fauna, mobile creeping and walking epifauna (e.g., gastropods) and swimming epifauna (e.g., caridean shrimp), (2) mobile species living freely under and over the leaf canopy (e.g., fishes), and (3) infaunal species, including burrowers and tube dwellers as well as those animals creeping or crawling at the sediment water interface.

Benthic Communities: The number of species and individuals of benthos are significantly greater in seagrass than in bare sediments, indicating that the finer grained sediments of the seagrass areas and the refugia from predators and high energy offered by their canopies support more diverse and abundant benthic communities. Previous studies conducted in the Saudi waters of the Gulf with samples collected from the seagrass beds and adjacent sand/silt habitats showed a 274% to 467% increase in density and 186% increase in biomass in the benthos of seagrass beds compared to those in the adjacent nonvegetated habitats (McCain, 1984; KFUPM/RI, 1987; Coles and McCain, 1990) (Table 3.22); however, this trend was not evident in the diversity of macrobenthos. The increased heterogeneity and complexity of this habitat result in the richness of fauna, particularly epifauna in a seagrass habitat compared to a non-seagrass habitat

TABLE 3.22. *Comparison of macrobenthic structural parameters between the seagrass bed and adjacent sand/silt habitats in the nearshore region.*

Study	Region	Biomass (g. m^{-2})		Density (ind. m^{-2})		Species richness (per m^2)		Diversity	
		Seagrass bed	Sand/silt habitat	Seagrass bed	Sand/silt habitat	Seagrass bed	Sand/silt habitat	Seagrass bed	Sand/silt habitat
KFUPM/RI (1987) McCain (1984)	Bandar Mishab – Manifa	—	—	450-36,200	840-9,670	15-84	22-91	0.5-5.5	1.9-5.5
KFUPM/RI (1988)/ Coles and McCain (1990)	Safaniyah –Salwa	10.3	3.6	550-51,970	120-9,170	35-78	15-51	—	—
KFUPM/RI (2003)	Safaniya – Ras Tanura	0.6-4.7	0.2-5.6	2,580-12,153	1,173-8,683	47-68	17-51	3.8-4.6	2.9-4.7

(McCain, 1984; Coles and McCain, 1990). Basson, et al. (1977) had reported the occurrence of over 500 species of benthic fauna from seagrass beds. This includes about 140 species of burrowing polychaetes, about 90 species of gastropods, 70 species of bivalves, over 45 species of decapod crustaceans, and 35 species of amphipods. Later studies recorded more species (KFUPM/RI, 1987, 2003) from the seagrass beds of the northern Saudi coast of the Arabian Gulf. This extensive seagrass study recorded a total of 1,128 benthic species with polychaetes, gastropods, and amphipods as the most species rich taxa (Table 3.23).

TABLE 3.23. *A list of benthic organisms recorded from the seagrass beds of the northern Saudi coast of the Arabian Gulf*.*

Taxa	Number of species	Taxa	Number of species	Taxa	Number of species
Porifera	33	Copepoda	43	Pelecypoda	77
Hydroida	23	Cumacea	33	Gastropoda	248
Actiniaria	2	Decapoda	44	Scaphopoda	7
Polychaeta	309	Penaidea	1	Stomatopoda	2
Oligochaeta	18	Caridae	6	Polyplacophora	6
Amphipoda	100	Nebalia	2	Asteroidea	6
Caprellidea	6	Bryozoa	23	Ophiuroidea	20
Isopoda	23	Echiura	1	Echinoidea	15
Myodocopa	19	Halocaridea	2	Holothuroidea	7
Podocopa	18	Pycnogonida	5	Cephalochordata	1
Tanaidacea	11	Sipunculoida	13	Pisces	2
Cirripedia	1	Turbellaria	1	***Total No. of Species***	***1,128***

*Based on KFUPM/RI 1987, 2003.

The dominant infaunal taxa recorded from the seagrass beds were bivalves (507 ind. m^{-2}), polychaetes such as *Exogone clavator* (208 ind. m^{-2}), *Euchone* sp. (116 ind. m^{-2}), *Prionospio* sp. (115 ind. m^{-2}) and ophiuroids (169 ind. m^{-2}) (KFUPM/RI, 2003). Large macrofauna are often noticeable in seagrass beds. The common and conspicuous organisms noted in the seagrass beds from the central part of the Saudi coast were bivalves, pen shell *Pinna muricata*, bubble shell, *Bulla ampulla, Chama* sp., carnivorous snail, *Murex* kusterianus, tunicates *Phallusia nigra* and *Botryllus* sp., black sea cucumber *Holothuria atra,* sea urchins and sponges (Basson, et al., 1977, KFUPM/RI, 2011).

McCain (1984) observed that seagrass benthic communities are similar in various parts of the northwestern Arabian Gulf at a given season, but shows seasonal variation. In addition, the benthic fauna in seagrasses and sand/silt habitats in the Gulf are principally suspension feeders, which feed on suspended organic particulates, which are abundant in the Gulf (Price, et al., 1993).

Dugong (Dugong dugong): They are the largest marine mammalian grazers of the tropical Indo-west Pacific region, where they feed primarily on nearshore seagrasses (Lipkin, 1975; Johnstone and Hudson, 1981; Marsh, et al., 1982; Preen, 1995). The Arabian Gulf supports a population of approximately 5,800 dugongs, and the Gulf is believed to have the second largest population in the world after Australia (Preen, 1989), but concentrated in a much smaller area. The distribution of dugongs is primarily restricted to the southwest and southern Gulf, between Ras Tanura on the Saudi coast, to Ras Ghanadha in the UAE (Preen, 2004). In the western Arabian Gulf, dugongs can be found in abundance between Bahrain and Qatar and between Saudi Arabia and Bahrain, south of the Saudi Arabia-Bahrain Causeway and North of Uqair (Preen, 2004).

It appears that temperature is the limiting factor controlling the distribution of dugongs in the Arabian Gulf (Preen, 2004). Dugongs are tropical and subtropical in distribution and the extremes of their latitudinal range correspond with a mean surface water temperature of 23 °C (Nishiwaki, et al., 1979). The absence of dugongs in the northern Arabian Gulf (north of Ras Tanura) is attributed to the lower average monthly water temperature (< 19 °C for about four months), which is unsuitable for this mammal species. They are seen even in the high saline waters of the Gulf of Salwa (salinity of 50 ppm to 70 ppm), and therefore, it is assumed that salinity is not a factor controlling their distribution in the Gulf (Preen, 2004).

Studies indicate that dugongs prefer species of the genera *Halophila* and *Haladule* as food items (Preen and Marsh, 1995). This is because the former seagrass species are highly digestible, nutrient rich and grow rapidly, which shows that dugongs maximize the intake of nutrients rather than bulk (Lanyon, 1991; Aragones, 1996, cited in UNEP 2002). They usually feed in large herds (median herd size 140), which often graze the same location for periods of up to a month or more (Preen, 1995). Dugongs normally uproot the whole plant while feeding, but only leaves will be eaten, if it cannot be uprooted. Such grazing may have a profound impact on the seagrass; however, according to Preen (1995), recovery of the seagrass after the grazing by dugongs is rapid. This is because dugongs will not methodically crop all the seagrass in an area. There will be patches of ungrazable reserve (Noy-Meir, 1975), which are the key to the resilience of the seagrass meadows in the face of intensive grazing disturbance and can recolonize the areas through the rapid rhizome spread characteristic of these species (Marba and Duarte, 1998).

Dugongs are vulnerable to human pressures because of their life history and their dependence on seagrasses that are restricted to coastal habitats. Therefore, dugongs faced catastrophic mortality during the 1991 Gulf oil spill. Large-mesh fishing nets pose another threat to dugongs in the Gulf. Currently, dugongs are classified as vulnerable to extinction under the 1996 World Conservation Union (IUCN) Red List of Threatened Species. It is deemed A1 class, in which the population reduction happens for at least 20% over the last 10 years or three generations, whichever is the longest (Bryden, et al., 1998).

Other Inhabitants of the Seagrass Beds: Worldwide, seagrass beds are recognized to be one of the potential nursery habitats for shrimp and fishes (Haywood, et al., 1995; Bertelli and Unsworth, 2013). In the western Arabian Gulf, juveniles of *Penaeus semisulcatus* have been recorded in significant numbers only from the seagrass bed habitats (KFUPM/RI, 2003). The juveniles of *P. semisulcatus*, when they become about 1 cm long, are found among seagrass beds and remain there for several months until they grow to nearly adult size (Basson, et al., 1977).

A higher number of species have been recorded from stations with seagrass beds compared to bare areas (Rabaoui, et al., 2015). According to a recent study, the most common species recorded from seagrass beds of the Saudi waters of the Gulf include white-spotted spinefoot *Siganus canaliculatus*, Orangefin ponyfish *Leiognathus bindus*, pigfaced leather jacket *Paramonacanthus choirocephalus*, striped eel catfish *Plotosus lineatus*, common silver-biddy *Gerres oyena*, short-nosed tripodfish *Triacanthus biaculeatus*, striped piggy *Pomadasys stridens*, Haffara seabream *Rhabdosargus haffara*, bartail flathead *Platycephalus indicus*, and Bloch's gizzard shad *Nematalosa nasus* (KFUPM/RI, 2016).

Turtles and sea snakes are also important inhabitants of the seagrass beds (Miller, et al., 2004; Miller, 2011; Miller, et al., in this book). Of the five turtle species recorded from the Arabian Gulf, the Green sea turtle, *Chelonia mydas,* lives and feeds mostly on seagrass (Mortimer, 1981; Bonnet, et al., 1985; Lanyon, et al., 1989; Miller, 2011; Miller, in this book). Miller (1989b) identified foraging areas of green turtles in the Saudi waters of the Gulf, which include Dawhat Abu 'Ali, the shallow area north of Abu 'Ali and south of Safaniyah. More turtles were recorded from the most northerly seagrass beds and the reduced number of turtles toward the Gulf of Salwa in the south coincided with the decrease in the amount of seagrass (Miller, 2011b). In the case of sea snakes, there may be some specific habitat associations among the species, but because so many of the specimens have been recorded as beach washed carcasses, it is even more difficult to interpret habitat associations. Those sea snake species recorded from the shallow water areas are likely to utilize seagrass beds also. *Hydrophis* sp. are typically found in shallow water areas with sandy substrate (Martens, 1996). Although specimens recovered from Judhaim in the Gulf of Salwa had fed on sand dwelling gobiids (*Amblygobius albimaculatus*) and coral reef fish (*Plotosus lineatus*), indicating that they at least be in several different habitats (Martens, 1996). Other sea snakes in the region have been noted to feed on subtidal gobiids and mud skippers *H. lapemoides* and *H. cyanocinctus,* (Volsoe, 1939).

