Distribution and Abundance of Seagrasses in Qatar Marine Zone

Ekhlas M. M. Abdelbary and Aisha A. Al Ashwal

Abstract Seagrasses are submerged flowering monocot green plants and are primary producers of food for numerous marine animals. Seagrasses are of worldwide distribution, encountered at the lower intertidal zone and may be found at lower depths if the seawater is clear. Worldwide, the number of seagrass were estimated to be approximately 60–72. It is now evident that the number of seagrasses is almost 200 species comprising 25 genera and 5 families. Of these, 10 are on the Red List, counted as risking extinction, of which 3 are considered as endangered. The Western Indo-Pacific realm encompasses 13 species in 2 families: the Cymodoceaceae with 4 genera and the Hydrocharitaceae with 3 genera. Twelve (12) species extend into the Red Sea; 4 occur in the Arabian/Persian Gulf and 4 in the Arabian Sea. The overall distribution and abundance of seagrasses worldwide is little known and much so in the Gulf.

Keywords Arabian/Persian Gulf · Seagrasses · Hydrocharitaceae · Cymodoceaceae · Qatar marine zone

Abbreviations

CO_2	Carbon dioxide
EEZ	Exclusive Economic Zone
ESC	Environmental Science Center, Q U
GHG	Greenhouse gas emissions
Gulf	Arabian/Persian Gulf
IUCN	International Union of Conservation of Nature
km	Kilometer
km^2	Kilometer squared
m^2 m^3	(meter square, cubic meters)
MIC	Mesaieed Industrial City

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psu	Practical salinity unit (measure of seawater salinity/1gm salt/1000gm water)
QMZ	Qatar marine zone
QNV	Qatar National Vision 2030
QU	Qatar University
RLC	Ras Laffan Industrial City
SARC	Scientific and Applied Research Center (now ESC)
Syns.	Synonyms
UNEP	United Nations Environmental Programmes
WCMP	World Conservation Monitoring Programmes

1 Introduction

1.1 The Arabian/Persian Gulf/Gulf

The Gulf, a semi-enclosed shallow sea in a subtropical arid region, is an extension of the Indian Ocean. The Gulf is part of the Middle East at latitudes 24° and 30° N and longitudes 48° and 57° E, extending from northwest Iraq coastline by Shatt Al-Arab to southeast Gulf of Oman via the Strait of Hormuz. This shallow sea has an average depth of 36 m with a slope from Arabia to deep waters of 80–100 m in the Strait of Hormuz. It is about 1000 km long, with maximum width of 340 km between the UAE and Iran, and covers a surface area of 226,000 km^2.

The volume is approximately 8400 km^3. The freshwater that comes from the two rivers Tigris, the Euphrates, and the Karun at the delta of the Shatt al-Arab pour into the sea (Hunter 1982; Reynolds 1993; Siddeek et al. 1999; Elshorbagy et al. 2006). The mean annual evaporation rate is about 1.5 m/ann. Brewer and Drysen (1985) reported that water entering the Gulf from the Indian Ocean has a salinity of 36.5% which gradually increases to 40%. Whereas the sediment by the coast of Iran is muddy and sandy mud by Iraq and Kuwait, it is mostly sandy by Saudi Arabian, Qatari, Bahraini, and UAE coasts, thus providing a larger proportion of trawlable fishing area compared to other regions. However, due to monsoon-driven upwelling with anoxic conditions, the shelf bottoms deeper than 50 m are periodically affected by hypoxic conditions and accordingly with less trophic potential (Siddeek et al. 1999).

The Arabian Sea Ecoregion includes the Gulf within the tropical Indo-Pacific Ocean realm. The Western Indio-Pacific realm comprises two provinces: the Red Sea and the Gulf of Aden Province and the Somali-Arabian Province. The latter comprises four ecoregions: Arabian/Persian Gulf, Gulf of Oman, Western Arabian Sea, and the Central Somali coast (Spalding et al. 2007). The Arabian/Persian coastline covers eight countries: Iraq, Kuwait, Saudi Arabia, the Kingdom of Bahrain, Qatar, the United Arab Emirates (UAE), Oman on the western coastline of the Gulf, and Iran on its eastern coastline. These share the Gulf coastline, and the share of each country is as follows: Iraq 105 km, Kuwait 756 km, UAE 735 km, Bahrain 255 km, Qatar 909 km, Oman 3165 km, and Saudi Arabia 790 km (El Sayyed 2008).

There are two distinct water masses referred to as the Western Arabian Gulf Water and the Gulf of Salwa Water with differences in salinity and water temperature, the higher in the former in temperature and higher in the latter in salinity which result in the density difference between the two (Swift and Bower 2003). High salinity reaching to 57.7 g/l in the Gulf is attributed to its shallowness (John et al. 1990). The high salinity from high evaporation results in an outflow of about 1.5 to 2myr (Bidokhti and Ezam 2009). An estimated mass transport by the Gulf amounts to 34.5 x109 m^3/day. Employing the Knudsen relations, the annual mean Gulf water outflow transport was estimated about 14.7 x109m^3/day, compared to the observation of an annual mean of (17.3–21.6) x109 m^3/day from an Acoustic Doppler Current Profiler (ADCP) in the Strait of Hormuz (Ahmed and Sultan 1991; Bower et al. 2000).

According to Sheppard et al. (1992, 2010), a density gradient is the driving force of water circulation in the Gulf. Water of normal oceanic salinity enters through the Strait of Hormuz at the surface, and there is a compensating outflowing current of high salinity water along the bottom. The general circulation pattern is counterclockwise, where there are a water movement northward along the Iranian coast and a corresponding one southward along the Arabian coast. The tides vary from 3–4 m to 1 m from the north to south, respectively (Siddeek et al. 1999). The Gulf is known to be a sea with the highest salinity and highest seawater temperature and is the smallest in size as compared to other major seas (Fig. 1, Table 1). The Gulf encompasses a surface water body of 214×105 km^2, and compared to world oceans and seas, it has the least area (Al-Ansari 2009).

Due to the shallowness of the Gulf, a great difference of 37%–50% is reported for its salinity as compared to 35–39% in the ocean and attributed to the limited water exchange via the Strait of Hormuz. Freshwater from the rivers is limited and not sufficient to induce a drastic reduction in the seawater salinity. The Gulf lies entirely north of the Tropic of Cancer, and its climatic aridity is demonstrated by its high summer temperatures and relatively cool winters. The high salinity of the Gulf water is attributed to high temperatures and evaporation, the poor supply of freshwater from the rivers at the north, scanty rainfall, and the tight link with the neighboring water bodies. The clear link of the Gulf with the surrounding water bodies (U-shaped link, Fig. 2) influences its physical properties in particular sea temperature and salinity. The Gulf of Oman covers the coastlines of northeast UAE, the eastern coastline of Oman, and the southwestern coastline of Iran. The Gulf of Aden is shared by Somalia and Yemen, and the Arabian Sea coastline is shared by southern Oman and Yemen of the Arabian Peninsula.

In spite of its high salinity, high seawater temperature, and other limitations, the Gulf is considered to be highly productive with a number of ecosystems, including seaweed beds, seagrass meadows, coral reefs, mangroves forests, and mudflats (sabkhas) which collectively contribute significantly to the productivity of its marine resources (Sheppard 1993).

Fig. 1 The location of the Arabian/Persian Gulf in relation to the Gulf of Oman, the Arabian Sea, and the Red Sea. Source: http://www.lib.utexas.edu/maps/middle_east_and_asia/middle_east_ref_2013.pdf

Table 1 Average and maximum depths of the Arabian/Persian Gulf in comparison to major water bodies in the world

Water body	Area (10^6 km^2)	Size (10^6 km^2)	Average depth (m)	Maximum depth (m)
Pacific Ocean	165.20	707.6	4282	11,022
Atlantic Ocean	82.40	323.6	3926	9200
Indian Ocean	73.40	291.0	3963	7460
Mediterranean	3.00	4.200	1429	4600
Red Sea	0.44	0.215	490	2920
Arabian/Persian gulf	**0.23**	**0.009**	**30–50**	**90–100**

Source: Al-Ansari (2009)

Fig. 2 Link of the Gulf to major water bodies in the region. Source: http://www.worldatlas.com/aatlas/infopage/printpage/arabsea.htm

2 Seagrasses

Seagrasses are special among flowering plants being adapted marine life, flower and fruit completely immersed in seawater. Seagrasses are herbaceous aquatic monocots, dioecious rarely monoecious plants with creeping stems and rhizomes. Seagrasses belong to 5 families: Cymodoceaceae with 5 genera and 16 species, Hydrocharitaceae with 16 genera and 147 species, Posidoniaceae with 1 genus *Posidonia* with 10 species, Zosteraceae with 3 genera and 23 species, and Ruppiaceae with 1 genus and 8 species (The Plant List 2013).

