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CHARACTERIZATION OF DOHA BAY: A CASE STUDY

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ABSTRACT

Doha Bay is a semi-enclosed water body, located on the Arabian Gulf, bordering Doha, capital city of the State of Qatar. It currently receives untreated waters via several marine outfalls from Doha and surrounding areas. The untreated water consists of stormwater, but is also likely to include discharges from non-stormwater sources, which may contribute additional pollutants to the receiving sea waters. Due to shallow depth near the stormwater discharge outlets in the Doha Bay, there is a potential public health risk to recreational users from accumulated pollutants. The key objective of this study is to determine the existing environmental conditions of the marine environment, in the vicinity of four primary discharge outfalls (i.e. Souq Waqif, Rumailah, Tennis Court and Diplomatic outfalls) in order to assess the spatial extent of the pollutants that may have dispersed from each Outfall. An extensive sampling program was undertaken that includes an assessment of water and sediment quality, hydrodynamics and identification of sensitive ecological communities within the Doha Bay area. To achieve this, a series of sampling stations were positioned along multiple transect lines radiating out from each discharge point. The results of sampling program were assessed for compliance against a range of local, regional and international ambient marine water quality standards as reported in this paper.

Keywords: Arabian Gulf, sea outfalls, water quality, Qatar, marine habitat.

1 INTRODUCTION

A sea outfall can be defined as the discharge point of a waste stream into the sea areas. Sea outfalls can manage pollutants from a variety of sources including stormwater, wastewater, desalination and many different types of industrial plants (US EPA, 2006). The majority of the outfalls in Qatar are surface/shoreline type which mainly transport untreated storm water. In general, wastewater in Qatar is mainly reused and is not directly discharged into the Arabian Gulf (MME, 2018). It is common practice in Qatar to include groundwater collection systems within the stormwater networks. Dewatering resulting from construction activities is also discharged into the stormwater systems.

Sewage discharges are major sources of pollution in coastal areas of the Arabian Gulf countries (Mamoon et al., 2015, Naser, 2013). Although the standard of the sewage treatment system in the gulf countries is generally very high, a large quantity of domestic effluent is discharged to sea directly without adequate treatment. In addition to the biological and chemical pollutants, heavy metals are also present in the sewage effluents. These may result in the degradation of the marine and coastal environments, which eventually may affect the food chain affecting human health.

A large number of constituents (both organic and inorganic) may be present in storm water. These include nutrients, heavy metals, oil and grease, pathogens and many other organic and inorganic materials (Eriksson et al., 2007;Naser, 2013). Numerous studies have identified the primary/priority pollutants in storm water (Kayhanian et al., 2007; Zgheib et al., 2012).

As per MMUP (2014), untreated water is currently discharged into the Doha coastline via several stormwater outfalls. The untreated water consists of stormwater, but is also likely to include discharges from non-stormwater sources (e.g. dewatering effluent, loss from septic tanks and foul sewers, water from excess landscape watering, gardening and car washing), which may contribute additional pollutants to the receiving sea waters

In the middle east, a number of studies related to marine resources reported degrading trends in water quality, the causes of such degradation, and the environmental consequences of such activities (e.g., El-Rayis, 1998; Al-Ansi et al., 2002; Risk et al., 2009; Al-farawati, 2010; Shepperd et al., 2010). A toxic algal bloom in Kuwait Bay caused extensive fish kill in 1999; fish kills were also observed in 1996 and 1998 in the coastal waters of Qatar (Al-Ansi et al., 2002).

Measurements of change in infaunal communities have been widely used in identifying and monitoring man-made impacts on the sea. Macro-infauna (i.e. large enough to be seen with the naked eye), for example, have proven to be useful in assessing the environmental impacts of coastal discharges (Poore and Kudenov, 1978; Anderlini and Wear, 1995; Ashton and Richardson, 1995) and chemical contamination of sediments (Ward and Hutchings, 1996). This is largely because infaunal organisms are relatively non-mobile and tend to integrate the effects of pollutants over time (Warwick, 1993).

Discharges via shoreline outfalls have the capacity to directly impact the infaunal communities inhabiting the seafloor through exposure to contaminants that may be present in the discharge effluent, and potential changes to the sedimentary characteristics of the seafloor (i.e. fine sediment accumulation). The ecological consequences of discharges will further depend on the quantity and quality of the discharge effluent, the physical and chemical nature of the sediments, the depth of water and prevailing hydrographic conditions. The magnitude and persistence of these impacts will also depend on the vulnerability of the benthic communities themselves.