Pearl oysters are also associated with the seagrass beds. The most preferred site of spat settlement is the leaves of seagrass, especially *H. uninervis*. There would be hundreds of spats in each grass blade. When the grass blades begin to die and come adrift, the young oysters apparently release their attachment and re-attach to the remaining upright blades. This will be continued until the young ones attain the size to attach to any solid substrata.

Discussion

Goods and Services of Seagrass Beds in the Western Arabian Gulf Marine Ecosystem

Goods and services of seagrass beds are essentially the benefits that humans derive from the ecological functions of seagrass bed systems (Millennium Ecosystem Assessment, 2005; Hein, et al., 2006; Beaumont, et al., 2007; Foster, et al., 2013). Previous studies assessed the role of seagrass beds as a nursery, and feeding and breeding grounds for a variety of fish and invertebrate species (Bell and Pollard, 1989; Orth, 1992; Ronnback, 1999; Nagelkerken, et al., 2002; Minello, et al., 2003; Heck, et al., 2003). These roles can be summarized as follows: (1) seagrasses provide shelter to other organisms from predation due to their structural complexity, (2) seagrass beds provides food to a large number of organisms in the form of seagrass, epiphytes, detrital material as well as macrofauna and meiofauna, and (3) the physical structure of the seagrass reduces the water energy of incoming currents and waves, and immigrating early life stages of fish and shell fish can, therefore, settle in these "calm" waters, and allowing significant organic carbon deposits to develop, sequestering carbon dioxide (CO_2). Worldwide, only limited assessments on the goods and services provided by seagrass beds have been conducted so far (de la Torre-Castro and Rommback, 2004; Duffy, 2006; Duarte, 2002; Cullen-Unsworth and Unsworth, 2013) and as per our knowledge, no such studies have been conducted in the Arabian Gulf. This section attempts to discuss the goods and services provided by seagrass beds in the western Arabian Gulf, based on the framework provided by the Millennium Ecosystem Assessment (2005); Hein, et al. (2006) and Beaumont, et al. (2007) and the assessment in the seagrass beds made by in other parts of the world (de la Torre-Castro and Rommback, 2004; Dufffy, 2006; Cullen-Unsworth and Unsworth, 2013).

As per the abovementioned framework, the ecosystem services provided by or derived from seagrass beds may be divided in to four categories: (1) provisioning, (2) regulating, (3) cultural, and (4) supporting services (Millennium Ecosystem Assessment, 2005; Beaumont, et al., 2007; Foster, et al., 2013) (Table 3.24). It is these services that make seagrass ecosystems critical contributors to the well-being of the western Arabian Gulf, and the economy worldwide.

Provisioning Services

They are the products obtained in the system. Seagrass beds support commercially important species and species with high economic value through their role in subsistence fisheries. Seagrass beds provide an indirect food source for the resident fauna and temporary visitors. Generally, in the western Arabian Gulf, only very few animals such as dugongs, green turtles, as well as some sea urchins and fishes directly use seagrass vegetation as a source of food (Price, et al., 1993). The majority of the residents in this habitat consume seagrass indirectly after it has been broken down by mechanical and microbial action to become available through detrital food chains. Because of this food provision for fishes and shrimps, seagrass beds in the western Arabian Gulf are considered to be an ideal fishing ground. This has been revealed by scientific studies (KFUPM, unpublished data) as well from the consideration of fishermen that higher catches of fishes record in and in the seagrass bed than the adjacent nonvegetated areas. Worldwide, fishermen consider seagrass to be the most important fishing grounds. A survey conducted in tropical East

TABLE 3.24. *Goods and services provided by or derived from seagrass beds in the western Arabian Gulf*.*

Services	Example of Goods and Services Provided or Derived
Provisioning	
Food	Conversion of light energy in to biomass. Production of fish and shell fishes, nursery ground for juveniles of fishes and shell fishes. Provision of commercial and artisanal fisheries. Feeding grounds for dugongs and turtles.
Regulating	
Gas and climate regulation	Production of O_2 and sink of CO_2; responses to large climatic changes (CO_2, temperature and sea level increases)
Bioremediation of waste	Storage and recycling of pollutants
Disturbance prevention	Erosion and sediment control, provision of low energy areas (control of wave and tide energy), protection of the coastline.
Cultural	
Recreational	Provision of opportunities for recreation and tourism
Educational	Provision of scientific and educational information
Supporting	
Biodiversity	Provision of habitat for resident and transient species
Nutrient cycling	Export of organic matter and nutrients (both in water column and in sediment), burial of organic matter and nutrients, global carbon budget,

*Based on the Millennium Ecosystem Assessment, 2005; Hein, et al., 2006; Beaumont, et al., 2007; Foster, et al., 2013; de la Torre-Castro and Rommback, 2004; Dufffy, 2006; Cullen-Unsworth and Unsworth, 2013.

Africa shows that when fishermen were asked to rank habitat importance for fish, 70% of the respondents ranked seagrass as the prime fishing habitat and only 23% ranked coral reefs first (de la Torre-Castro and Rommback, 2004). With regard to the western Arabian Gulf, according to a previous estimate, the 410 km^2 seagrass bed of Tarut Bay supports the production of ~4 million kg of fish and shrimp annually worth $22 million (Price, et al., 1993). In the western Arabian Gulf, seagrass beds serve as an important nursery grounds for juvenile fishes, shell fishes and other marine organisms. A best example is the vast seagrass beds of the Manifa-Tanajib Bay System (MTBS) that serve as an ideal nursery grounds for fishes and shrimps (KFUPM/RI, 2003).

Elsewhere in the world, seagrass has several other uses, such as their leaves and roots being used for construction of fishing traps and carpets, leaves for salad, manure and fodder, seeds for consumption, and for traditional medicines (Moberg and Folke, 1999; de la Torre-Castro, 2006); however, such uses have not been recorded in the western Arabian Gulf region.

Regulating Services

These services result from the capacity of ecosystems to regulate climate, hydrological and bio-chemical cycles, earth surface processes, and a variety of biological processes. Gas and climate regulation is an ecosystem service where living marine organisms contribute considerably to the maintenance of the chemical composition of the atmosphere and oceans. Seagrass and the organisms in the seagrass beds play a major role in climate control through their regulation of carbon fluxes (Beaumont, et al., 2007). Because much seagrass production ends up in underground tissues and ungrazed detritus, seagrass beds are an important global sink for carbon, accounting for an estimated 15% of net CO_2 uptake by marine organisms on a global scale, despite contributing only 1% of marine primary production (Duarte and Chiscano, 1990). A recent estimate suggests that there could be as much as 73 billion metric tons of CO_2 already being stored in the world's seagrass beds (Cullen-Unsworth and Unsworth, 2013). Therefore, seagrass beds help to reduce marine carbon emission. Because biodiversity can affect the capacity of a marine environment to act as a carbon sink, this service is directly linked with the species diversity of the associated organisms in the seagrass bed. While other habitats such as coral reefs and mussel beds are predicted to decline as a result of rising sea temperatures, ocean acidification and increased industrialization, seagrass beds have physiological characteristics that will likely make them less vulnerable to global environmental changes (Cullen-Unsworth and Unsworth, 2013).

Other regulatory services also include the role of seagrass beds in removing pollutants through storage, burial and recycling. This is being done in a way that marine living organisms store, bury and transform many wastes through assimilation and chemical de- and re-composition, either directly or indirectly (Mangi, et al., 2011). For example, the bioturbation reworking and mixing of sediments process as carried out by megafaunal and macrofaunal organisms living in the seagrass bed will serve to bury and recycle wastes through assimilation and chemical recomposition and simple burial with no assimilation at all. These detoxification and purification processes are of critical importance to the health of the marine environment, particularly the Arabian Gulf, where a large-scale of the human pressures in the form of release of oil and heavy metals into the marine environment are taking place.

Seagrass beds may be a natural and sustainable form of coastal erosion protection. The studies conducted elsewhere in the world showed that seagrass beds provide natural sea defense by acting as buffer zones to wave action and storm surges (Brampton, 1992; Pethick, 1992). The presence of seagrass beds can dampen and prevent the impact of tidal surges and storms and floods through binding of sediments and wave attenuation (Moller and Spencer, 2002; Widdows and Brinsley, 2002). In addition, seagrass meadows increase sediment accretion and raise the seafloor at average rates of 2 to 3 mm $year^{-1}$, thereby contributing to mitigate the impacts of sea level rise and increased storminess with climate change (Duarte, et al., 2013).

Cultural Services

These services relate to the benefits that people obtain from ecosystems through recreation, cognitive development, relaxation, and spiritual reflection. These services depend upon a human interpretation of the ecosystem, or of specific characteristic of the ecosystem. Importantly, in the western Arabian Gulf, seagrass beds are always a component while studying the marine ecosystem's health or procuring the baseline data of any coastal marine environment. This is because of the importance of seagrass in the fishery and nursery habitats of juvenile organisms, and its biodiversity properties. In this region, because of the rich oil and gas deposits, the offshore facility creation and their periodic upgrading are mandatory for the production and transportation of oil and gas.

In the western Arabian Gulf, seagrass provides an ideal area for recreational SCUBA diving and snorkeling. There are several diving groups in this region who provide chances for recreational diving in seagrass beds (e.g., Half Moon Bay area) for interested people, including students and researchers.

In some parts of the world, seagrasses form part of the traditional beliefs and practices, and some members of the population express religious values related to seagrasses. For example, in the tropical East Africa, seagrass is closely connected with the religious practices of Muslims (de la Torre-Castro and Rommback, 2004). During the holy month of Ramadan, Muslims in this region follow strict fasting rules and because of this, they cannot perform the normal fishing method, which requires diving. Therefore, they switch over to "dema" fishery, which is a fish trap method, solely used in the seagrass beds. This is also an example of seagrasses permitting fishermen to maintain their source of income. A similar shift in fishery has not been reported from the western Arabian Gulf.

Supporting Services

These are the services that are necessary for the production of all other services of the seagrass bed. Among the most important and well-studied ecosystem services provided by seagrass beds is the provision of habitat for small animals, and therefore, the enhancement of secondary production (Duffy, 2006). Seagrasses are considered to be classic ecosystem engineers, transforming relatively monotonous sediment bottoms into structurally complex, diverse and highly productive habitats. The higher diversity and standing stock of seagrass associated fauna compared to an adjacent nonvegetated habitat in the western Arabian Gulf has already been mentioned elsewhere in this chapter.