The risk of extinction is indicated for 10 out of the 60 plus accepted species, of which 3 are considered as endangered (Short et al. 2011). In fact there are 25 genera in the 5 families and a total of 197 accepted species. Only genera within the two families the Cymodoceaceae and Hydrocharitaceae occurring in the region are included in this study. The family Cymodoceaceae includes only marine species and comprises 5 genera: *Halodule* with 5 species, *Cymodocea* with 4 species, *Syringodium* with 2 species, *Thalassodendron* with 2 species, and *Amphibolis* with 2 species. All genera occur in the region except for *Amphibolis*. The family Hydrocharitaceae includes freshwater and marine species and is represented by 3 marine genera in the region: *Enhalus* is a monotypic genus, *Halophila* with 3 species out 14 recorded species, and *Thalassia* with 2 species. Both families share a few common characters: plants submerged with rhizome and roots without vessels; leaves variable; reproduction asexual and sexual; and flowers unisexual. The Western Indo-Pacific realm encompasses 13 seagrass species, and of these, 12 occurred in the Red Sea (El Shaffai 2011). Eight of these species are reported in the Eritrean Red Sea coast with little known about their overall distribution and abundance, 9 species in Yemen, 10 species in Sudan, and 9 species in Saudi Arabia coastal waters, and 11 species were reported for Egypt excluding *Halophila ovata* Gaudich. This species was reported by Ostenfeld (1909) as a neglected *Halophila* species found in the Philippines. Further studies suggested the possibility of its being a mistaken name for *Caulina ovalis* R.Br. and accepted as an illegitimate synonym of *H. ovalis* (R.Br.) Hook.f. (Florabase). This was confirmed by Hartog and Kuo (2006), and they described a new species from Japan and neighboring countries as *Halophila gaudichaudii* Kuo based on detailed examination of fresh and herbarium material. For southeast Arabia and for the Gulf, four species are known to occur.

The distinction between seagrass species is based on the mode of the plant growth, the leaf morphology, and the characteristics of the floral parts. The keys to the families, genera, and species presented are based on a number of contributions focusing on the identity of seagrasses (Menez et al. 1983; Wang et al. 2010; Sullivan 1994; Hartog and Kuo 2006; El Shaffai 2011).

Simple Key to the Two Families Hydrocharitaceae and Cymodoceaceae

Dioecious herbs; monopodial or sympodial. Rhizome with simple or branched roots. Leaves ligulate. Flowers unisexual without distinct perianth. Gynoecium with superiorapocarpous bicarpellate ovary. -------------------------*Cymodoceaceae.*

**Monoecious or dioecious herbs. Rhizome with simple roots. Leaves eligulate. Flowers unisexual with distinct petals and sepals. Gynoecium with inferior syncarpous unilocularovary.-------------------------------------- *Hydrocharitaceae.*

Simple Key to the Genera of the Cymodoceaceae in the Region

1a. Rhizome sympodial with branched roots. Leaves falcate/sickle-shaped, reddish, margin serrated long up to 15 cm and c.1 cm across, 7–17-nerved appearing clustered toward the apex of an elongated upright stem. Male flowers with sessile anthers with apical appendages. Gynoecium with bifid style. Fruit long c.6 cm and free floating.--*Thalassodendron.*

1b. Rhizome monopodial with branched or unbranched roots. Leaves flat variable. Male flowers with pedunculated anthers. Styles divided or undivided:

2a. Leaves subulate/terete. Roots branched. Inflorescence cymose. Anthers at samelevel on peduncle without appendages. Style bifid.---------------*Syringodium.*

2b. Leaves flat. Roots branched or unbranched. Inflorescence solitary:

3a. Roots branched. Leaves wide, 7–17-nerved. Anthers at same level on peduncle. Gynoecium with long bifid style.---*Cymodocea.*

3b. Roots unbranched. Leaves flat, narrow, 3-nerved. Anthers not at same levelon the peduncle. Gynoecium style undivided.---------------------------------*Halodule.*

Thalassodendron (reef grass) with one species *T. ciliatum* (Forssk.) den Hartog in the region.

Syns. *Cymodocea ciliata* (Forssk.) Ehrenb. ex Asch., *Thalassia ciliata*, *Zosteria ciliata.*

Rhizome sympodial woody; leaves flat grouped at top of erect shoots, falcate, c.15 cm long; leaf sheath present. The species is the only one that does well on reef and rocky substrate.

Syringodium (tubular seagrass/manatee grass) with one species *S. isoetifolium* (Asch.) Dandy in the region.

Rhizome monopodial with branched roots; leaves cylindrical, very long; sheath persistent. Special pollination. Inflorescence solitary male flowers detach during pollination; female flowers arise above water for a short while and short lived.

Halodule (needle leaf seagrass) with one species *H. uninervis* (Forssk.) Asch.

Rhizome monopodial with unbranched roots; leaves flat, 3-nerved with mid-nerve prominent, apex tridentate, and leaf sheath persistent.

Cymodocea (sickle-leaved seagrass) is represented by two species in the region. Both species have delicate monopodial rhizomes with branched roots; leaf blade linear-ovate, petiolate reddish-tinged, linear, flat to slightly falcate, c.10–15x1cm, leaf sheath present not persistent, leaf scars present on shoot. Inflorescence solitary; male flowers stalked with two anthers set at the same height, female flowers sessile, carpels free, style short with two long stigmas.

Cymodocea rotundata Ehrenb. & Hempr. ex Asch./smooth ribbon grass has leaves with round apex and entire margin, and *C. serrulata* (R.Br.) Asch. & Magnus/ serrated ribbon grass has leaves with round apex and serrate margin.

The Hydrocharitaceae is known as the tape grass family with three marine genera: *Enhalus*, *Halophila*, and *Thalassia*.

Simple Key to the Genera of the Hydrocharitaceae in the Region

1a. Slender herbs with alternate sessile leaves:

2a. Leaves slightly falcate. Female inflorescence shortly pedunculate 1. *Thalassia.*

2b. Leaves not falcate. Female inflorescence long pedunculate... 2...*Enhalus.*

1b. Robust herbs with opposite or binate usually petiolate leaves... 3. *Halophila.*

Thalassia (turtle seagrass) is represented by one species *T. hemprichii* (Ehrenb. ex Solms) Asch.

Leaves slightly falcate and resemble *Cymodocea rotundata* in having round leaf tip but its leaves are emarginate. Female flowers are shortly pedicellated.

Enhalus is a monotypic genus with one species *Enhalus acoroides* (L.f.) Royle.

Leaves alternate on two rows, variable, sessile with a very different mode of pollination where at anthesis the male flowers detach and float at the surface and female flowers elongate to bring flowers to the surface. After pollination, the spathe bends back to be submerged, and the fruit is developed under the surface. Female inflorescence long pedunculated.

Halophila (Caribbean seagrass) is represented by four species, all with pairs of petiolate leaves and either dioecious or monoecious. *Halophila* is euryhaline and considered as one of the most tolerant to a wide range of salinities and hence has a widespread distribution.

H. decipiens Ostenf. (delicate paddle grass). Monoecious. Rhizome with black fiber. Stem short with lateral hairy shoots. Leaves strap-shaped, margin finely serrulate.

H. ovalis (R.Br.) Hook.f (oval paddle grass). Dioecious. Rhizome with lateral glabrous shoots. Leaves ovate not spathulate, margin entire, 1–4 cm at <45–60 angle.

H. minor (Zoll.) den Hartog Dioecious. Rare (El Shaffai 2011; Gaiballa 2005).

H. stipulacea (Forssk.) Asch. Dioecious. Stem branched. Leaves distichous linear with serrulate margin.

Phillips (2003) observed that leaf blades of *H. stipulacea* in the vicinity of the Hawar islands were bigger than seen elsewhere in the Arabian Gulf.

3 Seagrass Communities

Seagrasses form dense meadows in healthy locations where the seafloor sediment is of sand and mud in shallow coastal waters from the lower intertidal zone down to depths of less than 5 m and down to 12 m depending on water clarity. They anchor themselves on the seafloor by a network of rhizomes and roots. The vegetative shoot system of stems and leaves originate from the underground rhizomes. The roots have no vessels and absorb nutrients but play no part in water absorption. The leaves are thin enabling the penetration of sunlight rays, absorption of nutrients, and exchange of gases. Through the process of photosynthesis, they utilize the carbon dioxide in the water, hence reducing GHG emissions and reducing the acidification of seawater. The root systems of seagrasses stabilize the soft bottom sediments of sands and mud and protect the shoreline by slowing the rate of erosion.

