Marine Environmental Baseline Survey and Action Plan - Summary Report

KAUST,
Saudi Arabia
July 2016

جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology

Five Oceans
Environmental
Services LLC

// Glossary

KAUST – King Abdullah University of Science and Technology

EIA – Environmental Impact Assessment

5OES – Five Oceans Environmental Services LLC

KEA – Key Ecological Attributes

PERSGA – The Regional Organisation for the Conservation of the Environment of the Red Sea

AIMS – The Australian Institute of Marine Science

KSA – Kingdom of Saudi Arabia

PME – Presidency of Meteorology and Environment

ANZECC – The Australian and New Zealand Environment and Conservation Council

USEPA – United States Environmental Protection Agency

CMOR – Coastal and Marine Resources Core Lab

NTU – Nephelometric Turbidity Units

TOC – Total Organic Carbon

TDS – Total Dissolved Solids

TSS – Total Suspended Solids

VPH – Volatile Petroleum Hydrocarbons

EPH – Extractable Petroleum Hydrocarbons

LoD – Limit of detection

EAP – Environmental Action Plan

SST – Sea Surface Temprature

PAR – Photosynthetically Active Radiation

GBH – Girth at Breast Height

GIS – Geographical Information System

SCUBA – Self-Contained Underwater Breathing Apparatus

1 // Executive summary

This report has been prepared as part of a project undertaken by King Abdullah University of Science and Technology (KAUST) to provide a summary of a study of the marine and coastal areas surrounding the University, identify changes since the construction of the facility, and provide a framework for the monitoring and management of environmental aspects of the area. This report forms the third and final report in a series of three. Further details of the marine and coastal study can be found in the Marine Environmental Baseline Survey Report mentioned below.

Reports which form part of the series are:

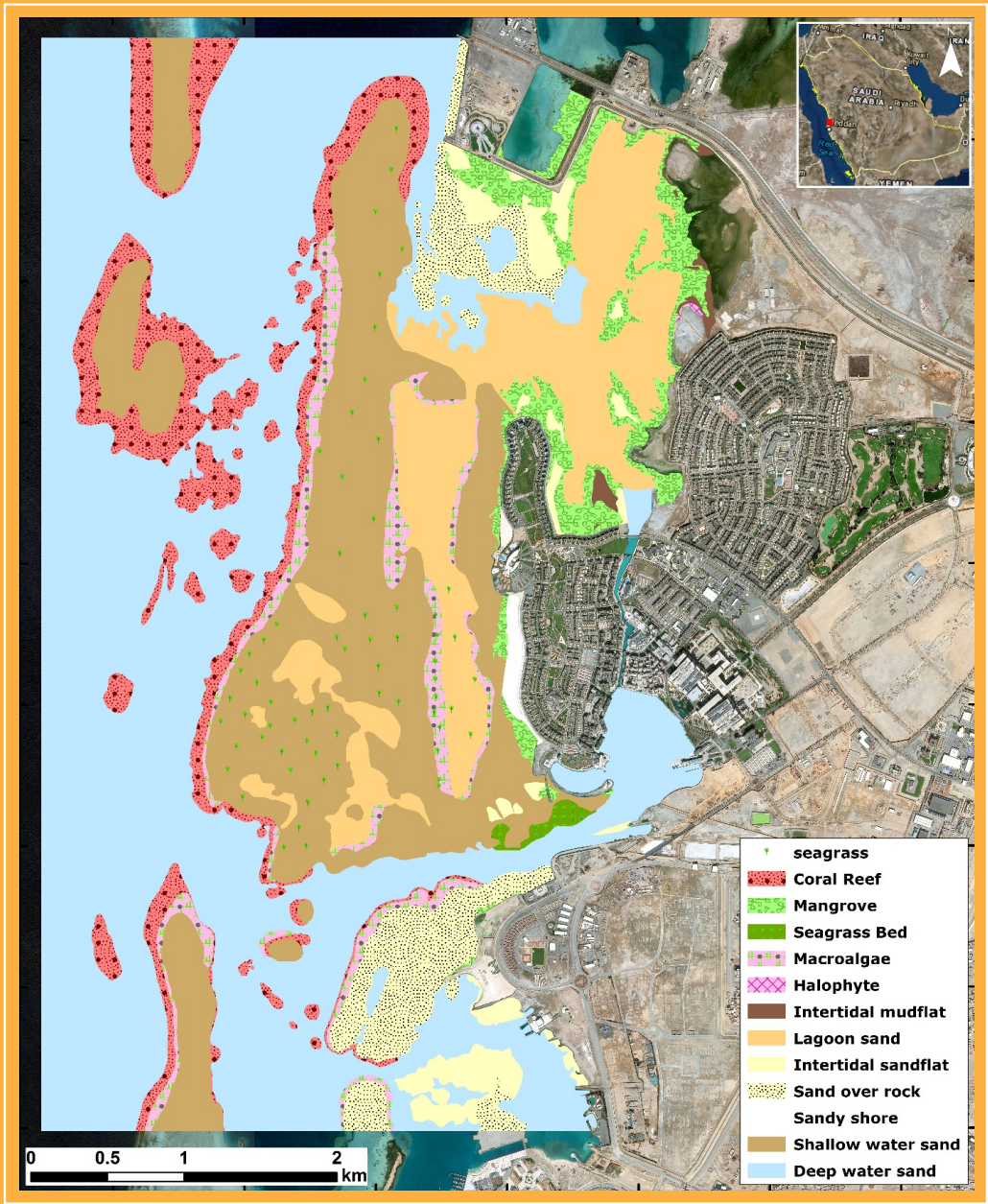
1. Marine Environmental Baseline Survey Report: Presents the current status of physical and biological components of the marine and coastal area of the project site, reviews the findings against the previous Environmental Impact Assessment (EIA) undertaken in 2008

2. Environmental Action Plan Report: A report focusing on the mitigation, remediation and management of environmental aspects determined in the first report

3. Summary Report: A summary of the status of the resources and management objectives of the longer term aspects of the project based on the baseline survey and action plan documents.

Consultant: Five Oceans Environmental Services LLC (www.5OES.com)

The baseline survey included an investigation of seawater and sediment quality within the nearshore, lagoon, channel and offshore area, with findings compared to national criteria and international guidelines, as well as ecologically orientated surveys focusing on the status of major habitats including shoreline areas, mangroves and coral communities. The baseline survey revealed that seawater quality is comparable to conditions prior to the construction of KAUST, with minor elevations in salinity and temperature recorded only at the common utilities discharge point. Sediment quality investigations revealed that sediment grain size varied with location, with higher inputs of fine material within areas of reduced water movement. Signs of anoxia were present within some samples, and anoxic conditions were reported within lagoon and mudflat areas, as well as channel locations, where accumulations of finer material had occurred. Organics were representative of ambient conditions or in-line with the pre-construction baseline (e.g. total nitrogen, TOC), and hydrocarbons were not detected in measurable quantities.