The economic value of the ecosystem goods and services that seagrass beds provide is estimated to be in excess of those provided by many other recognized productive habitats as a result of their high nutrient cycling capacity (Cullen-Unsworth and Unsworth, 2013). The ecosystem service in the form of nutrient cycling comes around $1.9 trillion per year globally (Waycott, et al., 2009). Although seagrasses occupy only less than 0.2% of the area of the world's oceans, they are estimated to contribute 10% of the yearly estimated organic carbon burial in the ocean (Duarte, et al., 2005; Duarte, et al., 2013). This carbon burial is not only comprised of seagrass bed carbon, as at least 50% of the carbon arises from external sources due to their particle trapping capacity (Kennedy, et al., 2010). As seagrass beds are capable of storing significant amounts of CO_2, the protection of this ecosystem service enables the beds to become an important part of future climate change mitigation (Duarte, et al., 2013).

Natural Pressures on Seagrass Beds

Natural stress factors play a pivotal role in limiting the fewer seagrass species in the Arabian Gulf (Sheppard, et al., 2010; Erftemeijer and Shuail, 2012). Seagrass in this region are subject to extreme salinity (above 60 psu) and high temperature variations (10 °C to 39 °C) and in such conditions not all species can survive (Price, et al., 1993; Kentworthy, et al., 1993; Durako, et al., 1993; KFUPM/RI, 2014). That is why the Arabian Gulf presents a reduced seagrass flora compared to other parts of the Indian Ocean. For example, 11 seagrass species reported from the Red Sea (Aleem, 1979; Jacobs and Dicks, 1985), seven species each from the Arabian Sea (Sheppard, et al., 1992; Jupp, et al., 1996) and the Gulf of Aqaba (Hulings, 1979; Hulings and Kirkman, 1982) and eight from the Gulf of Suez (Sheppard, et al., 1992), while only three species have extensive distribution in the Arabian Gulf (Sheppard, et al., 1992). According to Den Hartog (1970) the three species, *H. uninervis*, *H. stipulacea* and *H. ovalis* surviving in this region are opportunistic, pioneering species with a broad tolerance and ability to recover rapidly. Of these three, *H. uninervis* is the most broadly euryhaline and is thriving at salinities of 65 in the Gulf of Salwa (KFUPM/RI, 2014).

The euryhaline nature of this species has also been reported from elsewhere in the world, for example, in Australian waters, this species grows under salinities ranging from 48 to 62 (Masini, et al., 2001).

Despite the extreme seasonal variation in surface temperature within the Arabian Gulf, the existing seagrass species did not show any systematic change in biomass with season (Price and Coles, 1992). According to Price and Coles (1992), surface temperatures being variable seasonally and diurnally, do not necessarily reflect the environment in which seagrasses live. Subsequently, the effect of temperature can be observed in the intertidal zone, which seagrasses do not colonize in the western Arabian Gulf.

Human Pressures on Seagrass Beds

Seagrass communities are considered to be one of the most highly threatened marine habitats along with coral reefs, mangroves and salt marshes (Short and Wyllie-Echeverria, 1996; Duarte, 2002; Waycott, et al., 2009). Globally, this is mainly because seagrass beds occur in inshore waters normally less than 10 m deep where threats from such human activities as the destruction of physical and biogenic habitat, eutrophication and overfishing can be significant (Watling and Norse, 1998; Howarth, et al., 2002; Cloern, 2001; Jackson, et al., 2001; Thrush and Dayton, 2002; Grech, et al., 2012).

In the western Arabian Gulf, the largest single man-made incident that affected the marine environment was the 1991 oil spill. Although it was the largest oil spill in history, it did not affect the seagrass beds in an irrecoverable manner as the high impact was restricted to the intertidal regions (Durako, et al., 1993; Kenworthy, et al., 1993). In recent times, the major human pressures impacting the seagrass beds include oil-related activities and coastal development, which involves landfilling and dredging, and fishing activities (Sheppard, et al., 2010). It is important to note that these stressors affect not only the seagrass beds, but also the abundance and diversity of the associated macrofauna (Whanpetch, et al., 2010).

The human pressures and their impacts on seagrass in the western Arabian Gulf (Table 3.25) include upgrading existing facilities or the installation of new facilities that are required for maintaining and/or increasing the offshore oil and gas production. For these, many construction activities are taking place in and around various oil fields. For example, recently, large-scale oil-related construction activities have taken place in the MTBS.

During the 2008 to 2010 period, a causeway was constructed across the mouth of the MTBS to provide the transporting facility and access to offshore drill sites (Figure 3.69). The Causeway consists of a main route with lateral branches connecting to 25 offshore drill site islands (Chapter 3.8). The main causeway is about 20 km long, allows two-lane traffic in both directions, and connects the drill site islands through subsidiary routes. The total length of the lateral causeways and coastal offshoot is about 23 km. The causeway and drill site islands were constructed by means of dredging sand from adjacent borrow areas using cutter suction dredgers and pumping it into the reclamation areas. Seagrass beds were avoided during dredging and filling. Mitigation measures recommended by the Environmental Impact Assessment (KFUPM/RI, 2006) were followed, which include providing openings along the main causeway in the form of 14 long and short bridges, and deployment of silt screens during reclamation and excavation to minimize the dispersion of sediment. Even though several bridges were established along the causeway, 8 km of the bay mouth was also left opened after the construction.

TABLE 3.25. *Human pressures and their impacts on seagrass in the western Arabian Gulf**.

Activity	Impacts
A. Oil-related activities	
1. Drilling	• Although the actual footprint of drilling is small, the release of drill cuttings and other drill wastes can cause burial of seagrasses beyond the immediate vicinity of the drill area.
2. Coastal installation or facilities (e.g., causeways)	• The reclamation for the causeway construction caused the burial of seagrasses.
2. Dredging/trenching	• Dredging and trenching removes existing seagrass beds and is a cause of habitat loss.
3. Turbidity and sedimentation	• Turbidity reduces the rate of photosynthesis • Sedimentation affects the burial of seagrasses and smothers the larger epifauna, thereby causing death..
4. Sidecasting of spoils	• Trenched materials sidecast can also cause burial of seagrasses
5. Laying of underwater pipelines and cables	• Laying of underwater pipelines and cables normally use only a small area on the seabed and impacts will also be small, but can have a positive impact due to reef effects.
6. Anchoring of vessels	• Anchoring of vessels for the construction activities can cause damage to the seagrass beds.
7. Oil spills	• Oil is toxic to seagrass and can hinder growth.
B. Coastal development	
1. Coastal constructions	• Physically uproots and destroys seagrass • Construction and infrastructure along the coast removes seagrasses and increases runoff, sedimentation, and pollution, affecting seagrasses and fisheries. • Increase erosion.
2. Land reclamation	• Removes seagrass and other coastal vegetation that filter sediment. • Too much sediment hinders seagrass growth by blocking the light needed for photosynthesis.
C. Fishing activities	• Cause physical damage to seagrasses due to trawling as well as anchoring. • Disturb seagrass associated flora and fauna • If seagrass beds are lost or fragmented, fish and other invertebrates disappear.
D. Other threats	
1. Excess nutrient inputs	• Sewage discharge can cause algal blooms that restricts sunlight and use up oxygen.
2. Lack of awareness of the importance of seagrass	• Public must know the importance of seagrass through various measures of awareness programs and enforcing the laws.
3. Lack of tools and information	• Policymakers need tools and information to implement and enforce conservation measures.

*Based on Cullen-Unsworth and Unsworth (2013).

A study conducted in eight stations in and in the vicinity of the causeway in MTBS (Figure 3.69) including the pre-construction (2007), during construction (2008 to 2010) and post-construction periods (2013 to 2015) showed that there was a decrease in the percentage of seagrass cover in Manifa, probably as a direct impact of causeway construction (Figure 3.70). Of the three species (*H. uninervis, H. ovalis* and *H. stipulacea*) recorded, *H. uninervis* was the most abundant species and the latter two species were scarce. At the start of this study in 2007, all eight seagrass stations had more than 50% seagrass cover (Figure 3.70a). Three stations had 90% or more seagrass cover (Stations SG5, SG7 and SG8). Six of the eight seagrass stations showed a decrease in seagrass cover by at least 30%, stations SG7, SG8, SG9, SG10, SG12 and SG13. These stations had no more than 30% seagrass coverage in 2007; with station SG13 having only 11% cover, a decrease from the original 70% in 2007. Station SG3, a station located more inside the Tanajib Bay system than the other stations, was the only station to show an increase in seagrass cover. Even at this station, the increase in seagrass cover was not particularly large, although recovery since 2008 was evident.