The seagrass ecosystem ranks as one of the high productive marine ecosystems. Seagrasses are primary producers sustaining numerous large marine animals including marine turtles and dugongs and others of various sizes such as herbaceous nudibranchs. They are the basis of many food chains, hence supporting commercial species of fish, shrimps, and crabs as well as being nursery grounds and refuge areas for various larvae and juveniles of seafood species. Equally, seagrass leaf blades and stems provide suitable habitat for microorganisms, and various organisms including suspension feeders, bivalves, gastropods, and echinoderms such starfish and brittle starfish species that utilize their vicinity as habitat and some organisms survive on the detritus from the breakdown of their leaves and stems (Paterson et al. 2004). There is no doubt that seagrass communities promote marine biodiversity. Seagrass beds occur sometimes offshore mangrove stands which are also known as feeding rounds. There is evidence that many species of crustaceans and fish commute between seagrass beds and mangroves (SCENR 2004).

Unfortunately, destruction of seagrass communities is occurring everywhere in the regional waters, and therefore they are diminishing and are being lost at an alarming rate. According to Short et al. (2011), 10 species are on the IUCN Red List of risk of extinction, and 3 are endangered out of the estimated total number of 72 species. This is attributed to human impacts in the coastal zone mainly seabed dredging and drastic changes in their habitat and to marine pollution from different sources. Dredging increases particulate matter and hence reduces water clarity affecting light visibility and causing sedimentation on the seagrass mats. Climate change is now a significant global threat. According to FAO 1982, climate change might alter the surviving conditions for seagrass by altering their environmental conditions.

Seagrasses capture and retain carbon and hence are hotspots for accumulation of carbon in the biosphere comparable to temperate and tropical forests (Fourquerean et al. 2012; Campbell et al. 2015). Their role as important reducers of GHG emissions has not as yet been studied fully, whereas their counter and sometimes coexisting partners, the seaweeds, have been proven to be very important in GHG emissions.

Studies carried out by Greiner et al. (2013) proved the value of seagrass ecosystem as a storage of carbon and nutrients. The “blue carbon” in marine sediments is now a focus of many recent studies. This encouraged the experimentation with seagrass plantation, and results proved a success (Whitehead 2015). The role of seagrasses as well as seaweeds in the reduction of GHG emissions not previously recognized now is shown to have a significant role in GHG emissions.

Seagrasses are found across the world, from the tropics to the arctic (Fig. 3), and are by the coastlines, with a global area of 300,000–600,000 km^2, and have declined in area by 29%. In recent times, seagrasses are continuously declining with a yearly rate of 1.5% and continue to decline. Their areas are being replaced by muddy and sandy soils (Short et al. 2007).

Regional waters are comparatively saline particularly the Gulf where the salinity gradient is variable from one location to another. The seagrass species reported in the Gulf are known to be tolerant of higher salinities (Erftemeijer and Shuail 2012), and they have been reported from numerous locations in regional waters (Table 2).

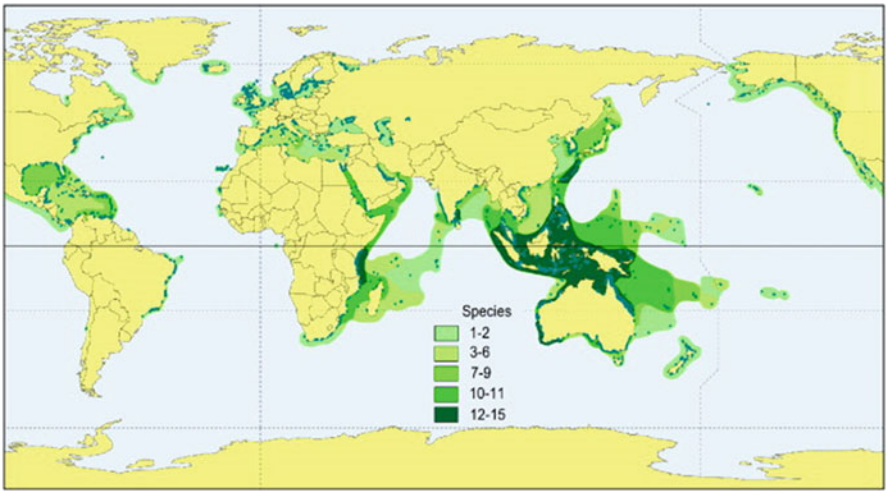

Fig. 3 Diversity of seagrasses in worldwide. Shades of green indicate the number of species reported for a given area. The darker shades of green indicate more species are present. Source: Short et al. (2007)

4 Distribution of Seagrasses along the Coastline of the Red Sea

The Red Sea is a long narrow basin approximately 2000 km long, with an average breadth of 280 km and maximum breadth of 306 km at its southern end and narrowing to 26 km near its entrance to the Gulf of Aden at Bab al-Mandeb. Its continental shelf area is to 200 m depth and around 180,000km^2 or 41% of the total area of about 440,000km^2 (Hariri et al. 2000). The main tropical marine habitats that exist occurred in the Red Sea. These include the back reef environment which is a sandy, shallow coastal habitat of less than 10 m depth. This habitat type is suitable for seagrass meadows to develop in particular when annexed to beaches and mangrove stands. Too shallow waters do not support seagrass meadows since they might exposed at low tide to the air conditions that do not support seagrass growth. The type of the seafloor is an important parameter for the growth of seagrasses. Generally, water depth is known to be directly correlated with the amount of sun light penetration through the water column.

Twelve (12) seagrass species belonging to the seven accepted genera have been reported to occur in the Red Sea and the Gulf of Aden (UNEP 1997; Hariri et al. 2000; Lipkin et al. 2003; Gaiballa 2005; Gladstone et al. 2006; El Shaffai 2011). Eight species occur in the north of the Red Sea (north of 25°and south of the Gulfs), whereas the central zone (18°–25° N) comprises the highest diversity attributed to great diverts habitat and environmental conditions (Jones et al. 1987). Studies on seagrass standing crop have been undertaken mostly in the northern part, and the highest biomass is associated with *Thalassodendron ciliatum*, *Thalassia hemprichii*,

Table 2 Distribution of seagrasses species in the regional seas

	Family Cymodoceaceae					Family Hydrocharitaceae						
Water body	*Cymodocea rotundata* Asch. & Schweinf.	*Cymodocea serrulata* (R. Br.) Asch. &Magnus	*Halodule uninervis* (Forssk.) Asch.	*Syringodium isoetifolium* (Asch.) Dandy	*Thalassodendron ciliatum* (Forssk.) den Hartog	*Enhalus acoroides* (L.f.) Royle	*Halophila decipiens* Ostenf. Hartog	*Halophila minor* (Zoll.) den Hartog	*Halophila ovalis* (R. Br.) Hook..f.	*Halophila pinifolia* (Miki)den Hartog	*Halophila stipulacea* (Forssk.) Ashch.	*Thalassia hemprichii* (Ehrenb.) Asch.
Arabian Sea Oman/O & Yemen/Y	Y	Y	O,Y	O,Y	O,Y	Y			O,Y		O,Y	Y
*Gulf of Oman Oman/O & Iran/I			O, I	O	O				O, I			
Arabian/Persian gulf			+	+					+		+	
Red Sea	+	+	+	+	+	+	+	+	+	+	+	+

aS. UAE, S. Oman & SW Iran

and *Syringodium isoetifolium* (Chiffings et al. 1995). For Saudi Arabia, 10 species of seagrasses were reported (Aleem 1979; Menez et al. 1983; Bruckner et al. 2011; Lipkin et al. 2003).

The approximate locations of some of the major grass beds have been mapped, although the extent and distribution in most countries have not yet been determined (Al-Muzaini and Jacob 1996). For Yemen nine species were documented along its coastlines, of which three of them on the Gulf of Aden coast (Hirth et al. 1973; Menez et al. 1983; UNEP 1997; Rouphael et al. 1998; Mistafa 2005; Wilson and Kalus 2000; Wilson et al. 2003; Lipkin et al. 2003). Four seagrasses species are common along much of the Oman coastal area. Isolated pockets of dense beds have been reported for eastern Oman and the Gulf of Aden (Yemen) (Hirth et al. 1973). Rouphael et al. (1998) listed 11 species including *Halophila ovata*. The southern part has less species. The reduction in the reported species is attributed to less sampling in distant area of Yemen and Eritrea.