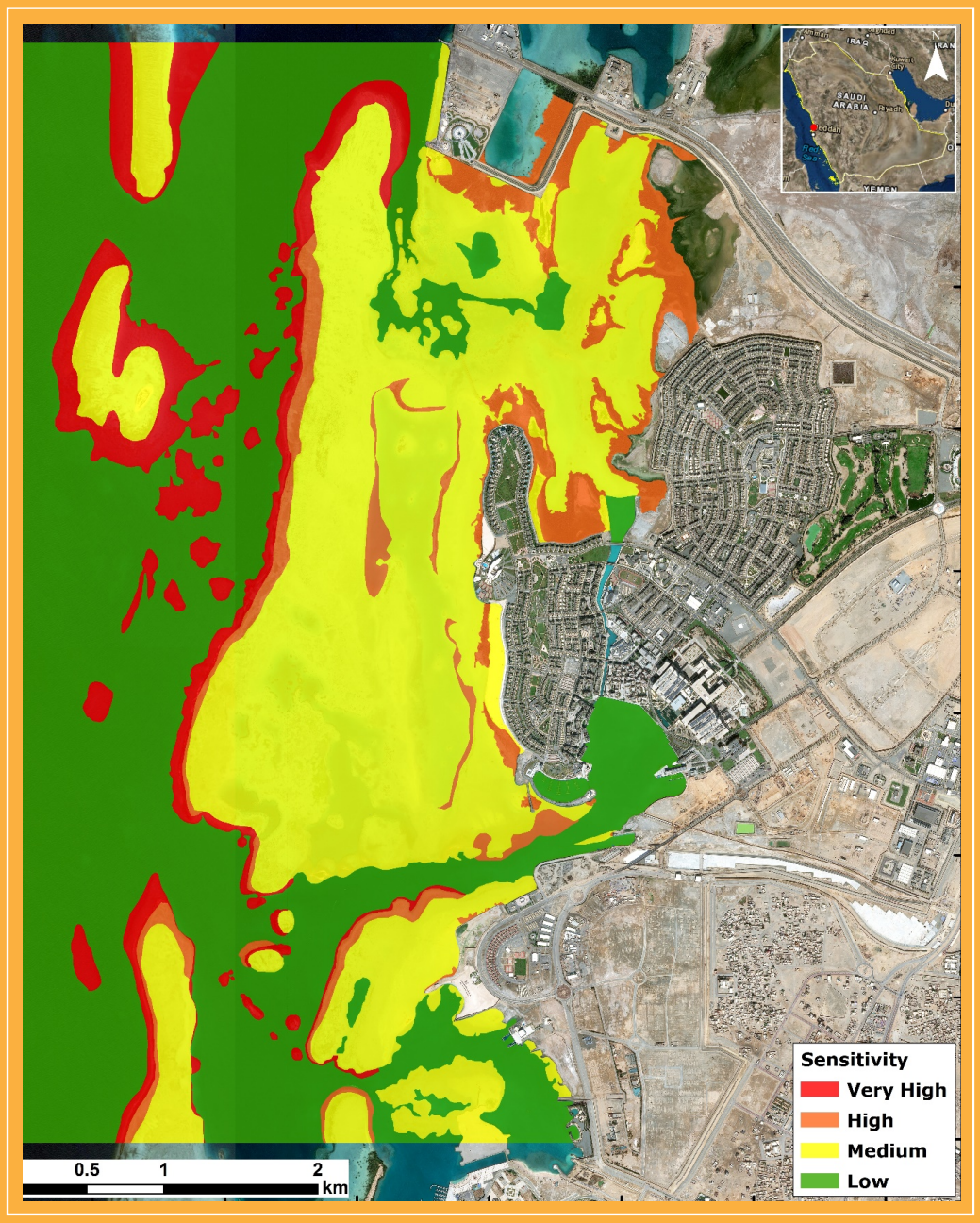
Trace and heavy metals were recorded in most samples at concentrations within expected limits. However, signs of accumulation of several metals are notable in the main approach channel basin, marina and CMOR areas with Arsenic, Chromium, Copper, Nickel, Zinc and Vanadium exceeding at least one of the lower threshold toxicity limits. The immediate cause is uncertain, although the area has been subject to considerable capital marine dredging and construction activities, as well as regular marine operations (vessel activity). Most metals are also closely correlated, indicating a potentially common source. Investigation of associated infauna communities infer that sediment conditions adjacent to the marina may be adverse for infaunal communities.

Habitat and ecology surveys revealed only minor damage to shoreline and intertidal areas from the construction and on-going operation of KAUST. The survey documented a variety of habitats including artificial beaches, intertidal sand and mudflats, mangroves, seagrass, as well as macroalgae and coral communities in the lower intertidal and upper subtidal zones. A review of satellite imagery highlighted changes, primarily based on the direct loss of habitats in the central-southern portion of the project area, where the marina and CMOR stations have been constructed. Elsewhere, based on the data, no significant discernible changes were documented when ecology and habitats were compared to the pre-construction baseline: most habitats were still present and in similar condition. Several areas of construction waste and litter accumulation were identified for remediation.

Mangroves were subject to an intensive survey aimed at describing the status of mangrove stands throughout the site. The boundaries of mangrove stands were mapped and survey stations established to provide data on indicators: tree heights, girths and densities, as well as associated ecology. For the most part stands were relatively dense and included large trees between 3-5m in height. Large numbers of seedlings and saplings were recorded in most areas, and a significant proportion of trees were fruiting at the time of the survey. A review of satellite imagery highlighted an overall expansion in mangrove area from 75 hectares in 2005, to 91 hectares in 2016. Increases were associated with the establishment of saplings and small shrubs in nearshore areas. The pre-construction baseline and EIA indicated that mangroves were subject to grazing impacts; following access restriction to the site and the removal of livestock, natural expansion had resulted in a significant new growth of mangrove trees. Other flora at the site includes a variety of macroalgae and seagrasess. The latter were recorded in many areas, although no dense seagrass beds occur.