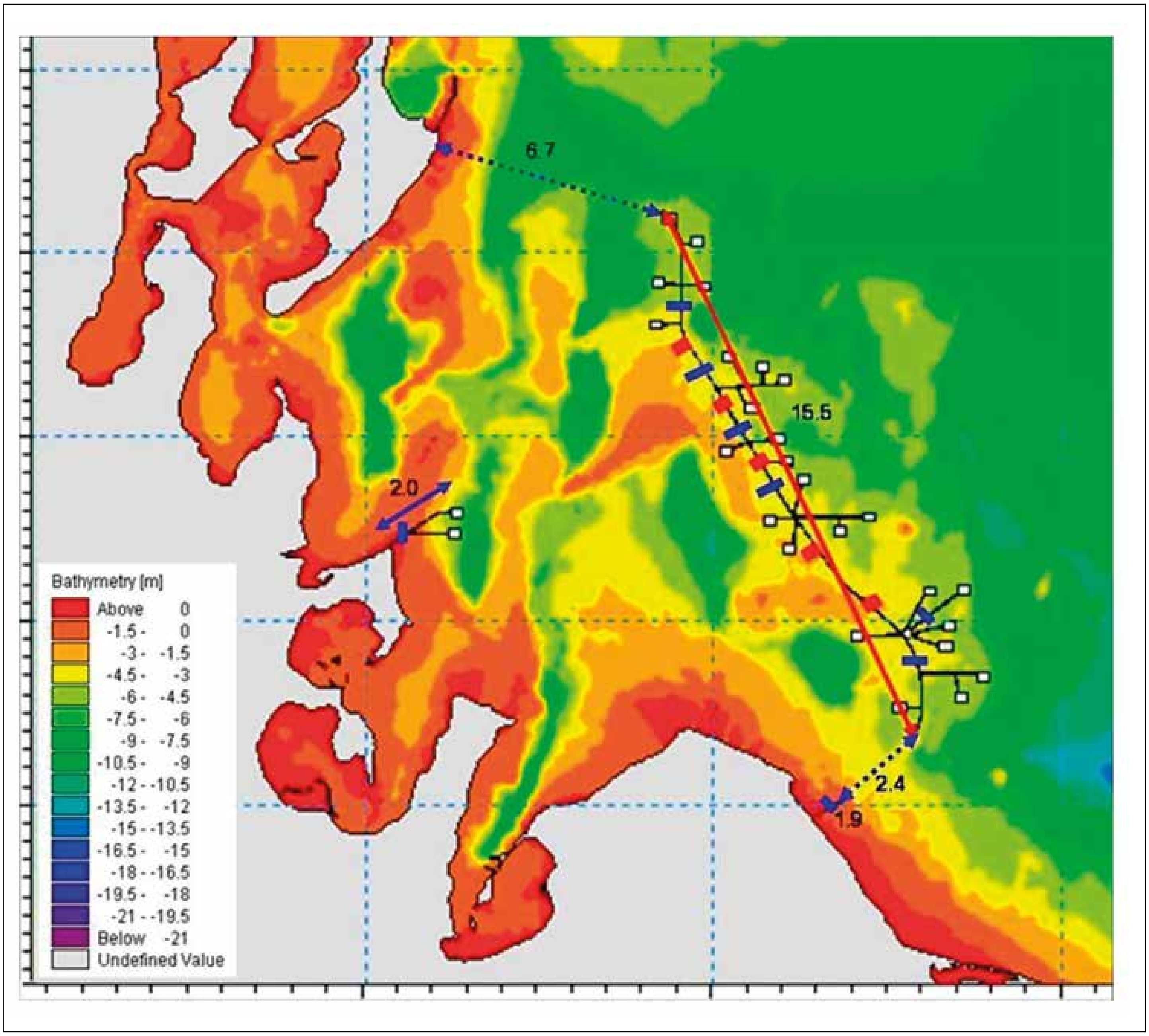

FIGURE 3.69. *Map showing the causeway in the MTBS and seagrass stations (KFUPM/RI, 2015b).*

Monitoring after the construction showed increasing trends in percentage cover of seagrass in most of the stations (Figure 3.70b). Subsequently, compared to the status of seagrass during the pre-construction period, station SG3 showed a comparatively lower percentage during the post-construction period, while all other stations showed a higher percentage during the post-construction period (Figure 3.70b). Cabaço, et al. (2008) investigated the burial thresholds (i.e., the burial levels causing 50% and 100% shoot mortality) and the mortality burial curves were estimated for 15 seagrass species. All the species investigated reached 50% shoot mortality at burial levels ranging from 2 cm (*H. ovalis,* a local species in the MTBS) to 19.5 cm (*Posidonia australis*). *H. uninervis*, the predominant seagrass in the MTBS, was found to reach 50% shoot mortality at a 4 cm burial level (Cabaço, et al., 2008). These experiments showed that the effects of burial

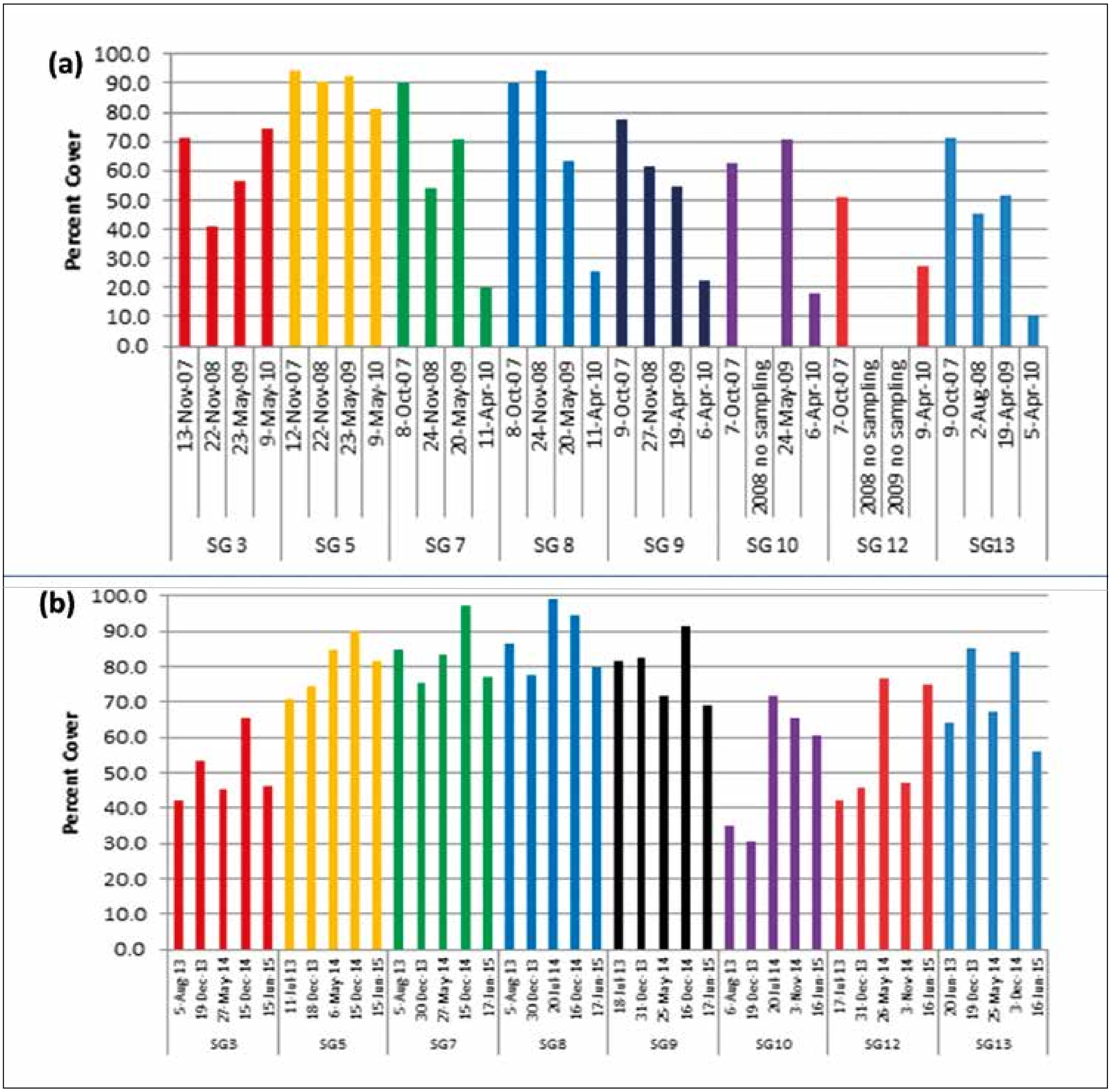

FIGURE 3.70. *Percentage of the seagrasses coverage at stations in the MTBS during (a) pre-construction and during construction (November 2007 to May 2010), and (b) post-construction (August 2013 to June 2015) (KFUPM/RI, 2015b).*

and erosion on seagrasses are species specific and strongly size-dependent. Significant relationships were identified between burial thresholds and shoot mass, rhizome diameter, aboveground biomass, horizontal rhizome elongation and leaf length. *H. uninervis* appears to be quite susceptible to burial impacts, and the construction of the causeway with associated increases in turbidity and sedimentation seems to have stressed populations of seagrass in the region.

Dredging and reclamation are not just associated with oil-related activities, but are a serious threat to the marine environment of the Arabian Gulf from the large-scale urban development (Sheppard and Price, 1991; Erftemeijer and Lewis, 2006; Erftemeijer and Shuail, 2012). Intense real estate developments in the UAE, Qatar, Saudi Arabia, Kuwait and in Bahrain caused several hundred square kilometers of damage to the seabed, both from the infilling and dredging (De Jong, et al., 2005; Al-Kalali and Subasing, 2008; Erftemeijer and Shuail, 2012). In most cases, reclamation for the development activities required dredging of large quantities of sand from areas where dense to sparse seagrass beds existed. The destruction of seagrass beds directly affect the associated fauna and in turn fishery potential of the region. Activities, such as construction of causeways, may restrict access to available seagrass feeding grounds for dugongs and turtles.

Fishing activities also have the potential to cause damage to the seagrass beds. Although there are no published records from the Arabian Gulf on such impacts, studies from other parts of the world shows that damage from fishing gear varies in severity (Cullen-Unsworth and Unsworth, 2013). Shearing or cutting of leaves, flowers, or seeds, and uprooting of plants without major disruption of the sediment, are most often caused by dragging of gear, such as long haul seines or bottom trawls. Where the seabed is disturbed from the dragging of gear, there turbidity from re-suspended sediments may reduce water clarity, affecting seagrass growth, productivity, and in severe cases, survival.

Discharge of wastewater from sewage outfalls, factories, or from general agricultural runoff, may also cause excessive phytoplankton and epiphyte growth, shading seagrass, with the overall impacts depending on the severity of light reduction.

Management Measures for Protecting the Seagrass Beds

As a response to the global seagrass loss from human pressures, there were recommendations for extensive conservation efforts involving comprehensive nutrient management schemes, sanctuaries or protected areas, restorations, and education for the public and resource managers (Kentworthy, et al., 2006; Orth, et al., 2006). In some cases, restricting the input of nutrients and sediments alone were found to be the effective conservation efforts (Preen and Marsh, 1995; Tomasko, et al., 2005).

Even though collective management measures for protecting the seagrass are not yet implemented in the Arabian Gulf involving all the nearby countries, efforts have been made at regional levels. An example is the Kuwait Action Plan (KAP) coordinated by the Regional Organization for the Protection of the Marine Environment (ROPME) (IUCN/UNEP, 1985). IUCN/UNEP (1985) focused largely on uncontrolled habitat destruction and widespread pollution and concluded that any legislation aimed at preventing impacts must be followed by enforcement. In addition, none of the Gulf States have started baseline mapping followed by periodic monitoring. KFUPM/RI (2015) has recently updated the biotopes in the waters of Saudi Arabia and this study forms the first comprehensive baseline assessment of seagrasses in Saudi Arabia. Subsequently, their enforcement and implementation were often inadequate (Phillips, 2003; Erftemeijer and Shuail, 2012). Further, conservation strategies were recommended in some reports produced from this region for preventing uncontrolled habitat destruction in the Arabian Gulf area (Price, 1982; TMRU, 1982; Price, et al., 1983). As per these recommendations, conservation measures had been proposed in Bahrain and Saudi Arabia. Guidelines were reported in the recent past for minimizing environmental impacts from dredging (Erftemeijer and Lewis, 2006; PIANC, 2010) and desalination plants (Latteman and Hopner, 2008). Seagrass protection measures in the Arabian Gulf also benefited from the conservation measures and plans made for dugongs, i.e., the 2007 Dugong Memorandum of Understanding (signed by the UAE, Iran and Bahrain) (UNEP/CMS, 2007).