However, the occurrence of seagrass species in the Red Sea is believed to be via the Indian Ocean, and one species, *H. stipulacea*, is believed to have spread in the Mediterranean Sea through the Suez Canal estuaries (El Shaffai et al. 2014). The distribution of seagrass species in some countries with coastlines on the Red Sea based on a number of resources is shown in Table 3.

5 Distribution of Seagrasses along the Coastline of the Gulf

Seagrass meadows in the Gulf occur in nearshores and shallow waters less than 10 m as underwater meadows or pastures, characterized by high biological productivity. Sandy and muddy substrates lead to more growth of seagrass. The largest areas of seagrass beds occur off the coasts of the UAE and between the Kingdom of Bahrain and Qatar with an estimated area of 5500 and 1000km^2, respectively.

There is abundant literature on seagrasses related to their world distribution and value as an ecosystem supporting a magnitude of marine organism. Yet much more is needed to document their exact coverage in the Gulf and evidence of their value as a critical marine habitat. It is established that seagrasses consolidate and stabilize bottom sediments, create and maintain good water quality (clarity), produce oxygen, and provide food and nursery ground for many animals, including dugongs, turtles, and fishes. It is in these seagrass habitats that marine turtles feed. The seagrass beds therefore produce a quantity of organic material that directly supports feeding, food chains (turtles and dugongs – the largest population of dugongs known outside Australia), and the "detritus" food chains, which support marine fisheries. Fig. 4 illustrates the distribution of seagrass beds at the southwestern zone of the Gulf.

Seagrasses are common in shallow areas ($<$10 m). Three species of seagrasses are widely distributed along the shores of all countries surrounding the Gulf. *Halodule uninervis* is the most widely distributed, and *Halophila stipulacea* is the least common, but forms dense meadows in some areas (Basson et al. 1977); *Halophila ovalis* is rare. These three species form either monospecific or mixed-species

Table 3 Distribution of seagrasses species along the Red Sea coastline

Country	Family Cymodoceaceae					Family Hydrocharitaceae							Total	References
	Cymodocea rotundata Asch. & Schweinf.	*Cymodocea serrulata* (R.Br.) Asch. & Magnus	*Halodule uninervis* (Forssk.) Boiss.	*Syringodium isoetifolium* (Asch.) Dandy	*Thalassodendron ciliatum* (Forssk.) den Hartog	*Enhalus acoroides* (L.f.) Royle	*Halophila decipiens* Ostenf.	*Halophila minor* (Zoll.) den Hartog	*Halophila ovalis* (R. Br.) Hook.f.	*Halophila pinifolia* (Miki) den Hartog	*Halophila stipulacea* (Forsskål) Ascherson,	*Thalassia hemprichii* (Ehrenb. ex Solms) Asch.		
Egypt	+	+	+	+	+	+	+	+	+	+	+	+	12	Menez et al. (1983); Jacobs (1985); Lipkin et al. (2003); Shabaka (2014); Mohamed (2007) and El Shaffai et al. (2014)
Sudan	+	+	+	+	+	+		+	+		+	+	10	Menez et al. (1983); Lipkin et al. (2003); Gaiballa (2005); EIA (2007); Coral petroleum operating Co. Ltd 2008 and Elhag (2011).
Eretria	+		+	+	+	+			+		+	+	8	Menez et al. (1983); Lipkin et al. (2003); Hiabu,(2006)

(continued)

Table 3 (continued)

Country	Family Cymodoceaceae					Family Hydrocharitaceae							Total	References
	Cymodocea rotundata Asch. & Schweinf.	*Cymodocea serrulata* (R.Br.) Asch. & Magnus	*Halodule uninervis* (Forssk.) Boiss.	*Syringodium isoetifolium* (Asch.) Dandy	*Thalassodendron ciliatum* (Forssk.) den Hartog	*Enhalus acoroides* (L.f.) Royle	*Halophila decipiens* Ostenf.	*Halophila minor* (Zoll.) den Hartog	*Halophila ovalis* (R. Br.) Hook.f.	*Halophila pinifolia* (Miki) den Hartog	*Halophila stipulacea* (Forsskål) Ascherson,	*Thalassia hemprichii* (Ehrenb. ex Solms) Asch.		
Saudi Arabia	+		+	+	+	+		+	+		+	+	9	Aleem (1979); Menez et al. (1983); Bruckner et al. (2011) and Lipkin et al. 2003.
Yemen	+	+	+	+	+	+			+		+	+	9	Hirth et al. (1973); Menez et al. (1983); UNEP (1997); Rouphael et al. (1998); Mistafa (2005); Wil-son and Kalus (2000); Lipkin et al. (2003) and Wilson et al. (2003).

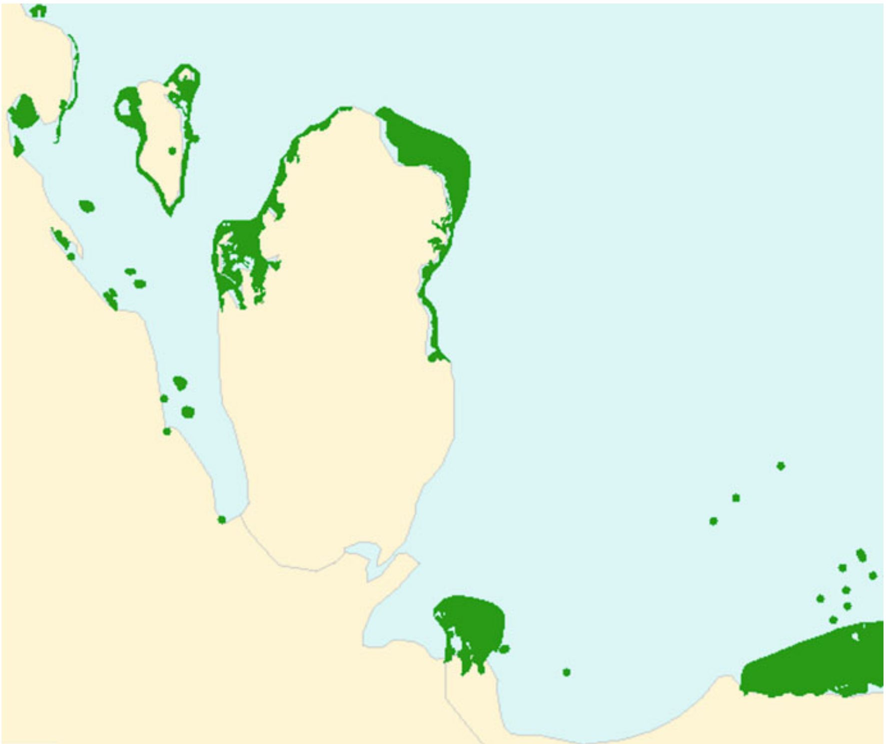

Fig. 4 Known distribution of major seagrass assemblages in the southwestern Gulf. Source: The status of sea in Qatar (SCENR 2004)

meadows in the Gulf. At least two species (*Halodule uninervis* and *Halophila ovalis*) were recorded in Iran (Menez et al. 1983) and Kuwait. For Iraq seagrasses were not recorded (Erftemeijer and Shuail 2012; Phillips 2003).

Four seagrass species are known for the Arabian/Persian marine region, of which *Halodule uninervis* and *Halophila ovalis* are the most prevalent. Recent records of *Syringodium isoetifolium* (Asch.) Dandy and *Thalassodendron ciliatum* (Forsskål) den Hartog were reported in the Gulf of Oman (Wilson and Kalus 2000). Table 4 shows the occurrence of seagrass species in the Gulf countries based on various contributions.