Coral reef surveys included both outer (offshore areas) and inshore fringing reef. Outer coral reef areas were relatively intact, diverse and had high live coral cover. Inshore fringing reef areas are degraded in all areas, with evidence of significant historical impacts by regional scale events thought to be a significant factor (i.e. coral bleaching, coral predation, disease etc.). This is a pattern reflected on a regional scale. A significant proportion of the recorded impact along the fringing reef was thought to pre-date the construction of the site, due primarily to coral bleaching events, but also other regional scale forms of continued gradual mortality. A direct comparison of two survey locations between 2007 and 2016 did show that there have been also been significant declines in live coral cover since the construction period, and at least some areas were thought to have been impacted by increased sedimentation rates, perhaps due to construction activities in the main channel related to the outfall and intake. Coral cover to the south of the main channel was higher than elsewhere, indicating that local hydrodynamics may have an effect on the distribution of local scale impacts including the dispersal of sediment and other particulate matter. Ongoing mortality was evident in most of the fringing areas surveyed, some currently unexplained, or due to disease, predation or competition by sponges and macroalgae. Other available data indicates that the fringing reef and nearshore patch reefs in the wider Thuwal area are amongst the most degraded in the wider Makkah Province. Monitoring the status of these communities is highlighted as high priority, along with the inclusion of determining factors: including water quality, sedimentation, nutrients and temperature, as well as coral predators and diseases, to allow for regional scale events to be distinguished from local scale impacts which may then in turn be mitigated through environmental management planning.

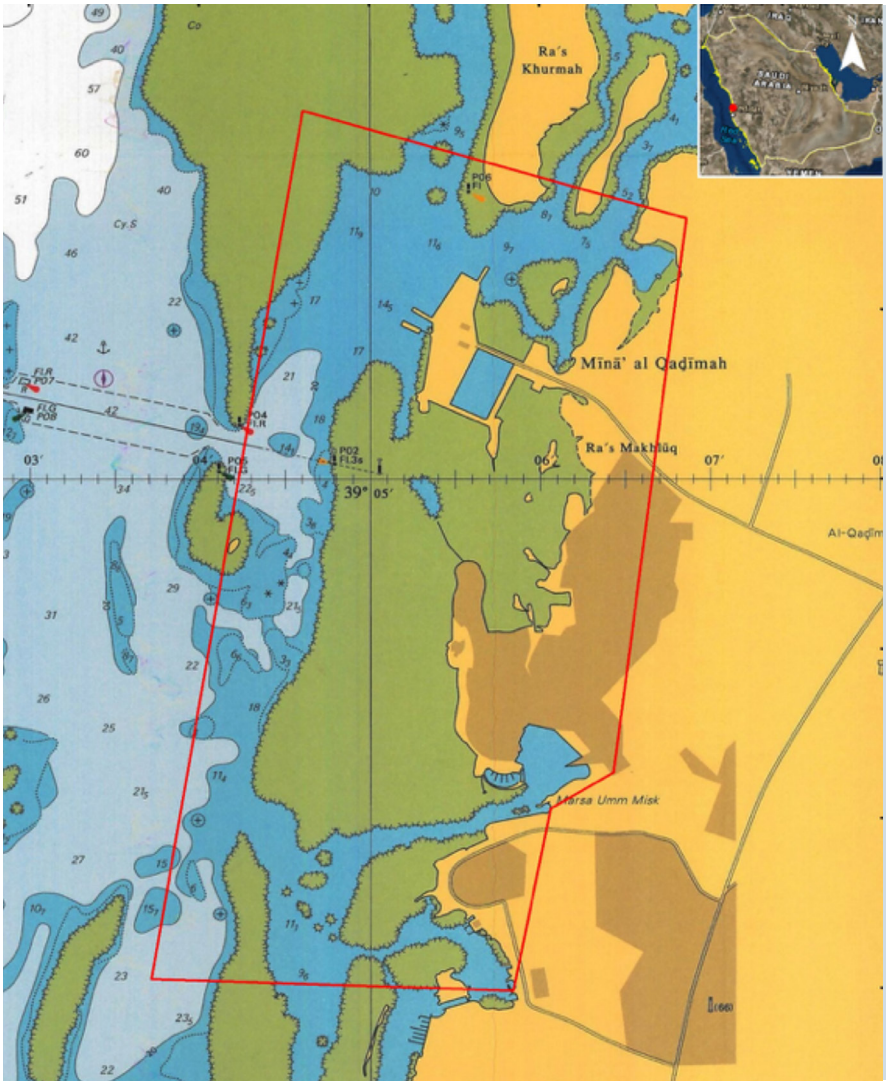
Sensitive habitats were mapped based on the areas surveyed and from the basis of the development of the Environmental Action Plan (EAP) report. Key Ecological Attributes (KEAs) of the site were used to help develop the EAP. The initial chapters of the EAP deal with overarching policy and the objectives and scope of the EAP. This is followed by a chapter outlining how the EAP will be resourced, including consideration of costs, equipment and facilities. The document then details the core elements of the EAP: Mitigation & restoration, monitoring, research, mapping & data management, and training, education & outreach. These are all focussed onspecific habitats that have been selected as an initial focus for management, including coral reefs, seagrasses, mangroves and the shoreline. Key ecological attributes of each of these habitats are identified, along with indicators of their status that enable monitoring, mitigation and restorative actions to be defined in order to improve conditions and successfully manage the marine and coastal environment at KAUST into the future.



2 // Surveys

The baseline survey was undertaken between the 14th and 25th of March, 2016 by Five Oceans Environmental Services LLC (5OES), a consulting company specialising in marine and coastal ecology and environmental management services.

The methods followed those published by regionally and globally recognised bodies including The Regional Organisation for the Conservation of the Environment of the Red Sea (PERSGA), and The Australian Institute of Marine Science (AIMS), and replicated aspects of the original baseline survey where necessary.



Surveys included shoreline and coastal waters within the vicinity of the University, including beaches, intertidal and lagoon areas, seagrass and algal beds, as well as coral reefs. Offshore outer reef areas were also included to allow for an assessment of areas used for scientific research and recreation.

Field surveys focused on determining the chemical and physical attributes of seawater and sediments, with an emphasis on establishing a baseline with regards to toxicology and potential environmental stressors. A key consideration was the evaluation of Key Ecological Attributes (KEAs), based on habitats and ecology, as well as their sensitivity.