In Saudi Arabia, Environmental Impact Assessments (EIAs) are mandatory prior to the construction of large-scale projects. EIAs recommend mitigation measures, which are implemented during the construction phase to avoid, minimize or compensate for adverse impacts on the seagrass beds and other environmental resources. EIAs often recommend excluding the seagrass vegetated zones from the boundaries of designated dredging areas to avoid or minimize adverse impacts resulting from elevated sedimentation rates and direct removal that cause seagrass mortality. Silt curtains are often deployed during the reclamation and excavation activities to control the dispersion of sediment plume (KFUPM/RI, 2010a, 2010b). Typically, use of a silt curtain is not recommended if the velocity of the water is greater than 0.5 m/s; therefore, the abovementioned activities should be conducted only during low flow times. There are other management measures for protecting seagrass beds while performing dredging and trenching (KFUPM/RI, 2010a, 2010b). The most important are: (1) when the prescribed threshold value for turbidity (20 NTU) (PME, 2007) at the seagrass bed is exceeded for a sustained duration of six hours, dredging activity must be temporarily ceased until the turbidity regime has returned to acceptable levels, (2) when the sedimentation rate sampled every two weeks indicates an exceedance of the threshold value (10 $mg/cm^2/day$) (PME Draft Standards, 2007), dredging activity must be temporarily ceased until the water condition has returned to acceptable levels, and (3) the operation of cutter suction dredges or trailing suction hopper dredges are recommended to be avoided for dredging as these create more sediment plumes and environmental damage than using a backhoe dredger.

In large-scale projects, an Environmental Compliance Monitoring Program is implemented by a third party during the construction period to verify the implementation of the various mitigation measures discussed in the EIA report. In some cases, a Post-Construction Monitoring Program is also implemented for 2 to 3 years to study the post-construction changes and recovery processes, if any, in the study area. Although, a period of 2 to 3 years is a relatively short period to document seagrass recovery, which typically requires decadal time scale, even for the fast growing species present in the Gulf (Duarte, et al., 1995).

In most cases, seagrass loss is recoverable because they have the potential to recover when environmental conditions return to their original state (Erftemeijer and Shuail, 2012). Generally, recovery of seagrass beds from significant human pressures may take decades depending on the scale of impact. Nevertheless, the recovery process is comparatively fast in the Arabian Gulf because of the opportunistic character of the existing three seagrass species. Apart from the recovery in the impacted area, seagrasses have also been found to colonize new areas created during land reclamation, for example, newly created subtidal areas in the West Bay Lagoon area in Doha (Jones, et al., 2007) and Palm Jebel Ali, where transplantation further increased the area of seagrass beds (Katakura, et al., 2008).

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APPENDIX I

Environmental Studies

of the Sustaining Research Project Conducted by Research Institute of King Fahd University of Petroleum and Minerals (KFUPM/RI) and Funded by Saudi Arabian Oil Company (Saudi Aramco).

Project	Project Title	Project Start	Project End
GST E-4009	Meteorological and Oceanographic Data Report	01-Sep-77	01-Mar-79
CEW0000	Preliminary Benthic Biology Survey	01-Jan-80	01-Jan-12
24004	Simulation of an Oil Spill in the Arabian Gulf	01-Jul-80	31-Dec-80
TC-4030	Pollutant Pathways Characterization in Shallow Bay Systems	01-Jul-81	01-Jul-83
24010	Ambient Air Suspended Particulate Sampling and Characterization	01-Oct-81	30-Nov-82
TSI 57-111	An Analysis of the Impact of the Ghazlan Generating Station on Benthic Marine Communities	01-Dec-81	01-Jan-82
RP878-1	Methodology for Evaluation of Multiple Cooling System Effects	01-Jan-82	01-Jan-83
24011	Trace Metals in Marine Sediments and Water Columns	20-Feb-82	30-Nov-82
AER-5229	A Survey of Infaunal Communities of the Western Arabian Gulf	01-Jun-82	01-Jun-83
TC-3598	Marjan Offshore Gas/Oil/Pipeline Current Data Analysis and Numerical Simulation	01-Oct-82	01-Oct-83
24028	Estimating Oil Spill Size by Visual Observation	13-Nov-82	15-May-83
24038	Ballast Discharge Evaluation at Yanbu' Natural Gas Liquids Facility	01-Nov-83	13-Jul-85
24058	Mixing Heights for Three Cities in the Eastern Province	01-Jan-84	30-Jun-85
24059	Marine Environmental Investigation in the Arabian Gulf with Emphasis on the Northern Area of Saudi Arabia	01-Feb-84	30-Sep-86
24065	Solid Waste Planning Guide	01-Mar-84	31-Dec-84
24079	Saudi Aramco Sustaining Research Project Marine Environmental Studies I	01-Oct-84	30-Oct-90
GST E-4032	Sampling and Monitoring Report	10-Nov-84	11-Nov-84
24108	Marine Environmental Effect of the Abu Ali-Berri Causeway Extension	01-Aug-87	28-Feb-88
24114	Groundwater Resources Evaluation in the Eastern Province of Saudi Arabia	31-Dec-87	31-Mar-88
24120	Wave Climate Study in the Arabian Gulf	15-Aug-89	15-Aug-91
24129	Marine Environmental Study at the Safaniyah GOSP-4 Offshore Facility	11-Dec-89	30-Sep-90

Project	Project Title	Project Start	Project End
24131	Sustaining Research Project Marine Environmental Studies	18-Aug-90	30-Sep-94
24137	Gulf Atmospheric Pollution 1991	01-Feb-91	30-Sep-92
24138	Arabian Gulf Oil Spill Research Program 1991 (also called Gulf Atmospheric Pollution 1991)	01-Feb-91	30-Sep-92
24142	Ras Tanura Refinery/Terminal Upgrade: Environmental Impact Assessment	15-Aug-92	15-Apr-93
21132	Solubility of Calcium Carbonate in Synthetic and Natural Oil Field Brines	01-Apr-94	31-Mar-96
24150	Contaminant Transport Model for the Ras Tanura Groundwater Investigation	22-Aug-94	15-Dec-95
24154	Sustaining Research Project Marine Environmental Studies Phase III	01-Jul-95	31-Mar-01
24162	Investigation of Ambient Concentrations of Automotive Emissions in Three Major Cities	01-May-97	30-Apr-98
24164	Development of Red Sea Biotope Maps Using Remote Sensing Imagery	01-Jul-97	30-Jun-99
CEW2217	Marine Biological and Oceanographic Database Development	15-Nov-00	15-Nov-02
CEW2236	Environmental Impact Assessment for Abu Safah Offshore AM Producing Facilities	01-Jun-01	31-Jul-01
CEW2233	Saudi Aramco/KFUPM-RI Sustaining Research Project Marine Environmental Studies Phase IV	01-Oct-01	30-Sep-06
CEW2242	Conceptual Estimate of Environmental Impacts of Existing and New Arabia-Bahrain Pipeline Routings	28-Oct-01	24-Apr-02
CEW2259	Duba Marine Terminal Permanent Berth (BI-8232) Environmental Impact Assessment for the Construction and Removal of Temporary Roads	15-Jan-03	31-Oct-06
CEW2269	Offshore MP Facilities Berri-119 Pipeline (BI-8294) Environmental Impact Assessment Study	01-Apr-03	31-Oct-03
CEW2278	Offshore MP Facilities 15 kV Cable (BI-8294) Environmental Impact Assessment	15-Sep-03	31-Dec-03
CEW2285	Environmental Impact Assessment North Safaniyah Artificial Lift (BI-10-0047)	12-Jul-04	09-Feb-05
CEW2287	Offshore MP Facilities Qatif QV Cable (BI-8294) Environmental Impact Assessment	26-Jul-04	29-Sep-04
CEW2310	Environmental Impact Assessment of the New Khursaniyah 30” Dia. Pipeline (BI-10-08022)	04-Jun-05	30-Nov-05
CEW2311	Environmental Impact Assessment Upgrade Northern Area Oil Operations Offshore Platforms Wastewater (BI-01-00197).	13-Jun-05	31-Oct-05
CEW2303	Environmental Impact Assessment for the Berri Causeway and Associated Drill Site Landfilling	24-Dec-05	12-Apr-06
CEW2325	Operational Marine Modeling System (OMMS)	01-Jan-06	31-Dec-08
CEW2328	Environmental Impact Assessment for Manifa Field Development (NAFD/L-001-06): Causeway Construction	11-Mar-06	30-Sep-06
CEW2329	Environmental Impact Assessment for Abu Ali Flanks Scraped Water Handling (BI-10-00220)	01-Apr-06	31-Jul-06
CEW2338	Environmental Impact Assessment for Manifa Field Development Program: Platforms, Pipelines and Submarine Cables (BI-01-00452 and BI-01-00453)	11-Nov-06	30-Jun-07
CEW2336	Marine Environmental Monitoring of the New Khursaniyah 30” Dia. Pipeline (BI-10-08022) Project	01-Jan-07	31-Dec-09
CEW2345	Environmental Impact Assessment for the King Abdullah University of Science & Technology Development Project	02-Jun-07	30-Jul-08
CEW2342	Marine Environmental Monitoring of the Manifa Causeway	12-Jun-07	30-Jun-10
CEW2343	Assessment of Ras Tanura Marine Environment and Bioaccumulation Monitoring along the Saudi Coastal Waters of the Arabian Gulf	21-Jul-07	30-Dec-10
CEW2350	Environmental Impact Assessment for Tanajib Channel and Basin Dredging	31-Jul-07	31-Oct-07