6 Distribution of Seagrasses along the Coastline of Qatar

Qatar is a small low-lying limestone peninsula situated midway along the western coast of the Gulf between latitudes 24.27°–26.10° N and longitude 50.45°–51.40° E semi-surrounded by the Gulf projecting northward about 160 km into the Gulf. Qatar

Table 4 Occurrence of seagrass species in the Arabian/Persian Gulf countries

Area	Iran	Iraq	Kuwait	Kingdom of Bahrain	Qatar	U. A. E.	Oman	Saudi Arabia
Halophila ovalis (R. Brown) hook. f	*		*	*	*	*	*	*
Halophila stipulacea (Forsskal.) Ascherson.				*	*	*		*
Halodule uninervis (Forsskal). Ascherson.	*		*	*	*	*	*	*
Syringodium isoetifolium Ascherson. Dandy				*			*	
Thalassodendron ciliatum (Forsskal) den Hartog							*	
∑ species	2	0	2	4	3	3	4	3

References: *Iran* Menez et al. (1983); Phillips (2003). *Iraq* Erftemeijer and Shuail (2012). *Kuwait* Menez et al. (1983); Al-Hasan and Jones (1989); Phillips (2003); Erftemeijer and Shuail (2012); Al-Bader et al. (2014) and Al-Yamani et al. 2014 *Bahrain* Menez et al. (1983); Vousden (1995); Nasser (2001); Pilcher et al. (2003); Phillips (2003); Al-Wedaei et al. (2011); Naser (2012); Zainal et al. (2012); Erftemeijer and Shuail (2012); Naser (2014) and Naser (2016). *Qatar* COWI (2001–2002); Phillips (2003); AlKhayat and Al-Mahannadi (2006); Al Jamali (2008); ESC (2008); ESC (2009); SCENR (2004); ESC (2010-2011); ESC (2011); Abdel Bary (2011); Abdel Bary (2012); Abdel Bary (2012); ESC (2014); Warren et al. (2015); Five oceans (2015) and Whitehead (2015). *UAE* Phillips (2003); Hallyer and Aspinalls (2005); AGEDI (2008); Howari et al. (2009); Abdeessalaam (2010); Llewellyn-Smith (2012); and Erftemeijer and Shuail 2012 *Oman* Al-Muzaini and Jacob (1996); Jupp et al. (1996); Goddard and Jupp (2001); Phillips (2003); CBD (2014) and Wilson (2000). *Saudi Arabia* Basson et al. (1977); Coles and McCain (1990); Price and Coles (1992); Willson et al. (2000); Sheppard and Borowitzka (2011); Qurban et al. (2011) and Bruckner et al. (2011)

is 185 × 85 km along its N-S axis, parallel to the eastern coast of Saudi Arabia, and shares its southern border with it and covers an area of approximately 11,000km^2 including a number of small offshore islands. Halul, the main oil storage and exporting port, is an inhabited offshore island. Major towns are located on the eastern sea coast, such as the capital Doha, and the major cities of Al Shamal, Al Khor, Al Dhakhira, and Al Wakra, in addition to the industrial cities of Mesaieed, Ras Laffan, and Dukhan. Over eighty percent (83%) of the inhabitants reside in Doha and its main suburb Al-Rayyan.

The total coastline including the islands is over 750 km approximately 23% of the coasts of the Gulf with numerous bays and undulations and protrusions seaward such as Ras Laffan, Ras Rekn, and Ras Ashirij plus the coastline of the islands. Beyond the coastline there is a wide intertidal zone encompassing mangrove forests and coastal coral reefs. The seabed is mostly sandy (c. 45%), with areas of coral reef (c. 10%) and rubble and rocky locations plus degraded coral reefs. In the productive shallows, coral reefs are common on hard substrate, and grass beds are widespread on soft sediments. Unfortunately many coral reefs suffered from climate change and various human impacts.

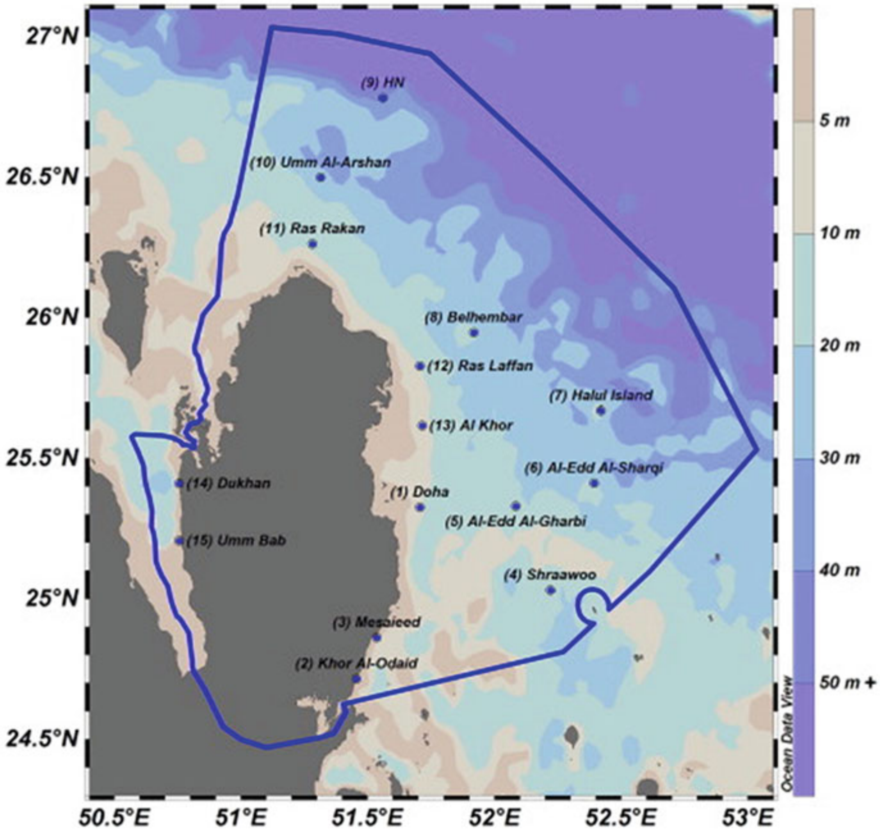

Fig. 5 Qatar marine zone (EEZ). Source: Dr. Sinan Husrevoglu, ESC

The total area of Qatar marine zone (Exclusive Economic Zone (EEZ) Fig. 5) is approximately 35,000km^2 almost 15% of the Gulf area extending about 95 nautical miles seaward to the east and about 51 nautical miles to the north. The waters around Qatar are extremely shallow with an average depth of 30 m in the north and east, while on the western side, it is only 20 m deep. The climate is characterized by a mild winter and a hot summer. Rainfall in the winter is slight, averaging some 80 mm/ year.

The coastal and marine areas of Qatar are of strategic importance since more than 90% of the country's economic development exists along the coastline SCENR (2004).

Qatar's cultural history and present life are linked to the sea. Qatar's main revenue and wealth is from gas production with the main source found on the northeastern section of its marine zone. Qatar marine zone (QMZ) encompasses a number of unique marine ecosystems which include seagrass meadows, seaweed beds, coral reef, and oyster ecosystem. Fishing in QMZ is the main source of the seafood and locally the fish is the preferred dishes.

Surveys of Qatar marine zone have shown that the intertidal habitats include sandy beaches, rocky shores, mangroves, and salt marches, whereas the nearshore subtidal habitat comprises seagrass beds and coral/hard bottom ecosystem.

Water temperatures 10 °C and 39 °C are reported for nearshore locations which could decrease to 4 °C during the cool season due of the Al Shamal winds. These drop can cause mortality of large number of tropical fauna. Summer winds are caused by the difference between land and sea temperature. The species existing in these marine zones endure these changes having adapted a tolerance of local conditions SCENR (2004).

Freshwater via the Strait of Hormuz reduce salinity. However, salinity in Qatar surface waters ranges from 39 psu and 41 psu and is higher deeper by 1–2 psu. Higher salinity is recorded at Khor Al Udaid (S. Qatar) to over 60 psu. At the Gulf of Salwa, salinity ranges from 55 psu to 70 psu from the north to south. These high salinities effect localized communities such as the algal mats at Salwa, S. Qatar (SCENR 2004). Three species are known to occur in Qatar marine zone. These are *Halophila stipulacea* and *Halophila ovalis* of the family Hydrocharitaceae and *Halodule uninervis* of the family Cymodoceaceae. Members of both families are dioecious submerged plants, and *Halodule uninervis* is the most common, *Halophila stipulacea* is fairly common, and *Halophila ovalis* is relatively rare (COWI 2001–2002; AlKhayat and Al-Mahannadi 2006; Al Jamali 2008; ESC 2008; ESC 2009; Abdel Bary 2011; Abdel Bary 2012; Abdel Bary 2015).

A fourth species *Syringodium isoetifolium* reported to occur on the western coastline (Qatar–Bahrain) apparently does not exist. Plates 1, 2, and 3 show the main features of the three species.

Most studies on seagrasses including their distribution and mapping were carried out on the eastern coastline of Qatar. A number of the surveys carried out showed that species composition and dominance differed at the different location (ESC 2008). Undersea videos showed that seagrasses were associated with the presence of species that feed on them such as turtles and others that use them as habitat such as sponges, bivalves, ascidians, most fish, and others.

Al Jamali (2008) carried out a survey on seagrasses and seaweeds in a lagoon in the vicinity of Doha West Bay (N. Doha) and reported *H. uninervis* and *H. ovalis* and seaweeds. A study on the distribution and abundance of seagrass meadows on the northeastern coastline, north of Ras Laffan and south of Al Mafjar (ESC 2010-2011), showed that coverage at different sites was variable (Figs. 6, and 7).