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KM

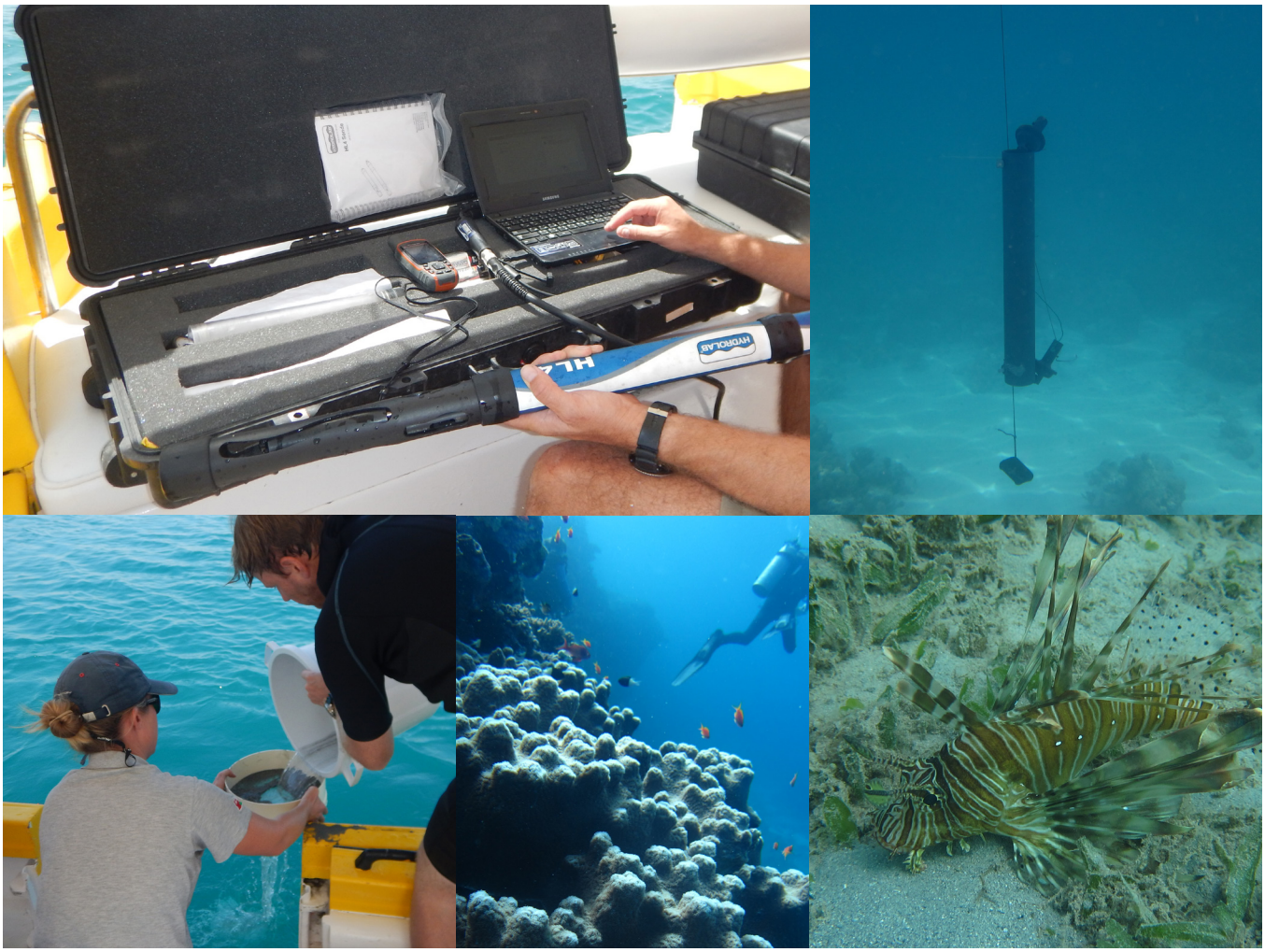
2.1 // Seawater and Sediment Quality

Seawater and sediment investigations were undertaken, with sampling locations determined based on consideration of previous surveys, as well as the location of coastal infrastructure (e.g. marina, dredging areas, intake and outfall pipeline corridors, and neighbouring activities).

Seawater quality investigations focused on vertical profiles from the surface to seafloor using an in-situ probe (Hydrolab HL4). Measurements included depth, pH, temperature, salinity, dissolved oxygen and turbidity, as well as measurements of light attenuation. Seawater samples were also collected using a 2.5L Niskin water sampler and sent to a laboratory to determine a variety of organic and inorganic parameters, as well as physical properties ranging from trace and heavy metals, hydrocarbons, to nutrients and oxygen demand measurements.

Sediment samples were collected by diver to allow for the extraction of samples from a variety of areas including lagoons, channels and coral reefs. All collections were undertaken using non-contaminating implements which were subject to a decontamination procedure between collections. These samples were also sent to a laboratory and analysed to determine grain size, trace and heavy metal concentrations, hydrocarbon content, nutrients, as well as invertebrate fauna living within the substrate (infauna).

The laboratory findings were compared to national standards including KSA Environmental Protection Standards, and PME's Ambient Water Quality Guidelines, as well as recognised international criteria including Australian and New Zealand (ANZECC), USEPA, UK, Canadian and Dutch Contaminated Lands Standards among others.