Project	Project Title	Project Start	Project End
CEW2344	Saudi Aramco/KFUPM-RI Sustaining Research Project, Marine Environmental Studies Phase V	15-Aug-07	16-Aug-12
CEW2353	Biodiversity of the Offshore Saudi Islands of the Arabian Gulf	21-Oct-07	31-Jul-11
CEW2354	The Western Arabian Gulf Ecosystem: A Reference for Researchers, Planners and Environmental Managers	21-Oct-07	31-Jul-11
CEW2355	Marine Atlas of the Western Arabian Gulf Phase I: Coastal and Marine Surveys and Photo Documentation	21-Oct-07	31-Jul-11
CEW2352	Environmental Impact Assessment for a Seawater Reverse Osmosis Water Treatment Plant at King Abdullah University of Science and Technology	03-Nov-07	31-Mar-08
CEW2343-01	Assessment of Ras Tanura Marine Environment and Bioaccumulation Monitoring along the Saudi Coastal Waters of the Arabian Gulf Additional Scope	01-Jan-08	30-Nov-08
CEW2357	Environmental Impact Assessment for Karan Platforms, Power (BI-10-00579) and Pipelines (BI-10-00580) Construction	01-Jan-08	31-Aug-08
CEW2359	Environmental Impact Assessment for Drill Cutting Disposal at Manifa	01-Jun-08	31-Dec-08
CEW2360	Environmental Impact Study for Channel Dredging at Safaniyah	07-Jun-08	31-Dec-08
CEW2370	Environmental Impact Assessment for Land Filling and Reclamation at Ras Tanura Refinery	15-Nov-08	31-Dec-09
CEW2373	Environmental Impact Assessment for the Upgrade of Crude Gathering and Power Supply Facilities Phase I: Safaniyah Field	27-Jun-09	31-Mar-10
CEW2380	Conduct LC-50 Drilling Fluid Sampling and Toxicity Testing	11-Nov-09	31-Dec-11
CEW2379	Environmental Impact Assessment for Installing Instrument Scraping Facilities at Zuluf and Marjan Oil Fields (BI-10-00187)	20-Feb-10	20-Apr-10
CEW2381	Environmental Impact Assessment for Upgrade of the Fire Protection System, Ju'aymah Offshore Platform (BI-10-00185)	24-Apr-10	31-Aug-10
CEW2382	Environmental Impact Assessment for Arabiyah-Hasbah Platforms, Power (BI-10-00916) and Subsea Pipelines (BI010-00917)	19-Jun-10	19-Dec-10
CEW2374	Fisheries Program: Population Dynamics and Stock Assessment of the Major Fisheries Resources in Saudi Arabian Waters	01-Jan-11	30-Nov-13
CEW2375	Fisheries Program Assessment and Management of Essential Fish Habitats in Saudi Arabian Waters	01-Jan-11	30-Nov-13
CEW2376	Fisheries Program Environmental Impacts of Fishing Methods in Saudi Arabia: Toward Mitigation and Management	01-Jan-11	30-Nov-13
CEW2377	Fisheries Program Development of a Strategic Framework for Fisheries Management in Saudi Arabia	01-Jan-11	30-Nov-13
CEW2385	GMARS Development of GIS Compatible Marine Database and Analysis System (GMARS)	01-Feb-11	31-Jul-12
CEW2389	Red Sea Environmental Impact Assessment for Drilling Exploration in the Shallow Waters of the Northern Red Sea	11-Jun-11	03-Jun-12
CEW2390	Tarut Bay Environmental Assessment Report for Tarut Bay Pipelines & Structural Support System	02-Jul-11	31-Dec-11
CEW2392	Safaniyah Pier Environmental Assessment for the Safaniyah Pier Trestle Replacement	23-Jul-11	31-Mar-12
CEW2399	Environmental Impact Assessment for Dredging (Category III) for Upgrade of Electrical Power Supply to Abu Ali Plants	15-Feb-12	15-Aug-12

APPENDIX II

Checklist of marine invertebrates

*Checklist of marine invertebrates occurring in the area of the Arabian Gulf. Bold Arabic numbers (**1** to **34**) indicate the references of record of the species. Note that the list represented in this appendix has been modified from those published in the references used. Some non-identified species or only identified to the order/family level were excluded from the present list. Taxa identified to only genus level (noted as Genus sp.) were kept but they may refer to one or many species (belonging to the same genus) recorded in one or various references; more details about this can be obtained from the original references of record. The species belonging to each class are listed in alphabetic order.* **1** Price (1991), **2** KFUPM/RI (1987), **3** Al-Yamani et al. (2012), **4** Hasam (1994), **5** Al-Naser et al. (2010), **6** Nithianandan (2012), **7** Smythe (1972), **8** Al-Khayat and Al-Ansi (2008), **9** Tehranifard and Dastan (2011), **10** Al-Khayat (2008), **11** Roper et al. (1984), **12** Sheppard and Borowitzka (2012), **13** Al-Yamani et al. (2011), **14** Carpenter et al. (1997), **15** KFUPM/RI (2003), **16** Apel and Türkay (1999), **17** Hogart and Tigar (2002), **18** Al-Sayed and Zainal (2005), **19** Al-Khayat and Al-Maslamani (2001), **20** KFUPM/RI (1990), **21** Grabe et al. (2004), **22** Murano (1998), **23** Razzaq (1991), **24** Abdulqader (1999), **25** Price and Jones (1975), **26** Enomoto (1971), **27** Hosny (2007), **28** Badawi (1975), **29** Chen et al. (2013), **30** Monniot and Monniot (1997), **31** KFUPM/RI (2006a), **32** KFUPM/RI (2013), **33** KFUPM/RI (2006b), **34** Njinkoué et al. (2006).

PHYLUM PORIFERA
Class Demospongiae
Adocia sp. **2**
Aplysina sp. **2**
Axinella sp. **2**
Biemna sp. **2**
Cacospongia sp. **2**
Gelliodes cf. *incrustans* **34**
Callyspongia cf. *siphonella* **34**
Callyspongia sp. **2, 34**
Choristida sp. **2**
Cinachyra sp. **2**
Ciocalypta sp. **2**
Cliona schmidti **2**
Cliona sp. **2**
Cliona vastifica **2**
Coelosphaera sp. **2**
Dysidea sp. **2**
Europon sp. **2**
Fasciospongia sp. **2**
Gelliodes cf. *incrustans* **34**
Gelliodes sp. **2**
Halichondria sp. **2**
Haliclona sp. **2**
Haliclona sp. **2**
Mycale sp. **2**
Niphates sp. **34**
Spongia sp. **2**
Tedania sp. **2**
Tethya aurantium **2**
Tethya sp. **2**
Tetilla sp. **2**

PHYLUM CNIDARIA
Class Anthozoa
Acanthastrea echinata **12**
Acropora clathrata **12**
Acropora downing **12**
Acropora horrida **12**
Acropora pharaonis **12**
Acropora valenciennesi **12**
Actiniaria sp. **2**
Anemonactis sp. **2**
Anomastrea irregularis **12**
Blastomussa merleti **12**
Coscinaraea monile **12**
Culicia rubeola **12**
Cyphastrea micropthalma **12**
Cyphastrea serialia **12**
Echinophyllia aspera **12**
Favia favus **12**
Favia pallida **12**
Favia speciosa **12**
Favites chinensis **12**
Favites pentagona **12**
Heterocyathus aequicostatus **12**
Hydnophora exesa **12**
Leptostrea inaequalis **12**
Leptostrea purpurea **12**
Leptostrea transversa **12**
Madracis kirbyi **12**
Montipora circumvallata **12**
Montipora spumosa **12**
Paracyathus sp.12
Pavona cactus **12**
Pavona diffluens **12**
Pavona explanulata **12**
Pavona varians **12**
Platygyra daedalea **12**
Platygyra sinensis **12**
Plesiastrea versipora **12**
Pocillopora damicornis **12**
Porites compressa **12**
Porites harrisoni **12**
Porites lutea **12**
Porites murrayensis **12**
Porites nodifera **12**
Psammocora contigua **12**
Psammocora haimeana **12**
Psammoseris sp. **12**
Pseudosiderastrea tayamai **12**
Siderastrea savignyana **12**
Stylophora pistillata **12**
Tubastraea aurea **12**
Turbinaria mesenterina **12**
Turbinaria peltata **12**
Class Hydrozoa
Aequorea pensilis **13**
Aglaura hemistoma **13**
Amphinema rugosum **13**
Campanularia crenata **2**
Clytia cf. *gravieri* **2**
Clytia discoida **13**
Clytia gravieri **2**
Clytia latitheca **2**
Corynactis sp. **2**
Cunina octonaria **13**
Cytaeis nassa **2**
Diphyes chamissonis **13**
Dynamena cornicina **2**
Dynamena crisioides **2**
Dynamena quadridentata **2**
Eirene viridula **13**
Eudendrium capillare **2**
Eudendrium sp. **2**
Eutima gegenbauri **13**
Gonionemus murbachi **2**
Halocordyle disticha **2**
Hydractinia cf. *diogenes* **2**
Liriope tetraphyla **13**
Obelia bispinosa **2**
Obelia cf. *dichotoma* **2**
Obelia sp. **13**
Octophialucium funerarium **13**
Plumularia cf. *setacea* **2**
Plumularia sp. **2**
Podocoryne sp. **13**
Rhizorhagium robustum **2**
Sanderia malayensis **13**
Sertularia distans **2**
Sertularia longa **2**
Solmundella bitentaculata **13**
Staurocladia vallentini **2**
Thyroscyphus fruticosus **2**

PHYLUM ANNELIDA
Class Polychaeta
Aglaophamus sp. **2**
Amaeana sp. **2**
Ampharete acutifrons **31**
Ampharete sp. **15**
Amphicteis gunneri **15**
Amphicteis sp. **2**
Amphiglena mediterranea **15**
Amphiglina sp. **2**
Amphinome sp. **15**
Amphisamytha sp. **2**
Amphitrite pauciseta **31**
Amphitrite sp. **15**
Anaitides sp. **2**
Ancistargis sp. **2**
Ancistrosyllis constricta **15**
Ancistrosyllis parva **15**
Ancistrosyllis sp. **15**
Aonides oxycephala **15**
Aonides sp. **2**
Aphrodita sp. **2**
Arabella iricolor iricolor **15**
Arabella sp. **2**
Aricidea curviseta **31**
Aricidea fauveli **15**
Aricidea jeffreysi **31**
Aricidea longobranchiata **15**
Aricidea sp. **15**
Aricidea suecica simplex **31**
Armandia intermedia **15**
Armandia sp. **2**
Asclerocheilus capensis **31**
Asclerocheilus sp. **2**
Autolytus prolifer **2**
Autolytus sp. **15**
Axiothella sp. **2**
Bhawania goodie **31**
Brada sp. **2**
Brada villosea capensis **32**
Branchiomma sp. **2**
Brania sp. **2**
Cabira sp. **2**
Capitella sp. **2**
Capitomastus sp. **2**
Caulleriella sp. **2**
Ceratocephale sp. **2**
Ceratonereis erythraeensis **2**
Ceratonereis mirabilis **2**
Ceratonereis sp. **2**
Chaetoparia sp. **2**
Chaetopterus sp. **15**
Chaetopterus variepedatus **31**
Chaetozone sp. **2**
Chane sp. **2**