The most common marine habitats in the Arabian Gulf are coral reefs and coral dominated substrata of hardgrounds, seagrass meadows and algal beds (Burt, 2014). Seagrasses are found throughout the Arabian Gulf, and cover much of the shallow nearshore seabed between Kuwait and the United Arab Emirates (UAE) (Green and Short, 2003; Phillips, 2002; Hasbún et al., 1998; Sheppard et al., 1992). They are also common in shallow waters around many of the offshore islands of the Gulf. Three species of seagrass commonly occur within the Arabian Gulf i.e. *Halodule uninervis, Halophila* ovalis, and *Halophila stipulacea*)(Figure 1).

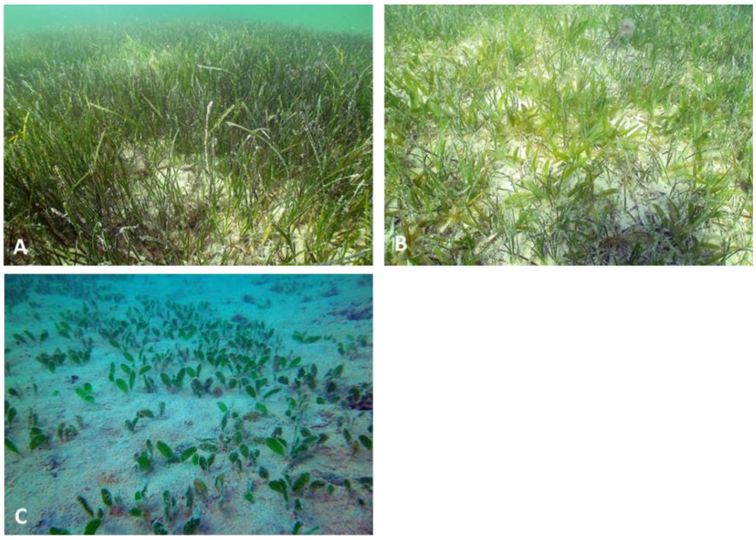

Figure 1 Halodule uninervis (A), Halophila stipulacea (B) and Halophila ovalis (C)

Seagrass beds are important coastal habitats along tropical, temperate and subarctic coasts, supporting the production of living marine resources (Hartog *et al.*, 1970; Zieman 1989; Thayer et al. 1984; Larkum et al. 1989). Seagrasses support complex food webs by virtue of both their physical structure and primary production, and are best known for their role as breeding grounds and nurseries for important finfish and shellfish populations. Human induced disturbance that has resulted in the loss or degradation of coastal seagrass habitat that has been documented around the world (Short and Wyllie-Echeverria, 1995).

The key objectives of this study is to characterise the marine environment of Doha Bay in terms of; water and sediment quality, hydrodynamics and define the presence of ecological communities and their relative sensitivity.

2. STUDY AREA

Qatar is located in the north-west side of the Arabian Gulf, with 563 km coastline with the Gulf representing 90% of its border. It's southern border is shared with Saudi Arabia (Burt et al., 2017, Mamoon and Rahman, 2017). Doha Bay is a semi-enclosed water body, located on the Arabian Gulf, bordering Doha, capital city of the State of Qatar. Four surface/shoreline outfalls are operational in this selected study area as shown in Figure 2. These outfalls are:

Souq Waqif – This outfall is located on the Corniche road, adjacent to Doha Harbour. GPS coordinates for the outfall are Easting 231995 (mQNG) and Northing 393194 (mQNG).

Rumailah - This outfall is located along the corniche road, near the Al Bidda Park. GPS coordinates for the outfall are Easting 230629 (mQNG) and Northing 393969 (mQNG).

Tennis Court - This outfall is located along the corniche road, Khalifa International Tennis and Squash Complex. GPS coordinates for the outfall are Easting 230644 (mQNG) and Northing 395315 (mQNG).

Diplomatic Area - This outfall is located near the Lusail Expressway, between West Bay and Katara. GPS coordinates for the outfall are Easting 231398 (mQNG) and Northing 397633 (mQNG).