In a study that carried out by the ESC (2011) in the marine zone on the southeastern coastline, in the vicinity of Al Besheireya Island, seagrasses were plentiful further away from the coastline, and the seagrass beds were sparsely vegetated where water clarity was poor (Fig. 8).

Underwater photography and videos were carried out to estimate coverage of seagrass along the northeastern coastline of Qatar. The three seagrass species were reported as well as assemblages of coral reefs and seaweed beds (Warren et al. 2015). A study carried out by Five Oceans (2015) at Umm Al Houl showed large areas were

Plate 1 *Halodule uninervis*

colonized by moderate to dense seagrass beds where the subtidal zone is of sand flats of varying coarseness. These covered extensive areas extending from the lower intertidal zone offshore to depths exceeding 10 m. The main areas of dense cover were recorded within a depth range of approximately 1–3 m. In deeper areas dense seagrass cover was rather patchy, giving way to sparser isolated beds further offshore. The width of the shallow water seagrass areas ranged from between 400 m to over 1 km depending on location; areas of thin sand substrate supported macro-algal communities dominated by brown algae often interspersed with seagrass of varying density (Fig. 9). At the extreme southeastern coastline of Qatar at Khor Al Udaid, *Halophila ovalis* and *H. uninervis* were recorded (AlKhayat and Al-Mahannadi 2006). Between Qatar and the UAE, the seabed is also shallow with high salinity but equally considered rich and productive biologically (SCENR 2004).

Plate 2 *Halophila ovalis*

Studies on the western coastline neighboring Bahrain and Saudi Arabia are few. The Gulf of Salwa is characterized by shallow and highly saline seawater. The seabed has reefs and seagrass beds that are highly productive and a main food source for the dugongs, marine turtles, and numerous marine organisms besides being nursery grounds for larvae and juveniles of a number of species most importantly fish and shrimps. The dugong population in the Gulf is considered as the world's second largest and is vulnerable to extinction. The survival of the species depends on seagrass beds (SCENR 2004; COWI 2001–2002).

Plate 3 *Halophila stipulacea*

Seagrass beds are common along the coastline at depths of 3–8 meters at several surveyed stations along the west coast of Qatar. These were found to comprise three species, *Halodule uninervis*, *Halophila ovalis*, and *Halophila stipulacea* (Plates 1, 2, and 3), and these were generally associated with relatively fine-grained sediment types. Most beds were dominated by *H. uninervis*, although mixed stands also occurred. Extensive continuous mats of *H. uninervis* were found from 0.75 m to 2.5 m. *H. uninervis* was abundant down to 4 m depth at least, but deeper than 2.5 m its growths was patchy, mostly due to the loss of continuous soft sediments and the presence of a rocky base in large patches. *Halodule* is recognized as the most tolerant of high salinity. It is most abundant in shallow waters where there were a dense, thick leaf baffle in the water column and an accompanying thick interlocking matrix of rhizomes in the sediment, which results in abundant decaying leaf litter (SCENR 2004).

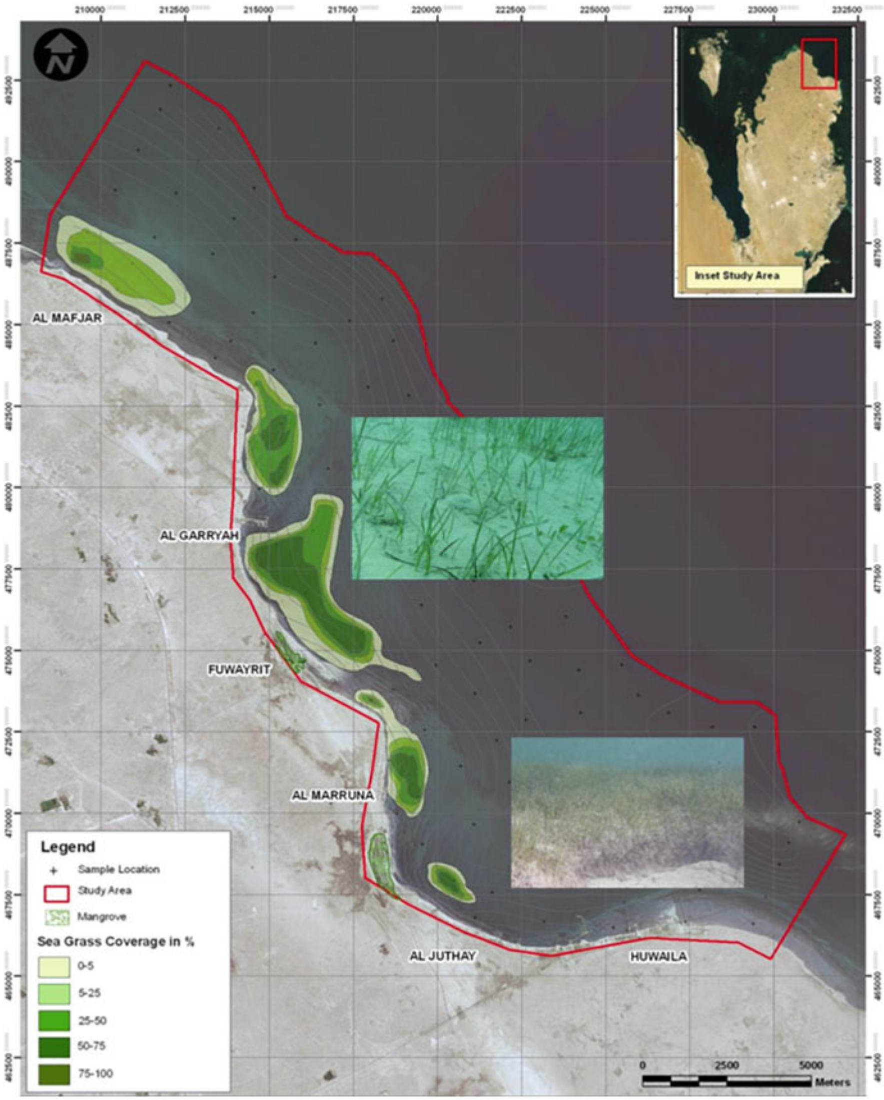

Fig. 6 Distribution and cover of seagrasses along the eastern coastline from N Ras Laffan to S Al Mafjar. Source: ESC (2010-2011)

Based on numerous studies, seagrass species occur at many locations on the eastern coastline. Records for the western coastline are few in limited studies. Figure 10 shows the distribution based on known GPS locations in studies carried out between 2001 and 2016, and Table 5 and Fig. 11 show the distribution given within the same period in water bodies in the vicinity of towns and cities (Figs. 12 and 13). Throughout seagrasses occur at depth between 1 and 5 m on sandy seafloor.

Fig. 7 Variation in seagrass density in seagrass meadows

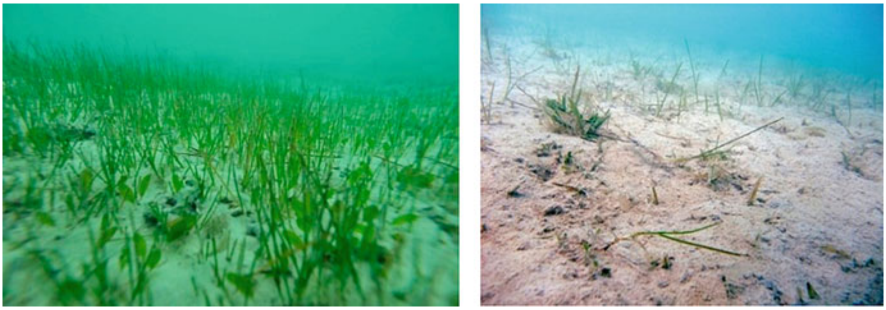

Fig. 8 Mixed stands of seagrasses on sandy beds. Source: ESC (2009)

7 Discussion

The Gulf countries have an economy based on oil production and petro-chemical industries. The main revenue and wealth of the region is based on an oil economy. The major production locations are in the Gulf, a semi-enclosed body of water with high salinity in a zone of high temperature and an arid climate. The high salinity is due to the lack of substantial rains and a limited inflow of freshwater from inland rivers or lakes plus the frequent hot drying winds in the region. Lack of freshwater lakes and rivers in most of the Gulf countries means a heavy dependence on desalination plants. These do increase the chemical content of the sea in chlorine and sodium. There is evidence that much need to be done to balance the advancement in industrial development with sustainability of natural resources.