Chloeia sp. **15**
Chone collaris **31**
Chone filicaudata **31**
Chone sp. **2**
Chrysopetalum sp. **2**
Cirratulus chrysoderma **15**
Cirratulus cirratus **15**
Cirratulus filiformis **15**
Cirratulus sp. **15**
Cirriformia filigera **31**
Cirriformia sp. **2**
Cirrophorus branchiatus **31**
Cirrophorus sp. **2**
Clymenella sp. **2**
Cossura coasta **15**
Dasybranchus caducus **15**
Dasybranchus sp. **2**
Decamastus sp. **2**
Diopatra sp. **2**
Dioplosyllis sp. **2**
Dispio sp. **31**
Dorvillea angolana **15**
Dorvillea rubrovittata **31**
Dorvillea rudolphi **15**
Drilonereis monroi **31**
Drilonereis sp. **2**
Drilonerels filum **2**
Ehlersia cornuta **2**
Ehlersia sp. **2**
Epidiopatra sp. **31**
Eteone foliosa **31**
Eteone sp. **2**
Euchone rosea **15**
Euchone sp. **2**
Euclymene lombricoides **31**
Euclymene luderitziana **15**
Euclymene oerstedi **31**
Euclymene sp. **2**
Eulalia sp. **2**
Euleanira sp. **15**
Eumida sp. **2**
Eunice antennata **15**
Eunice australis **15**
Eunice indica **2**
Eunice sp. **15**
Eunice vittatta **31**
Eunoe sp. **2**
Euphrosine capensis **15**
Euphrosine foliosa **15**
Euphrosine myrtosa **15**
Eurythoe parvencarunculata **15**
Eurythoe sp. **15**
Exogone clavator **15**
Exogone cornuta **2**
Exogone gemmifera **15**
Exogone normalis **15**
Exogone sp. **15**
Exogone verugera **2**
Filograna implexa **31**
Flabelligera affinis **31**
Genetyllis sp. **2**
Glycera longipinnis **31**
Glycera rouxi **2**
Glycera sp. **2**
Glycera spongicola **32**
Glycera tesselata **31**
Glycinde sp. **2**
Glyphanostomum abyssale **31**
Goniada congoensis **32**
Goniada emerita **31**
Goniada maculata **15**
Goniada sp. **2**
Goniadella gracilis **31**
Grubeulepis sp. **2**
Gyptis capensis **15**
Haplosyllis spongicola **2**
Harmothoe sp. **2**
Hesionides sp. **2**
Heteroclymene cf. *Quadrilobata* **2**
Heteromastus filiformis **15**
Heteromastus sp. **2**
Hipponoa gaudichaudi agulhana **31**
Hipponoa sp. **31**
Horstileanira sp. **2**
Hyalinocecia tubicola **31**
Hyboscolex longiseta **15**
Hydroides heteroceros **31**
Hydroides homaceros **2**
Hydroides monoceros **15**
Hydroides norvegica **2**
Hydroides sp. **2**
Hydroides uncinata **2**
Hypsicomus phaetonia **15**
Isolda pulchella **31**
Isolda sp. **2**
Jasmineira elegans **31**
Jasminiera sp. **2**
Laeonereis ankyloseta **31**
Lanice conchilega **15**
Laonice cirrata **31**
Laonome sp. **2**
Leiochrus sp. **2**
Leocrates claparedeii **15**
Leodora sp. **2**
Leonnates jonaseaumei **2**
Leonnates persica **2**
Lepidonotus sp. **2**
Linopherus sp. **15**
Loimia medusa **2**
Lumbrineriopsis sp. **2, 15**
Lumbrineris aberrans **15**
Lumbrineris albidentata **15**
Lumbrineris brevicirra **31**
Lumbrineris heteropoda **2**
Lumbrineris inflata **15**
Lumbrineris latrielli **15**
Lumbrineris megalhaensis **15**
Lumbrineris meteorana **31**
Lumbrineris simplex **15**
Lygdamis murata gilchrisi **15**
Lygdamis sp. **15**
Lysidice collaris **15**
Lysidice longiceps **15**
Lysidice sp. **2**
Lysilla sp. **2**
Magelona cincta **15**
Magelona papillicornis **31**
Malacoceros indicus **15**
Manayunkia sp. **2**
Marphysa bifurcata **15**
Marphysa sp. **2**
Marphysia mossambica **31**
Mastobranchus sp. **2**
Mediomastus capensis **31**
Mediomastus sp. **2**
Megalomma quadriculatum **15**
Megalomma sp. **2**
Melinna cristata **32**
Melinna monoceroides **15**
Melinna sp. **2**
Melinopsides capensis **31**
Mesochaetopterus minutus **15**
Mesochaetopterus sp. **15**
Mesospio sp. **2**
Micromaldane sp. **2**
Micronephtys spaerocirrata **2**
Mysta sp. **2**
Mystides angolensis **31**
Myxicola sp. **2**
Nainereis laevigata **2**
Neanthes sp. **2**
Neanthes unifasciata **2**
Nematonereis unicornis **15**
Nephtyis lyrochaeta **15**
Nephtyis sphaerocirrata **15**
Nephtys dibranchis **15**
Nephtys hombergi **15**
Nephtys polybranchia **15**
Nephtys tulearensis **2**
Nereimyra sp. **2**
Nereis coutierei **2**
Nereis persica **2**
Nereis sp. **15**
Nereis trifasciata **2**
Nicolea macrobranchia **15**
Ninoe sp. **2**
Nothria sp. **2**
Notomastus aberrans **31**
Notomastus fauveli **31**
Notomastus latericeus **31**
Notomastus sp. **2**
Odontosyllis polycera **2**
Onuphis eremita **15**
Onuphis geophiliformis **15**
Onuphis holobranchiata **15**
Onuphis sp. **15**
Ophelia sp. **2**
Ophelina acuminata **15**
Ophelina sp. **2**
Ophiodromus angustifrons **15**
Ophiodromus berristordei **15**
Ophiodromus sp. **15**
Orbinia angrapequensis **31**
Orbinia sp. **2**
Oriopsis bansei **31**
Oriopsis neglecta **31**
Oriopsis sp. **15**
Owenia fusiformis **31**
Owenia sp. **2**
Paleanatus chrysolepis **31**
Paleanatus debilis **31**
Panthalis sp. **2**
Paraamphinome indica **15**
Paralacydonia paradoxa **15**
Paralepidonotus ampullifеrus **2**
Paranaites sp. **2**
Paraonides lyra lyra **31**
Paraonides sp. **15**
Paraonis gracilis graicilis **15**
Paraonis gracilis oculata **15**
Paraschlerocheilus capensis **15**
Pectinaria antipoda **2**
Pectinaria capensis **31**
Pectinaria crassa **15**
Pectinaria koneri koneri **31**
Pectinaria neopolitana **31**
Pectinaria papillosa **15**
Pectinaria sp. **15**
Perenereis cultrifera **15**
Peresiella acuminatobranchiata **2**
Peresiella sp. **2**
Petaloproctus terricola **2**
Pherusa monroi **15**
Pherusa sp. **15**
Pholoe sp. **2**
Phyllochaetopterus elioti **31**
Phyllocomus hiltoni **31**
Phyllodoce capensis **15**
Phyllodoce castanea **31**
Phyllodoce longipes **31**
Phyllodoce malmgreni **15**
Phyllodoce sp. **15**
Phyllodoce tubicola **31**
Phylo capensis **15**
Phylo sp. **15**
Pilargis sp. **2**
Pionosyllis sp. **2**
Piromis arenosus **15**
Piromis sp. **2**
Pista brevibranchia **15**
Pista cristata **31**
Pista dibranchis **15**
Pista macrolobata **15**
Pista medusaera **2**
Pista sp. **15**
Pista typha **2**
Platynereis dumerilii **2**
Platynereis isolita **33**
Platynereis pulchella **2**
Platynereis sp. **15**
Podarke sp. **2**
Podarkeopsis sp. **2**
Poecilochaetus serpens **15**
Poecilochaetus sp. **2**
Polycirrus aurantiacus **31**
Polycirrus cf. *haematodes* **15**
Polycirrus plumosus **31**
Polycirrus sp. **2**
Polydora capensis **15**
Polydora ciliata **15**
Polydora kempi **31**
Polydora sp. **2**
Polyodontes sp. **2**
Polyophthaimus sp. **2**
Polyphysia crassa **15**
Pomatoleios kraussii **15**
Potamila linguicollaris **31**
Potamila reniformis **31**
Potamilla sp. **15**
Potamilla tanelli **15**
Praxillella sp. **2**
Prionospio bocki **15**
Prionospio cirrifera **31**
Prionospio cirrobranchiata **15**
Prionospio ehlersi **15**
Prionospio pinnata **15**
Prionospio sexoculata **15**
Prionospio sp. **2**
Procerastea perrieri **31**
Protodorvillea biarticulata **15**
Protodorvillea egena **2**
Pseudoclymene sp. **2**
Pseudomalacoceros sp. **2**
Pseudonereis anomala **2**
Pseudopolydora antennata **2**
Pseudopolydora sp. **2**
Pulliella armata **15**
Pycnoderma congoense **31**
Pygospio elegans **15**
Rhamphobrachium capense **31**
Rhamphobrachium sp. **15**
Rhodine sp. **2**
Rynchospio glutaea **15**
Sabella sp. **15**
Sabellaria intoshi **31**
Sabellaria sp. **31**
Sabellaria spinulosa alcocki **15**
Sabellides capensis **31**
Sabellides luderitzi **31**
Sabellides octocirrata **31**
Sabellides sp. **15**
Schistomeringos neglecta **2**
Schistomeringos rudolphi **2**
Scolelepis lefebvrei **15**
Scolelepis sp. **15**
Scoloplos armiger **15**
Scoloplos johnstonei **15**
Scoloplos johnstonei **31**
Scoloplos sp. **15**
Scyphoproctus djiboutiensis **31**
Serpula vermicularis vermicularis **15**
Sigambra sp. **2**
Sphaerodoridium benguellarum **15**
Sphaerodoropsis sp. **2**
Sphaerosyllis brenicirrus **2**
Sphaerosyllis capensis **2**
Sphaerosyllis semiverucossa **15**
Sphaerosyllis sp. **2**
Sphaerosyllis sublaevis **15**
Spherodoridium capens **31**
Spio filicornis **15**
Spio sp. **15**
Spiochaetopterus sp. **2**
Spiophanes bombyx **15**
Spiophanes soderstromei **31**
Spirobranchus tetraceros **15**
Spirorbis sp. **15**
Sternaspis scutata **15**
Sthenelais sp. **2**
Streblosoma hesslei **15**
Streblosoma persica **31**
Streblosoma sp. **2**
Syllides fulva **2**
Syllides sp. **2**
Syllidia armata **15**
Syllidia sp. **15**
Syllis exilis **15**
Syllis longissima **15**
Syllis sp. **15**
Syllis spongicola **31**
Tauberia sp. **2**
Terebella pterochaeta **15**
Terebella sp. **2**
Terebellides sp. **2**
Terebellides stroemi **2**
Thalenessa sp. **2**
Tharyx filibranchia **15**
Tharyx marioni **31**
Tharyx sp. **2 15**
Thelepus plagiostoma **15**
Thelepus sp. **15**
Timarete sp. **2**
Trichobranchus sp. **2**
Trypanosyllis zebra **2**
Typosillis prolifera **2**
Typosyllia sp. **2**
Typosyllis armillaris **2**
Typosyllis hyaline **2**
Vermiliopsis glandigerus **2**
Vermiliopsis pygidialis **15**
Vermiliopsis sp. **15**
Zeppelina sp. **2**
Class Oligochaeta
Bathydrilus adriaticus **2**
Bathydrilus sp. **2**
Duridrilus tectus **2**