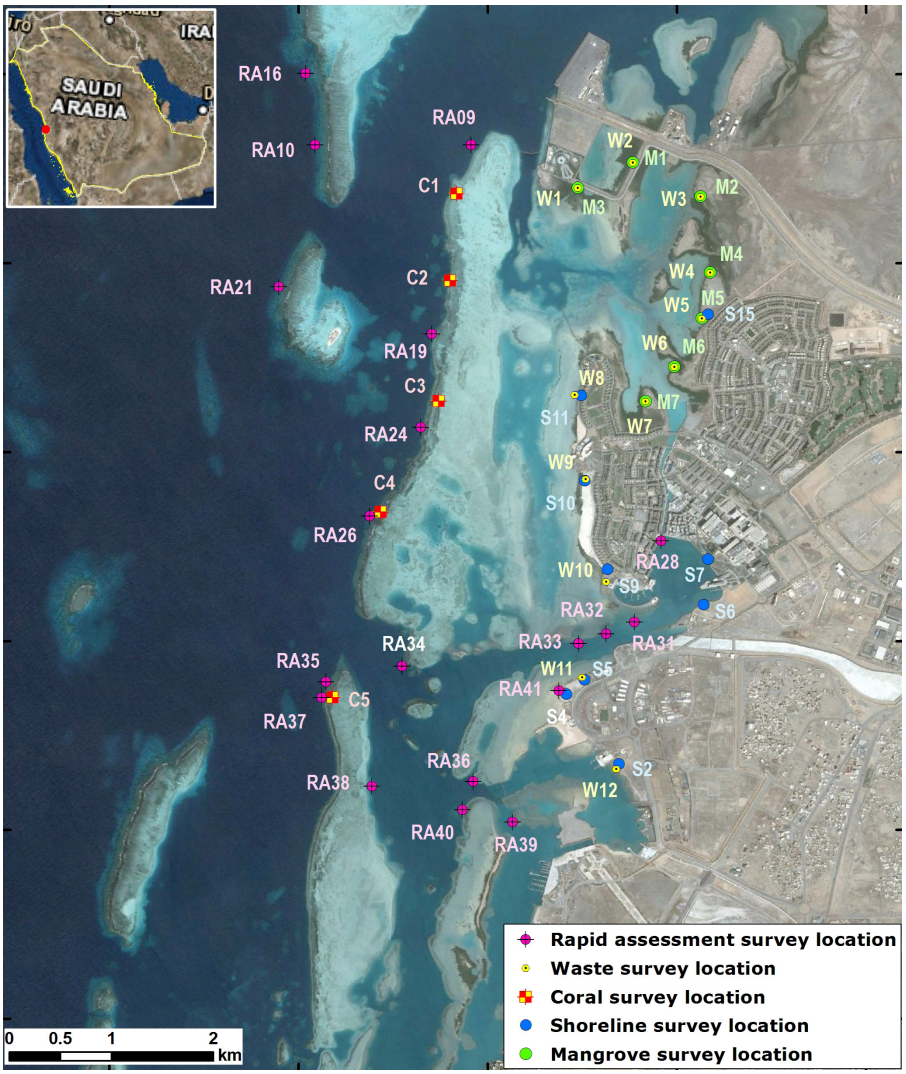


2.2 // Habitats and Ecology

The status of sensitive coastal and marine habitats were determined through the survey and assessment of shoreline and intertidal areas, mangroves, seagrass beds and coral reefs. Survey locations were based on the review of previous survey data to allow for replication where possible, whilst satellite imagery was also used to determine areas of interest prior to the survey.

Shoreline surveys repeated work undertaken in 2007 during the pre-construction baseline, using transect lines and quadrats across the intertidal zone to define substrates, habitats and ecological communities in terms of their zonation. Mangroves were surveyed using a combination of satellite imagery and infield ground-truthing , as well as transect lines, plot and quadrat based methods as developed by AIMS. Seagrass, macroalgae and coral reefs were determined through the ground-truthing and survey of satellite imagery derived polygons, as well as the application of transect and photo-quadrats following standard AIMS methods.

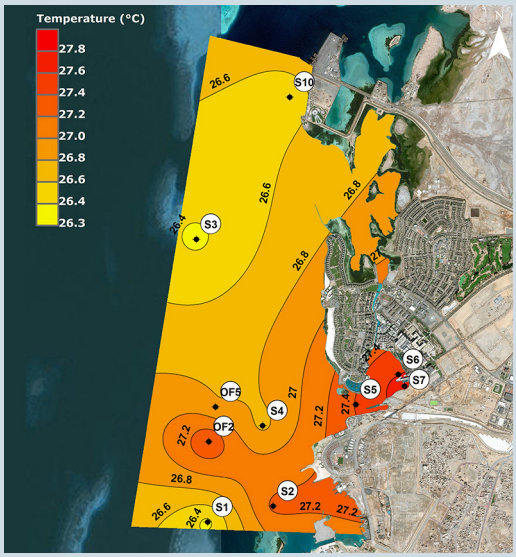
The findings provided quantitative data on the distribution, abundance and diversity of ecological components providing a basis for mapping and future monitoring.



3 // Findings

3.1 // Seawater Quality

Seawater quality incorporates both the physical and chemical properties of seawater, including temperature, salinity, specific conductivity, pH, turbidity, dissolved oxygen concentrations and pollutants such as heavy metals. Water profiles of temperature, salinity, specific conductivity, pH, turbidity and dissolved oxygen can provide an indication about the physical conditions of the water column in an area of interest, such as how well the water is mixed from surface to seabed, any differences between shallow and deep sites (e.g. shallower waters heating more rapidly than deep waters due to the impact of the sun), how much oxygen is available for marine life and whether turbidity levels may be a problem for light penetration to the seabed marine life. These parameters are also a useful tool to help identify the effect that additional inputs to an area, such as a freshwater discharge from a stream, or hot, treated water from a desalination plant etc. has on the local seawater physical properties. Monitoring heavy metal concentrations can help determine whether there has been contamination of an area e.g. from a hydrocarbon or chemicals spill. Seawater quality parameters were within all available limits and were generally indicative of ambient seawater conditions.

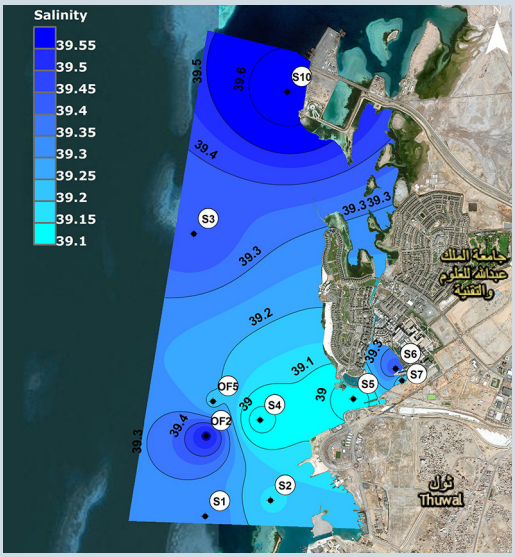


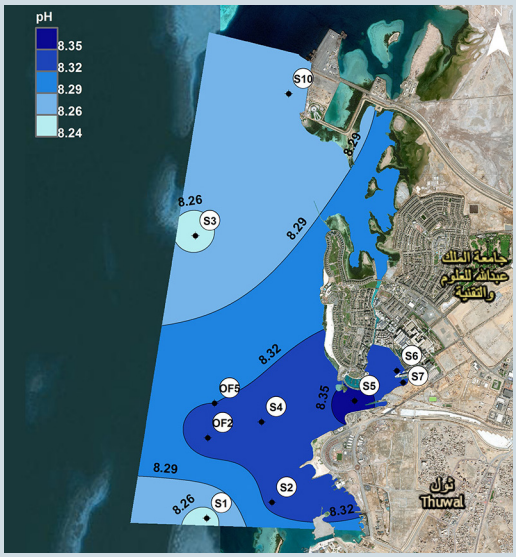
°C

MAX	AVERAGE	MIN
27.8	26.74	26.12

3.1.1 // Temperature

Most sites showed some evidence of thermal stratification, with the exception of shallow coastal areas. Highest site-averaged temperatures were recorded at sites close to the marina and CMOR station, reflecting the differences in station depth, as well as the relatively sheltered locations of these sites when considering wave exposure, wind-driven mixing and tidal flushing. Average water column temperatures recorded from sites adjacent to the outfall location were within the range of other stations, without any significant indication of temperature impact from potential outfall activity during the survey period. Overall sea surface temperatures were higher nearshore, in shallow or enclosed areas, decreasing slightly with distance offshore.