The Gulf waters are vital to the survival of the Gulf countries because for many it is their main source of freshwater. However, the Gulf waters suffer from a number of anthropogenic impacts including oil and related industries, continuous coastal developments, sewage and storm water discharge, desalination plants, ballast water discharge, and dredging operations on the seafloor for pipelines which have a heavy toll on marine life and add to that climate change effect. The number of desalination plants and their discharge of brine is a major problem for the future of the Gulf. Bashitialshaaer et al. (2011) drew attention to the consequences of brine

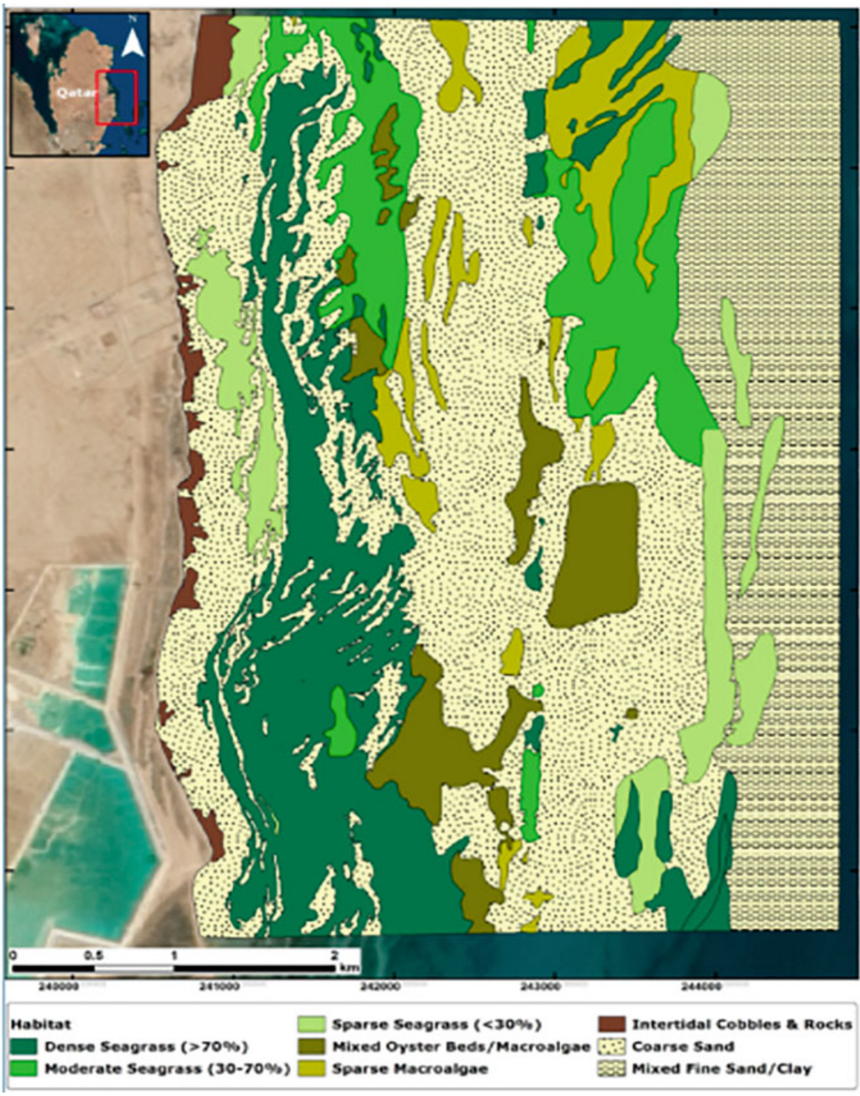

Fig. 9 Umm Al Houl habitat mapping survey results 2015. Source: Five Oceans (2015)

discharge from desalination plants in the Mediterranean, the Red Sea, and the Gulf showing the desalination capacity for a number of countries as per day and annually, and based on values of 1996 and 2008, they estimated the desalination capacity for 2050. For the Gulf, individual countries are detailed (Table 5) as compared to the highest values for the Mediterranean: Italy 483.7, Libya 638.4, Span 492.8, and 145.0 for Malta.

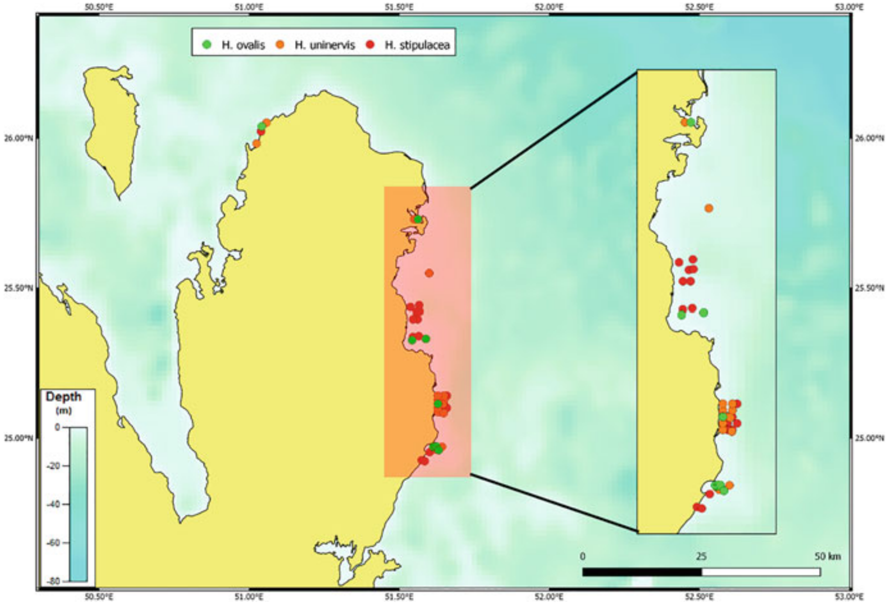

Fig. 10 Distribution of seagrasses in QMZ based on GPS locations. Source: Dr. Sinan Husrevoglu, ESC

The three seagrass species reported to occur in Qatar marine zone and generally in the Gulf are tolerant of salinity. *Halodule uninervis* is the most tolerant, and it is the most common of the three species.

Qatar is a fish-based diet nation similar to other Gulf countries and has the second largest population of the endangered dugongs, the engendered marine turtles feed in its waters, the Hawksbill turtles nest on Qatari coastlines, and Qatar is committed by international agreements to protect marine life.

Both seagrasses and seaweeds are primary producers and play an important role in the control of GHG emissions. The importance of seagrass meadows is in sustaining various organisms and most importantly their role in food security. They are an essential habitat for a number of marine organisms. Though seagrass meadows occupy <0.2% of the world's oceans, they are estimated to make use of roughly 10% of the yearly estimated organic carbon burial in the ocean (Cullen-Unsworth and Unsworth 2013).

Unfortunately, their value is not recognized as a vital resource. The global estimate of loss is 2–5%. Floating masses of seagrass and seaweed detritus were observed and are most likely a result of dredging operations. The irresponsible net-fishing in some areas impacts negatively on marine vegetation which is essential for the survival of marine organisms. Walton et al. (2016) reported extreme 15 N depletion in seagrasses, estuaries, and coasts in Qatar.

For seagrass beds to continue provision of subsistence to marine organisms and to play a major role in the much desired GHG emission control, environmentalists must

Table 5 Locations of seagrass beds

Location	*Halodule uninervis*	*Halophila stipulacea*	*Halophila ovalis*	Year(s) of record
Northern and eastern coastline				
Khor Al Reweis	+ [1]	+ [1]		2002
Al Khor	+ [4]	+ [1]	+ [3]	2013–2016
Al Dhakhira	+ [4]	+ [4]	+ [1]	2002–2014
Al Shaheen	+ [1]			2005
Ras Laffan	+ [8]	+ [1]	+ [4]	2007–2012
Al Besheireya	+ [2]	+ [3]	+ [2]	2009–2011
Lusail	+ [8]	+ [7]	+ [9]	2004–2016
West Bay project Doha	+ [2]	+ [1]	+ [1]	2008–2014
The pearl Doha	+ [6]	+ [6]	+ [6]	2005–2014
Al Safliya Island	+ [1]	+ [1]		2006
Umm Al Houl	+ [2]	+ [2]	+ [1]	2015
Al Wakra	+ [1]	+ [1]	+ [1]	2006
Mesaieed	+ [10]	+ [10]	+ [6]	2001–2010
Sherao Island	+ [1]	+ [1]	+ [1]	2010
Khor Al Udaid	+ [3]	+ [1]	+ [2]	2002–2008
Western coastline				
Fasht al Dibal	+ [1]	+ [1]	+ [1]	2007
Ras Ushairiq	+ [1]	+ [1]		2007
Al Zubara	+ [1]	+ [1]		2015
Khor Zekreet	+ [1]	+ [1]		2002
Umm Bab	+ [2]	+ [5]	+ [3]	2009–2011–2017
Khor Salwa		+ [1]		2002