Figure 2 Overview of the study area and outfall location

3. MATERIALS AND METHODS

An extensive sampling campaign was carried out for the assessment of water and sediment quality, hydrodynamics and identification of sensitive ecological communities within the Doha Bay area. Vessel based sampling to collect samples for the assessment of water quality, sediment quality and benthic marine infauna was undertaken at eighty (80) sampling locations around four discharge outfalls (i.e. Souq Waqif, Rumailah, Tennis Court and Diplomatic outfalls) between 15 March to 24 April 2016.

Towed video sampling was undertaken followed by subsequent ground truth verification using SCUBA. In order to assess the spatial extent of the pollutants that may have dispersed from each Outfall, a series of sampling stations were positioned along multiple transect lines radiating out from each discharge point. Sampling station arrangement at Souq Waqif outfall is shown in Figure 3a.

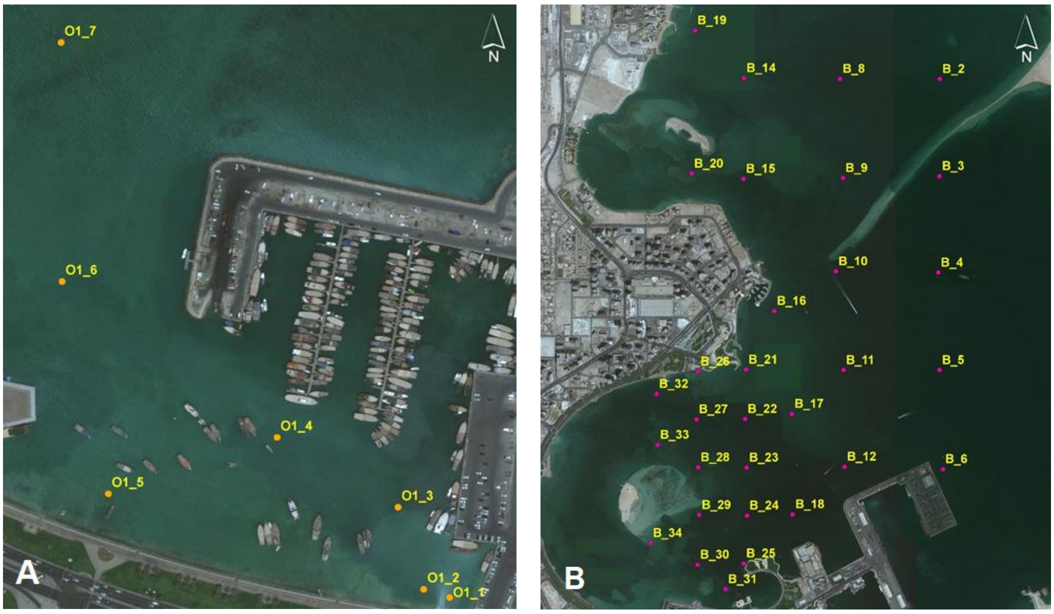

Figure 3 (a) Sampling locations at the Souq Waqif Outfall (b) Background Sample locations at Doha Bay

A uniform grid array of 'background' locations were also sampled to determine the characteristics of the marine environment (Figure 3b) at the time of sampling. This sampling strategy was employed to determine any background pollutant sources that may confound the results.

3.1 Marine Water Quality

Water quality samples for laboratory analysis were collected one meter below the seawater surface at all sampling stations.

Chlorophyll a, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), microbial parameters, nutrients, were assessed for compliance against available ambient marine water quality standards from Qatar (MoE, 2002), UAE Abu Dhabi (UAE MOEW, 1999), Australia (ANZECC, 2000).

Heavy metals, Total Petroleum Hydrocarbons (TPHs), and volatile TPH fractions – Benzene, Toluene, Ethylbenzene and Xylene (BTEX) were assessed for compliance against available ambient marine water quality standards from Qatar (MoE, 2002), UAE Abu Dhabi (UAE MOEW, 1999), Australia (ANZECC, 2000), the European Union (Directive 2008/105/EC) and the United States of America (US EPA, 2015).

3.2 Sediment Quality

Marine sediment quality samples for laboratory analysis were collected from the seabed at all sampling stations using a Van Veen grab (Figure 4). One sediment sample was collected from each of the eighty (80) sampling stations.

Figure 4 Marine sediment for chemical analysis and benthic infauna was recovered using a Van Veen grab

Biological and chemical parameters, heavy metals and Poly-Aromatic Hydrocarbons (PAHs) were assessed for compliance against available international standards from Australia (ANZECC, 2000), the Netherlands (MvV, 2000) and Canada (MoE BC, 2014).