psu		
MAX	AVERAGE	MIN
39.9	39.2	38.7

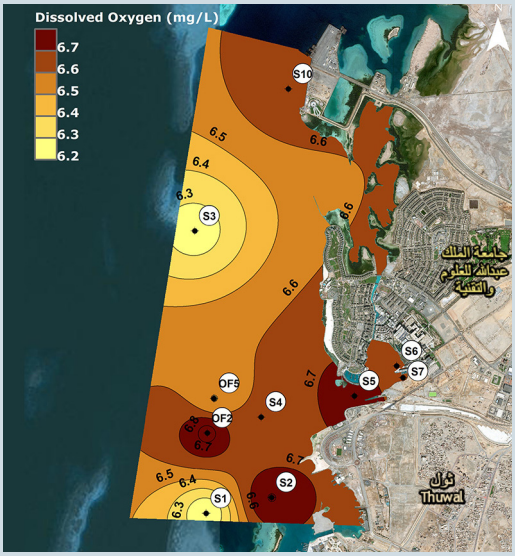
pH		
MAX	AVERAGE	MIN
8.37	8.31	8.23

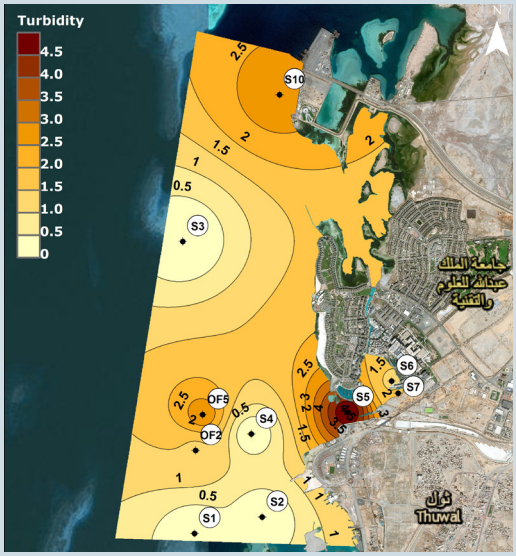
3.1.2 // Salinity

The majority of sites showed little overall variation in salinity with increasing depth,although several sites displayed a sub-surface maximum corresponding to the depth of the thermocline. The outfall station (OF2) showed this particularly clearly, with a peak of 39.9 psu recorded at 1.6m, before salinity decreased to approximately 39.3 psu at a depth of 2.1m. A slight increase in salinity was also observed near the seafloor at the same location, corresponding to the brine discharge from the desalination plant. However values observed were not noticeably higher than midwater or surface values observed at some of the other sampling sites, and were well within the PME discharge guideline of a 2 psu increase in salinity compared to the receiving environment. Depth profiles and surface spatial variability are shown in the figure above.

3.1.3 // pH

The highest pH values were recorded nearest the KAUST site, with the channel sites showing the highest water column-averaged pH. Values tended to decrease with increasing distance away from the coast. Water column profiles generally showed little clear pattern with increasing depth, with some sites showing a slight increase in pH values whilst other sites showed a slight decrease in pH values with increasing depth. Overall values were representative of ambient conditions.





mg/L

MAX	AVERAGE	MIN
6.87	6.53	6.21

NTU

MAX	AVERAGE	MIN
5.3	1.64	0

3.1.4 // Dissolved Oxygen

Depth profiles of dissolved oxygen varied between sites, with most sites showing little variability, although two sites showed an overall increase with increasing depth. Sites S10 and OF5 showed consistent decreases in oxygen concentrations with increasing depth, with site OF5 showing a slight sub-surface maximum corresponding to the depth of the start of the thermocline at that site. Overall the dissolved oxygen profiles closely corresponded to the pattern of thermal stratification at these sites, with decreases in oxygen concentration observed at the depth of the thermocline. This is not unusual in coastal waters, as the downward mixing of well oxygenated surface waters is limited by the presence of thermal stratification in the water column. Overall, concentrations of dissolved oxygen were consistent with ambient conditions and favourable for supporting marine ecology in all areas surveyed.

3.1.5 // Turbidity

Generally turbidity increased with increasing depth towards a maximum at or just above the seabed, indicating the deposition of finer sediment material. Locations with the highest measurements were located in the main approach channel and basin area adjacent to the marina and CMOR stations. These areas have been subject to the most excavation and dredging activities, as well as marine construction, and were observed to be areas where thick accumulations of fine materials were deposited. Vessel activity and tidal flushing may also result in the mobilisation of these fine materials. The turbidity levels recorded were relatively high in some areas, and were supported by observations of relatively high sedimentation rates at some reef locations. However, turbidity measurements within a similar range were present during the pre-construction baseline.

3.1.6 // Coliforms, Oxygen Demand and Organic Carbon

Total Coliforms were not detected in any of the collected samples, whilst Biological and Chemical Oxygen Demands were below the laboratory analytical limits applied: 2mg/L and 5mg/L respectively. Total Organic Carbon (TOC) was also undetected based on an analytical limit of 1mg/L. All applied detection limits were below the quality thresholds set out by PME guidelines.

3.1.7 // Heavy and Trace Metals

Heavy and trace metals including Arsenic, Barium, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Vanadium and Zinc were analysed in seawater samples. All concentrations were below the applied laboratory detection limits. Detection limits were appropriate, allowing for a comparison of all parameters against relevant criteria, and were below any guideline thresholds used for comparison during the survey.