[] Numbers refer to records

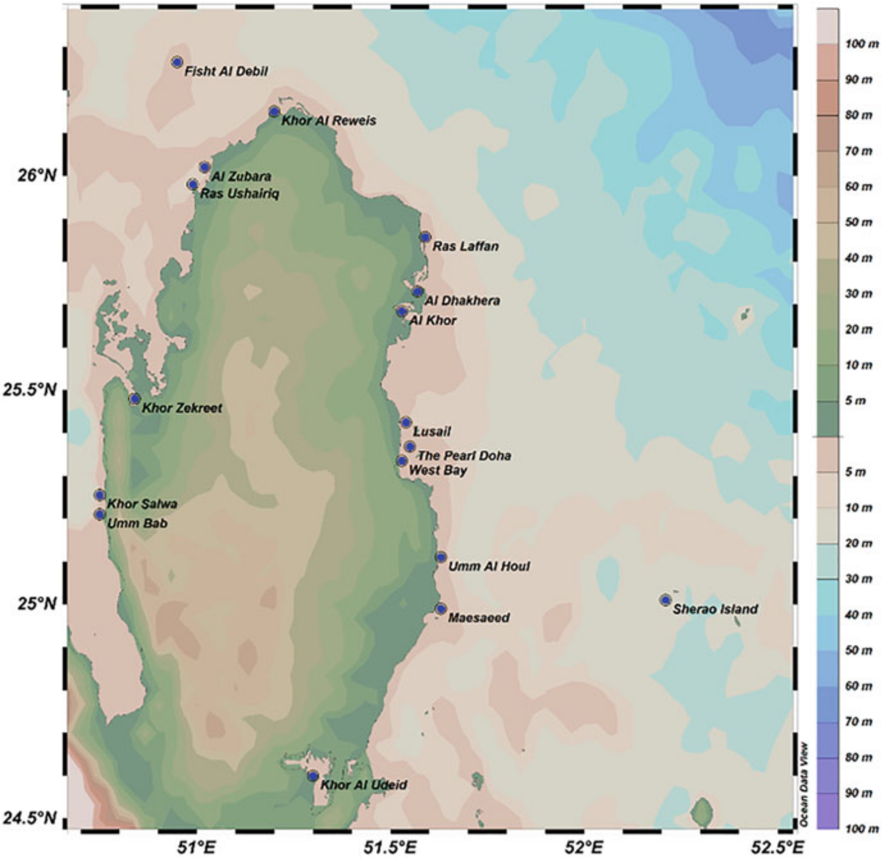

Fig. 11 Distribution of seagrasses in QMZ based on location records. Source: Dr. Sinan Husrevoglu, ESC

embark on an active program to protect the existing seagrass beds and to increase their diminishing cover by restoration and planting activities in areas now deprived of their earlier rich seagrass abundance. The technology and the know-how are available. This will also be a contribution by Qatar to reduce the negative impact of climate change and toward its commitment to reduce of CO_2 emissions from their industrial sources (Figs. 14, 15, and 16, Table 6).

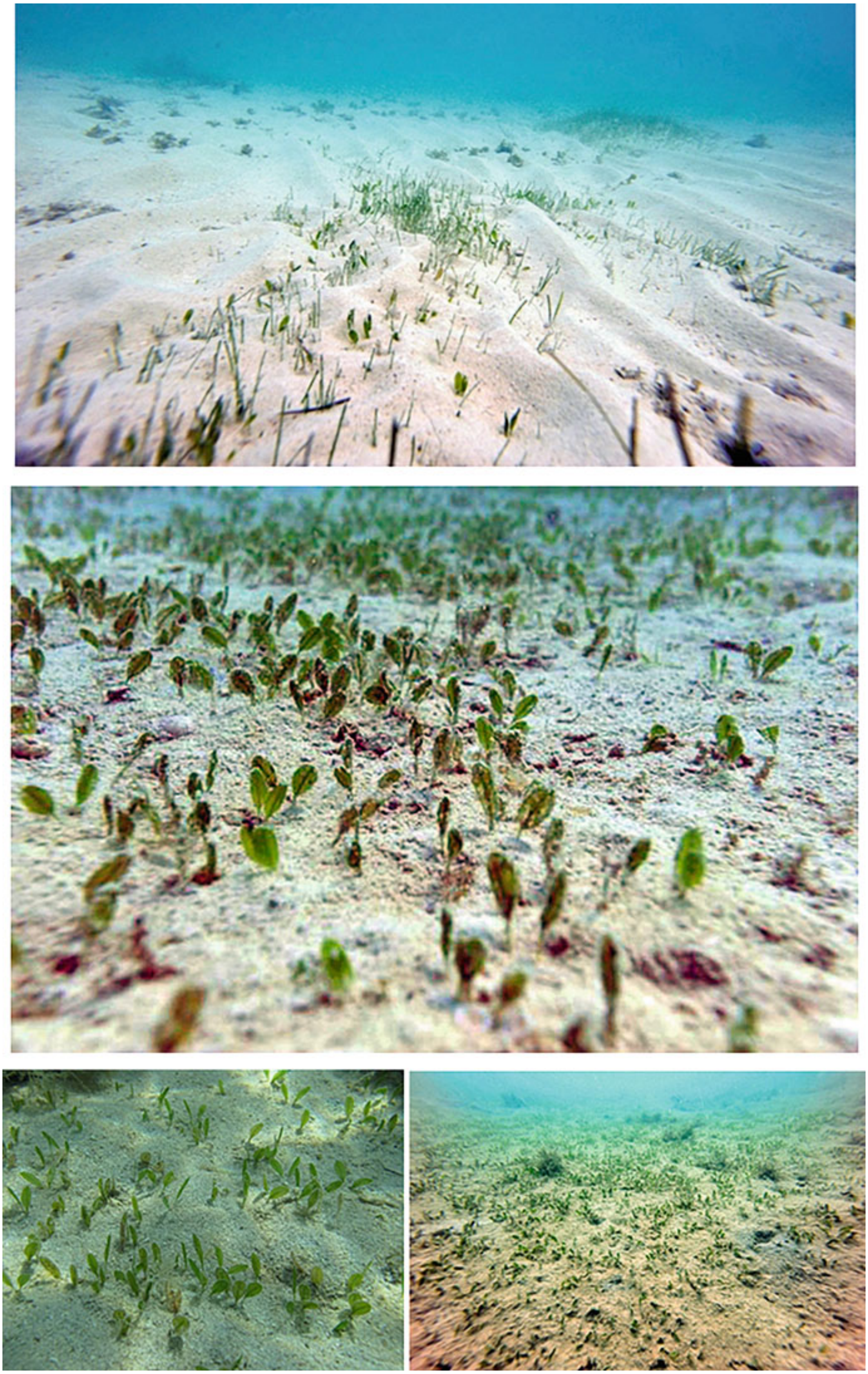

Fig. 12 Sandy seafloor with sparse and dense seagrasses

Fig. 13 Seagrass bed with fish, turtle, sponges, brittle starfish, bivalves, ascidians, seaweeds, and jellyfish

Fig. 14 Masses of seaweeds and seagrasses in fishermen nets, Al Shamal coastline, Qatar

Fig. 15 *Halodule uninervis* entangled in Brown seaweed *Hormophysea* along the western coastline near Salwa, QMZ

Fig. 16 Drifting masses of seagrasses and seaweeds possibly due to dredging operations on the seabed. S.QMZ

Table 6 Desalination capacity in 1000 m3/day for Gulf countries

Country of area	Brine location	Desalination capacity in 1000 m3/day					
		1996		2008		2050	
		QF	QB	QF	QB	QF	QB
Iraq	Ag!	324.5	757	476.6	715	2519.3	2519
Iran	AG	423.4	988	547.8	822	3138.2	3138
Qatar	AG	560.8	1308	1026.3	1539	4761.9	4762
KSA	Ag,RS	5006	11,681	7750.8	11,626	39,669	39,669
UAE	AG	2134	4980	6094.7	9142	22,532	22,533
Kuwait	AG	1284.3	2997	2308.7	3463	10,822	10,822

QF freshwater production from desalination, QB brine discharge
Source: Bashitialshaaer et al. 2011

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