No international standards were available for Total Petroleum Hydrocarbons (TPHs), Polychlorinated Biphenyl compounds (PCBs) and organotins in marine sediments. In order to assess the results, guidelines were taken from the Ecotoxicological Assessment Criteria published by OSPAR (2000) and National Action Levels from Finland, UK and Germany for the disposal of dredged material (OSPAR, 2004), which define concentration levels of a substance that present environmental risk.

3.3 Benthic Infauna

The benthic infauna samples was undertaken at eighty (80) sampling locations throughout the survey area. The benthic infauna data was prepared for multivariate statistical analysis in the software PRIMER-E v7 (PRIMER-E Ltd, UK) developed at Plymouth Marine Laboratory UK (Clarke et al, 2014). Chemical measurements below detection limits of the chemical method used were treated as no content (concentration of 0).

3.4 Seagrass

The towed video survey was undertaken to determine the composition and distribution of seagrass occupying the Doha Bay area. During this survey, an approximate total of 24 km of seabed was surveyed, and individual habitat observations were classified.

Sediment samples collected for the survey provided additional ground truthing data, and the physical characteristics and any flora/fauna recovered in the samples were utilized to assist in determining the key characteristics of the seafloor within the survey area. This included the distribution of sands and silts (grain size distribution), and spatial extent of key epi biota (e.g. seagrasses) that were present/absent in the sample. In addition, spot sampling using a drop-down camera was utilized at key locations to assist in interpolating the extent of habitats.

4. Results and Discussions

4.1 Marine Water Quality

Seawater temperature in the study area ranged from 23.83 to 27.08 ^{0}C (one meter below the surface). These values are within the normal range expected during the spring season (Sheppard et al., 2010). Salinity values ranged from 32.80 to 43.13 ppt which are within inshore areas of the Arabian Gulf typically range from 39 to 44 ppt (John et al., 1990). DO concentrations ranged from 4.10 to 7.34 mg/L across the study area. All measurements measured above the Qatar standard (>4 mg/L).

Laboratory results of Concentrations of TSS were compliant with Qatar National Standards (<30 mg/L), UAE Standards and ANZECC water quality guidelines at all stations (<5 to 22 mg/L). Concentrations of Total Phosphorus (TP) exceeded the Qatar National Standard (0.03 mg/L) at 76% of the stations. TP concentrations exceeded Tropical Australia standards at 72 of 80 sampling locations (90%), thus indicate a generally high phosphorus profile across the survey area. Concentrations of ammonia exceeded Qatar National Standard (0.015 mg/L) at all 80 sampling stations (100%) and ranged from 0.02 to 0.44 mg/L. It is notable that chlorophyll a was not detected (i.e. <0.005 mg/L) in any of the samples collected across the survey area.

BOD and COD did not exceed Qatar National Discharge Standard (50 mg/L) at any of the 80 sampling stations, nor was detected in any of the samples (<2 mg/L).

Bacteria was detected above the laboratory detection limits at one sampling location, the Souq Waqif discharge outfall. The relatively high occurrence of bacteria immediately adjacent to the Souq Waqif outfall suggests presence of foul water within the discharge effluent.

Concentrations of cadmium, copper, hexavalent chromium, iron, lead, mercury, vanadium and zinc were not recorded above the laboratory limits of detection. Concentrations of heavy metals were therefore compliant against available Qatar Standards, UAE Standards, EU and USA International standards.

Impervious surfaces (roads, parking lots and sidewalks) have the potential to accumulate pollutants, and act as a reservoir during periods of rainfall when contaminants are mobilised with the runoff, and discharged untreated into the marine environment. Some evidence suggests pollutant build up is excess abated in regions where rainfall is rare, and an antecedent dry period can lead to a build-up of pollutants until maximum accumulation rate is reached (Pitt, 1981). A 'first flush' effect, where pollutant concentrations during wet weather discharges peak toward the initial stages of rainfall have been observed for a range of pollutants (Buffleben *et al*. 2002). Accordingly, a spike in pollutant load at the discharge outfall and area of dispersion may be anticipated during and after a heavy rainfall event. A period of relatively frequent rainfall was observed in the weeks preceding the field survey and had the potential to influence results of this study.