3.1.8 // Inorganics and Microbiology

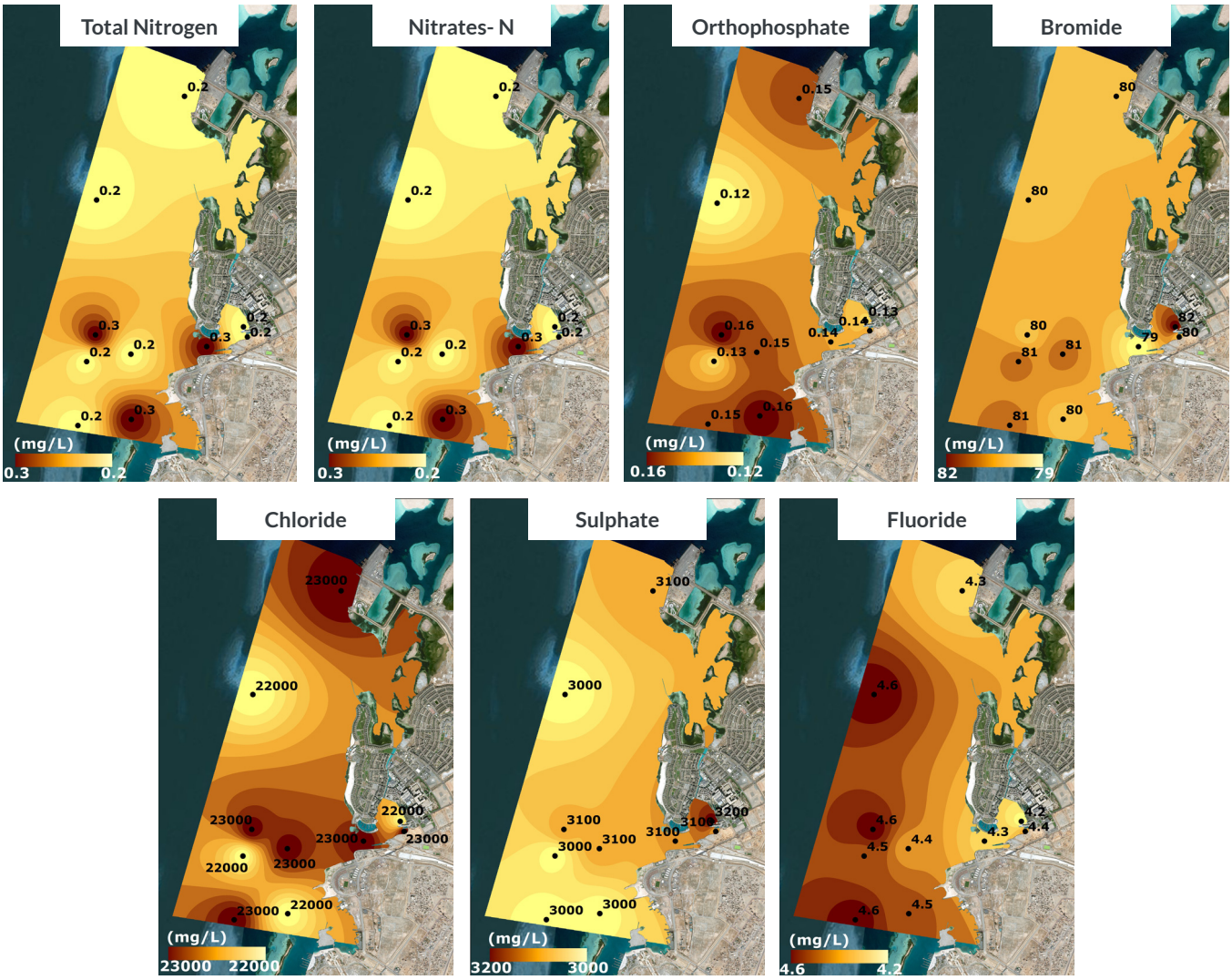
Monitoring nutrients and inorganics concentrations, and microbiology-related parameters such as coliforms, oxygen demand and organic carbon can help to identify whether there are potential anthropogenic impacts to the water column in the area that stand out above any expected natural variation. These could include nutrient changes due to fertilizer use in coastal areas or discharge of sewage. Coliforms, Oxygen Demand and Organic Carbon can provide information on the microbiology of water, particularly useful in the detection of an organic input such as sewage to receiving waters. Concentrations of some inorganic parameters such as Chloride and Fluoride exceed the KSA PME ambient water quality objectives, but are in line with concentrations previously measured in the local and wider Red Sea area.

Total Alkalinity was detected at a constant 120 mg/L, similar to the average alkalinity of seawater. Total Dissolved Solids (TDS) were also detected at concentrations representative of ambient conditions within the Red Sea (37.05 mg/L – 42.73 mg/l). Total Suspended Solids (TSS) concentrations were all below the laboratory detection limit, indicating concentrations of below 5mg/L.

Ammoniacal Nitrogen was also below detection limits (0.1mg/L), whilst Total Nitrogen, Nitrate and Phosphate were all present in measurable quantities, albeit similar to pre-construction baseline survey conditions. Phosphorous was not present in measurable concentrations (i.e. was less than 1mg/L in all samples).

Chloride concentrations exceeded the KSA PME ambient water quality objective value of 21,000 mg/L. However, the detected concentrations of 22,000 – 23,000 mg/L are similar to those reported in current literature for the Red Sea. Fluoride concentrations ranged from 4.2mg/L to 4.6mg/L, exceeding the ambient water quality objective proposed by PME. However, the findings fall within the range of the pre-construction baseline. Sulphate concentrations were also similar to those reported for the wider Red Sea (3,078 mg/L).

The lack of apparent relationship between the distribution of Total Nitrogen and Nitrate concentrations with Phosphate concentrations would suggest that the mild enrichment of these parameters observed within the sampling area are not necessarily from a common point source.