Heterodrilus maccaini **2**
Heterodrilus sp. **2**
Inanidrilus sp. **2**
Limnodriloides appendiculatus **2**
Limnodriloides bipapillatus **2**
Limnodriloides tenuiductus **2**
Limnodriloides sp. **2**
Olavius manifae **2**
Olavius verga **2**
Paranais litoralis **2**
Phallodrilus sp. **2**
Tectidrilus arabicus **2**
Tubificoides sp. **2**
Class Sipunculidea
Apionsoma trichocephalus **2**
Aspidosiphon sp. **2**
Phascolapsis sp. **2**
Phascolion convestitum **2**
Phascolion valdiviae var. sumatrense **2**
Phascolion sp. **2**
Phascolosoma sp. **2**
Siphonosoma sp. **2**
Class Echiura
Anelassorhynchus branchiorhynchus **3**
Listriolobus brevirostris **3**
Ikeda pirotansis **3**

PHYLUM ARTHROPODA
Class Crustacea
Acanthephyra sp. **13**
Acetes Japonicus **13**
Aeginella sp. **15**
Aeginellopsis arabica **15**
Aglaiocypris sp. **2**
Alocopocythere reticulate **2**
Alpheus sp. **13**
Ampelisca brevicornis **2, 15**
Ampelisca hemigera **15**
Ampelisca insignis **2, 15**
Ampelisca scabripes **2, 15**
Ampelisca sp. **2, 3**
Ampelisca tulearensis **2, 15**
Amphiascopsis subdebilis **20**
Amphiascus minutus **20**
Amphiascus sp. **2**
Amphilochus neapolitanus **2**
Amphilochus sp. **2**
Ampilochus hemigera **15**
Ampilochus neopolitanus **15**
Ampithoe falsa **2, 15**
Ampithoe ramondi **2, 15**
Ampithoe sp. **2, 3, 15**
Apanthura africana **2**
Apanthura sandalensis **3**
Apseudopsis sp. **2, 3**
Arabanthura enigmatica **2**
Arcturinoides sp. **2**
Astacilla mediterranea **2, 20**
Asteropterrgion sp. **2**
Atergatis integerrimus **3**
Azotostoma sp. **15**
Balanus amphitrite **3, 13, 19, 20**
Balanus sp. **3**
Balanus venustus **2, 20**
Biancolina sp. **15**
Bodotria parva **15**
Bodotria siamensis **15**
Bodotria similis **2, 15, 20**
Bodotria sp. **3**
Bodotria sublevis **15**
Branchinella spinosa **17**
Branchipus schaefferi **18**
Brianola sp. **2**
Bulbamphiascus inermis **2, 20**
Byblis sp. **3, 15**
Calanopia parathompsoni **20**
Calanopia sp. **2**
Callianassa sp. **13**
Callistocythere cf. *flavidofusca intricatoides* **2, 23**
Callistocythere cf. *intricatoi* **2**
Campylaspis glabra **15**
Campylaspis sp. **2, 3, 15**
Canuella furcigera **2, 20**
Canuella sp. **2**
Caprella danilevskii **2, 15**
Caprella sp. **15**
Carinocythereis batei **23**
Carinocythereis hamata **2**
Ceradocus rubromaculatus **2, 15**
Ceradocus serratus **2, 15**
Ceradocus sp. **2, 3**
Cerapus sp. **2**
Cerapus tubularis **2**
Cheiriphtis sp. **3**
Cheirocratus intermis **2**
Cheirocratus unidentatus **2**
Cheirophotis megacheles **2, 15**
Chiromantes boulengeri **16**
Cirolana parva **2**
Cirolana sp. **2**
Cirolana sulcata **2**
Cleistostoma sp. **3**
Cletodes cf. *dissimilis* **2**
Colomastix pusselia **2**
Corophinum sp. **3**
Cumella forficula **2, 15, 20**
Cumella nispida **15, 20**
Cumella sp. **2, 3, 15**
Cumopsis sp. **3**
Cyclaspis cingulate **20**
Cyclaspis hornelli **2, 15, 20**
Cyclaspis picta **2, 15, 20**
Cyclaspis sp. **3, 15**
Cyclopoid sp. **2**
Cyelaspis cingulate **2**
Cylindroleberis sp. **2**
Cymadusa filosa **2, 15**
Cymadusa sp. **3**
Cymodoce sp. **2**
Cypridina sp. **2**
Cypridinodes minuta **2**
Cyproidea sp. **3**
Cyproidea tecticauda **2, 15**
Cytherella sp. **2, 15**
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Venerupis deshaysei **7**
Venerupis rugosa **3**
Yoldia tropica **3**

Class Cephalopoda

Loligo duvauceli **11**
Octopus cyaneus **10, 11**
Sepia pharaonis **9, 10, 11**
Sepia arabica **11**
Sepia latimanus **11**
Sepia murrayi **11**
Sepia prashadi **11**
Sepia savignyi **11**
Sepiella inermis **11**
Sepioteuthis lessoniana **11**

Class Scaphopoda

Cadulus euloides **3**
Dentalium octangulatum **3, 8**
Laevidentalium longitrorsum **8**
Tesseracme quadrapicalis **3**

Class Amphineura

Chiton sp. **8**

PHYLUM ECHINODERMATA

Class Crinoidea

Amphilycus scripta **1**
Amphiodia (Amphiodia) obtecta **1**
Amphioplus (Amphioplus) seminudus **1**
Amphioplus (Lymanella) hastatus **1**
Amphipholis squamata **1**
Amphiura (Amphiura) crispa **1**
Amphiura (Amphiura) fasciata **1**
Amphiura (Amphiura) sp **1**
Amphiura (Amphiura) sp. *nov.* **1**
Asterina burtoni **1**
Asteropsis carinifera **1**
Astropecten indicus **1**
Astropecten monacanthus **1**
Astropecten polyacanthus phragmorus **1**
Astropecten polyacanthus polyacanthus **1**
Astropecten pugnax **1**
Decametra mollis **1**
Euretaster cribrosus **1**
Leiaster leachi **1**
Linckia multifora **1**
Luidia hardwicki **1**
Luidia maculata **1**
Macrophiothrix elongata **1**
Macrophiothrix sp. aff. Hirsuta cheneyi **1**
Macrophiotrix sp. **1**
Ophiactis savignyi **1**
Ophionereis dubia **1**
Ophiothela danae **1**
Ophiothela venusta **1**
Ophiothrix savignyi **1**
Ophiura kinbergi **1**
Paracrocnida persica **1**
Pentaceraster mammillatus **1**

Class Echinoidea

Brissopsis persica **1**
Clypeaster humilis **1, 2**
Clypeaster reticulatus **1, 2**
Clypeaster savignyi **2**
Clypeaster sp. **2**
Diadema setosum **1, 2**
Dougaloplus echinatus **2**
Dougaloplus personatus **2**
Echinodiscus auritus **1**
Echinodiscus auritus **2**
Echinoidea sp. **2**
Echinoidea unid. **2**
Echinometra mathei **1**
Lovenia elongata **1, 2**
Metalia sternalis **1, 2**
Metalia townsendi **1**
Prionocidaris baculosa **1**
Temnopleurus toreumaticus **1, 2**
Temnotrema siamense **1**
Temnotrema sp. **2**

Class Holothurioidea

Holothuria (Cystipus) rigida **1**
Holothuria (Halodeima) atra **1**
Holothuria (Halodeima) edulis **1**
Holothuria (Mertensiothuria) leucospilota **1**
Holothuria (Thymiosycia) arenicola **1, 2**
Holothuria (Thymiosycia) hilla **1**
Holothuria (Thymiosycia) impatiens **1, 2**
Holothuria sp. **2**
Labidodemas semperianum **1**
Leptosynapta chela **1, 2**
Ohshimella ehrenbergi **1**
Protankyra pseudodigitata **1, 2**
Stichopus variegatus **1**
Thone sp. **1**
Thyone dura **2**

Class Asteroidea

Asterina burtoni **2**
Astropecten hemprichi **2**
Astropecten monacanthus **2**
Astropecten polyacanthus **2**
Astropecten pugnax **2**
Astropecten sp **2**

Class Ophiuridea

Amphiodia microplax **2**
Amphiodia obtecta **2**
Amphiodia sp. **2**
Amphioplus hastatus **2**
Amphioplus personatus **2**
Amphioplus seminudus **2**
Amphipholis squamata **2**
Amphiura crispa **2**
Amphiura fasciata **2**
Amphiura sp. **2**
Amphiura tennis **2**
Ophiactis savignyi **2**
Ophiocentrus asper **2**
Ophiomyxa sp. **2**
Ophioneries dubia **2**
Ophiothrix savignyi **2**
Ophiura kinbergi **2**
Paracrocnida persica **2**

PHYLUM BRYOZOA

Class Gymnolaemata

Aeverrillia setigera **2**
Antropora minor (Antropora marginella) **2**
Crisia elongata **2**
Hippodiplosia otto-mulleriana **2**
Jellyella (Membranipora) tuberculata **2**
Microporella orientalis **2**
Nellia quadrilatera **2**
Parasmittina cf *tropica* **2**
Parasmittina dentigera **2**
Parasmittina egyptica **2**
Parasmittina gnata **2**
Parasmittina parsevali **2**
Parasmittina raigii **2**
Parasmittina signata **2**
Parasmittina unispinosa **2**
Patinella (Lichenopora) radiata **2**
Rhynchozoon larreyi **2**
Schizoporella unicornis **2**
Thalamoporella gothica **2**
Thalamoporella indica **2**
Watersipora subtorquata **2**

Class Stenolaemata

Celleporaria (Holoporella) labelligera **2**
Celleporaria labelligera **2**

PHYLUM CHORDATA

Subphylum Cephalochordata
Branchiostoma lanceolatum **2**
Subphylum Tunicata (Class Ascidiacea)
Aplidium rubripunctum **30**
Botryllus gregalis **30**
Botryllus niger **30**
Didemnum obscurum **30**
Didemnum yolky **30**
Diplosoma listerianum **30**
Ecteinascidia thurstoni **30**
Eusynstyela hartmeyeri **30**
Herdmania momus **30**
Lissoclinum fragile **30**
Phallusia nigra **30**
Polyclinum constellatum **30**
Styela canopus **30**
Symplegma bahraini **30**
Symplegma brakenhielmi **30**

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