Despite the rainfall observed prior to the field sampling, no strong evidence suggesting elevated concentrations of pollutants at and surrounding the discharge outfalls were observed in water quality analysis. Elevated levels of nutrients (ammonia, nitrate) were recorded (i.e. exceeded referenced standards) however no clear spatial trends were observed. High nutrient concentrations were recorded at multiple background stations that would indicate an elevated nutrient profile in the waters of the Doha Bay area at the time of sampling.

4.3 Sediment Quality

Aluminium, iron, manganese and barium were the dominant metals found in the sediment around all outfalls and background locations. Concentrations of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, vanadium and zinc were detected across all stations. Mercury and Selenium were not detected above the detection limit. High concentrations of aluminium, iron and manganese have been recorded in previous studies in the Arabian Gulf (Table able 1).

Background metal concentrations are attributed to a number of processes within the Gulf including physical and chemical weathering and hydrodynamic processes. These processes influence the release of metals into sediments from ophiolites (rocks from the Earth's crust, which are common in the eastern Gulf), which contain aluminium, iron, various nickel sulfide minerals, and metalliferous sediments of marine origin (Lorand and Ceuleneer, 1989; Leblanc and Ceuleneer, 1991).

In addition, aeolian transport represents a significant input of metals into the Arabian Gulf. Marine sediments receive a relatively large supply of mineral dust (of which 8 % is aluminium by weight) and fine terrigenous sediment from wind blown over areas of un-vegetated landscapes (De Mora et al., 2004; Schubler et al., 2005).

Table 1 Comparison of aluminium, iron, manganese and zinc concentrations in sediments found in this study with concentrations founds by De Mora et al. (2004).

Region	Aluminium (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Barium (mg/kg)
This study	393-13500	787-9,160	8.1-120	10.2-695
Qatar	484-18,000	305-5,680	13.2-127	-
UAE	534-26,000	874-29,600	32.9-360	-
Bahrain	601-8,954	471-6,475	22.6-84.3	-
Oman	632-18,300	334-11,600	27.8-265	-
Western Gulf	-	6,300-10,500	136-218	-

Barium, Cadmium, Copper and Nickel exceeded referenced standards during the study. These metals are crucial pollutants as they lack degradability and have documented toxicological effects on marine organisms (Huber et al., 2016). Copper and cadmium are constituents of motor oil and all three metals are present in fuel and vehicular wear on road surfaces (Drapper *et al*., 1999). It is possible that the metals have originated from the surrounding urban environment, and were mobilised to the marine environment via runoff during periods of high rainfall. There is no strong evidence to suggest that Nickel has originated from the discharge outfalls, and may have entered the marine environment through another pathway.

Organics such as PCBs, TPHs and organotins fell mostly below their respective detection limits, and were compliant against referenced environmental protection standards. High concentrations of PAHs were recorded around the Souq Waqif outfall where acenaphthene, flourene and phenanthrene exceeded referenced international standards at one or two locations. However, it is notable that the Souq Waqif sampling area fell within a busy commercial port, that hosts many potential sources of contamination. Any observed concentration gradient of contaminants associated with an outfall discharge should therefore be interpreted with caution.

Some point source contamination was observed during the survey. A Background location relatively isolated from land, recorded elevated levels of PAHs (chrysene, fluoranthene, pyrene, benzo(a)anthracene, benzo(a)pyrene and dibenz(a.h)anthracene) which exceeded referenced standards. A potential source of this contamination cannot be identified with any certainty, although it is clearly has not originated from any of the assessed outfall locations.

TOC ranged from less than 0.04 to 1.0 % in Background locations and 0.6 to 1.1% across the four outfalls. Studies have reported TOC values ranging from 0.5 to 3.2 % in the Arabian Gulf region (Basaham, 2009; Hartmann et al., 1971), comparable to levels of TOC observed in this study.

4.4 Benthic infauna

In total, the 80 samples recovered to assess the benthic infaunal community contained 4369 individuals from 96 taxa (i.e. 96 is the minimum number of species for all the samples grouped together). Both the biomass and diversity of benthic invertebrates is considered to be moderately high. The average number of individuals recovered per sample was 54.6, however there was some variation observed across the sampling groups. The average number of individuals per sample in each group are presented under Table 2.

Table 2 Mean abundance of benthic infaunal organisms across the study area

Sampling location	Sample number (N)	Average no. individuals per sample
Souq Waqif outfall:	7	23.6
Rumaila outfall	13	59.5
Tennis court outfall	16	52.8
Diplomatic outfall	13	24.3

Sampling location	Sample number (N)	Average no. individuals per sample
Background	34	73.3

The infaunal community was dominated by Polychaeta that comprised 57% of total infauna and was represented by 35 species (Nephtys tulearensis and Perinereis sp.) (Figure 5**Figure**). A low diversity of Crustacea was observed (876 individuals of 22 different taxa), as well as Amphipods (11 families) and Molluscs (584 individuals of 32 species) that overall represented a moderate level of diversity across the receiving marine environment.

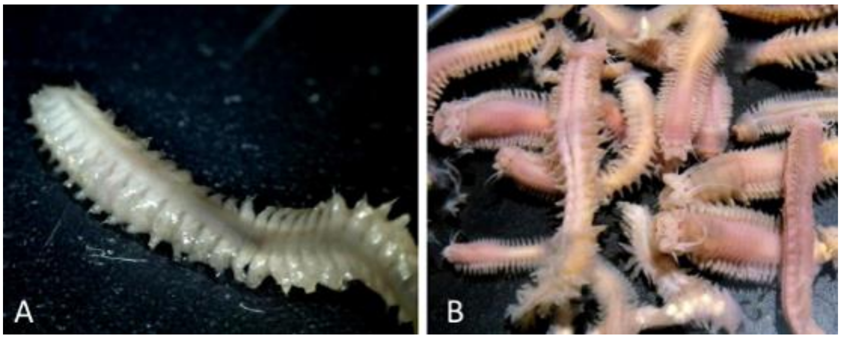

Figure 5 Ploycheate worms Nephtys tulearensis (A) and Perinereis sp. (B) from the family Nephtyidae.

Results from the Sea Outfalls study show differences in infauna composition between stormwater outfall locations to those found in background locations. It was observed that sediment characteristics, as well as concentrations of various hydrocarbon constituents, metals and total organic carbon to influence and drive the observed variability between samples, highlighting the sensitivity of the benthic infauna communities to stormwater pollutants.

The multivariate analyses of the infauna and environmental data revealed a difference in infauna compositions at outfall stations (four investigated outfalls) compared to background stations. Within each outfall area, there were no clear patterns of changing composition with distance from the outfall, but there was some grouping of stations. The environmental data showed some patterns within each outfall area, which to some extent could explain the differences in infauna composition.

4.5 Seagrass

Seagrass meadows were identified within the study area, forming non-contiguous meadows. Three species of seagrass (Halodule uninervis, Halophila stipulacea and Halophila ovalis) were recorded during the study, and are estimated to collectively cover approximately 0.22 and 1.94 km^2 of Dense and Sparse Seagrass respectively of the surveyed area (Figure 6). Dense Seagrass was only found in the Diplomatic area, towards the western and eastern side of Palm Island.

In most instances, these species co-occurred in mixed meadows, however the most abundant seagrass, as defined by areal dominance, was Halodule uninervis. This species constituted the majority of seagrasses observed and was particularly prevalent in the northern region of the survey area around Palm Island. Halophila ovalis was frequently recorded across a relatively large area, and dominated the seagrass community that extended South from the North-East edge of Doha Bay. Halophila stipulacea was sub-dominant and was generally observed occurring in small patches in close association with other species.

No seagrass occurred directly around the vicinity of the discharge outfalls, despite the presence of soft unconsolidated sediments and an appropriate depth (i.e. light availability) that would be suitable to drive photosynthesis.

Figure 6 Seagrass habitat map categorised into areas of dense coverage and sparse coverage of co-occurring seagrass species (Halodule uninervis, Halophila stipulacea and Halophila ovalis).

5 CONCLUSIONS

The existing marine environment, in the vicinity of four primary discharge outfalls (i.e. Souq Waqif, Rumailah, Tennis Court and Diplomatic outfalls) was assessed in terms of; water and sediment quality, hydrodynamics and define the presence of ecological communities and their relative sensitivity. This was achieved by undertaking an extensive sampling campaign between March and April 2016 at eighty (80) sampling locations throughout the study area. With the exception of TP and ammonia, most of the marine water quality parameters were compliant with Qatar National Standards. Aluminium, iron, manganese and barium were the dominant metals found in the sediment around all outfalls and background locations with concentrations of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, vanadium and zinc were detected across all stations. Both the biomass and diversity of benthic invertebrates is considered to be moderately high. The average number of individuals recovered per sample was 54.6, however there was some variation observed across the sampling groups.

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