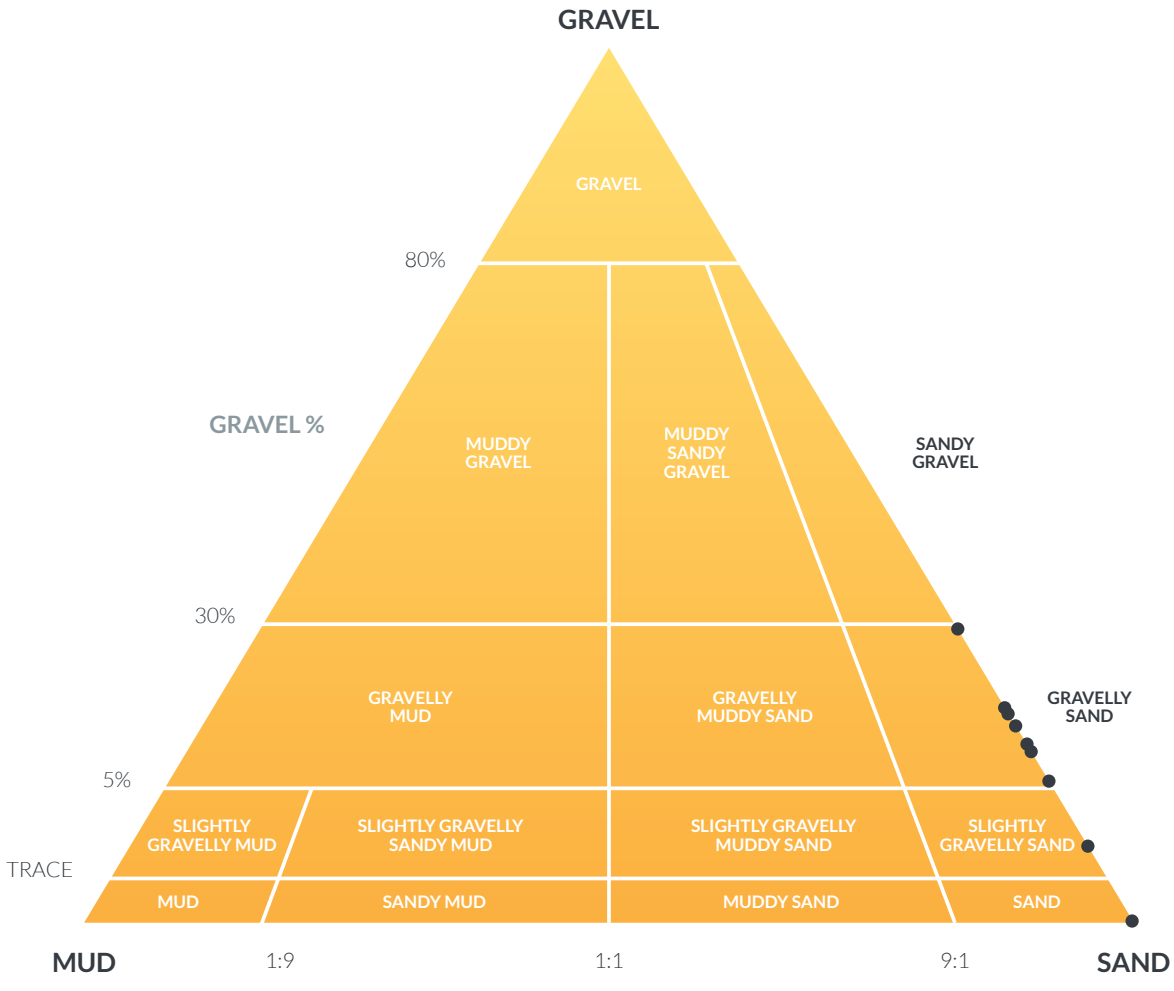


3.2 // Sediment Quality

In addition to measuring seawater quality, the quality of marine sediments can provide a large amount of additional information about an area. Pollutants are more likely to be adsorbed onto sediment particles, and therefore to persist for a longer time than water pollutants, which may easily be dispersed by simple mixing of the water column. Parameters analysed for sediment quality include Grain Size, Inorganics and Organics, Heavy and Trace metals, and Infaunal communities.

3.2.1 // Grain Size

The sediments occurring at the majority of the surveyed stations were categorized within the "Gravelly Sand" textural group, with other sediments falling into the "Sand", "Sandy Gravel" and "Slightly Gravelly Sand". The stations showed a variety of mean sediment types; Very Coarse Sand, Coarse Sand, Medium Sand and Fine Sand. Sediments were poorly sorted, for the most part. Average grain sizes from sediments ranged from 159.0 µm to 1096 µm, with an overall survey average of 489 µm. The classification of the sediments for the samples are shown in the ternary graph below.



3.2.2 // Inorganics & Organics

Similar to water quality monitoring, the presence of inorganics and organics in marine sediments can provide an indication of pollution in an area such as petroleum hydrocarbons from a spill or a leak, increased nutrients or organic carbon from sewage discharge or industrial actions etc. Concentrations of Total Nitrogen and Total Organic Carbon were representative of ambient sediment conditions, whilst no trace of petroleum hydrocarbons was found at any site, with the exception of a low concentration of EPH at site S1.

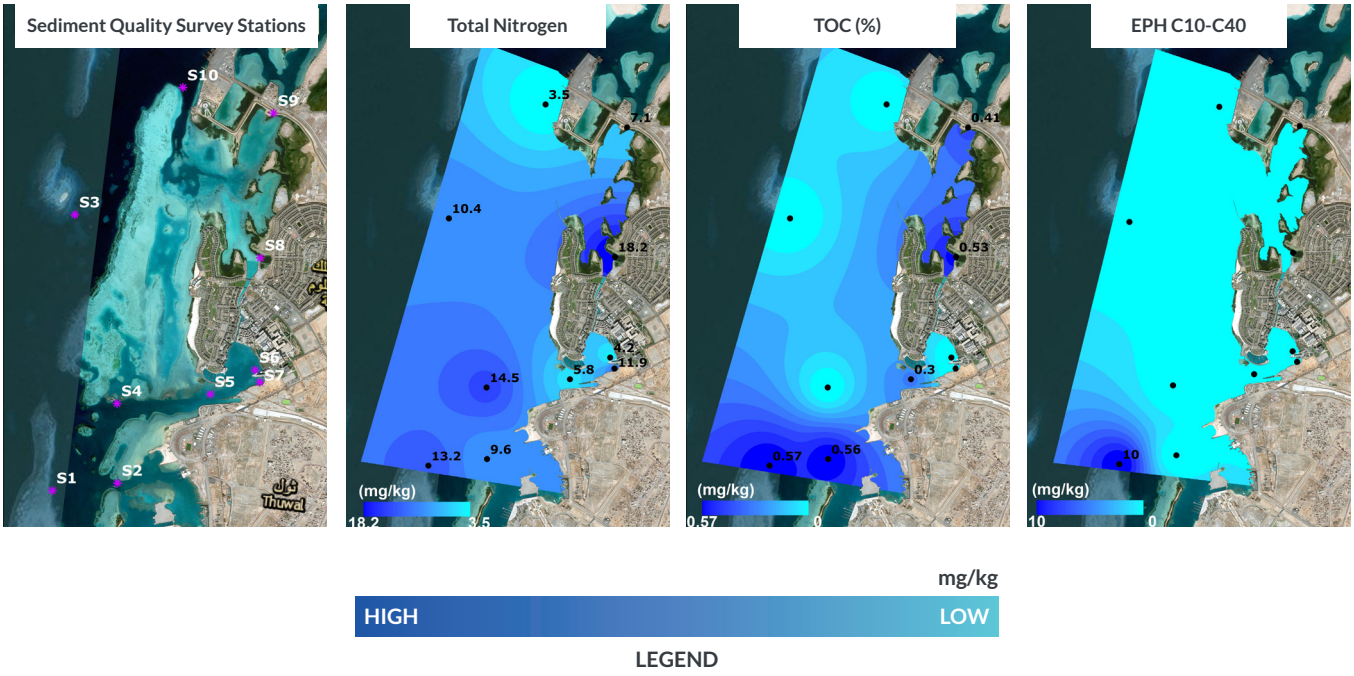
// Total Nitrogen

Total Nitrogen was detected in sediments from all sampling sites, with concentrations ranging from 3.5 mg/kg to a maximum of 18.2 mg/kg, with a survey average of 9.84 mg/kg. Lowest concentrations were recorded at the northern edge of the survey area, with low values also recorded in the harbour approach channel. Concentrations in sediments to the west and south of the survey area ranged from 9.6 mg/kg to 14.5 mg/kg.

// Total Organic Carbon

Total Organic Carbon (TOC) was detected at five of the ten sampling sites, with values ranging from 0.30% to 0.57%. TOC was undetected at five sites based on the laboratory applied Limit of Detection of 0.05%. TOC values in coastal marine sediments of the Thuwal area of Saudi Arabia were typical of those reported in available literature, with average TOC concentrations reported as varying between 0.22% to 1.92%. The values recorded were therefore considered representative of "normal" coastal conditions for this geographical area.

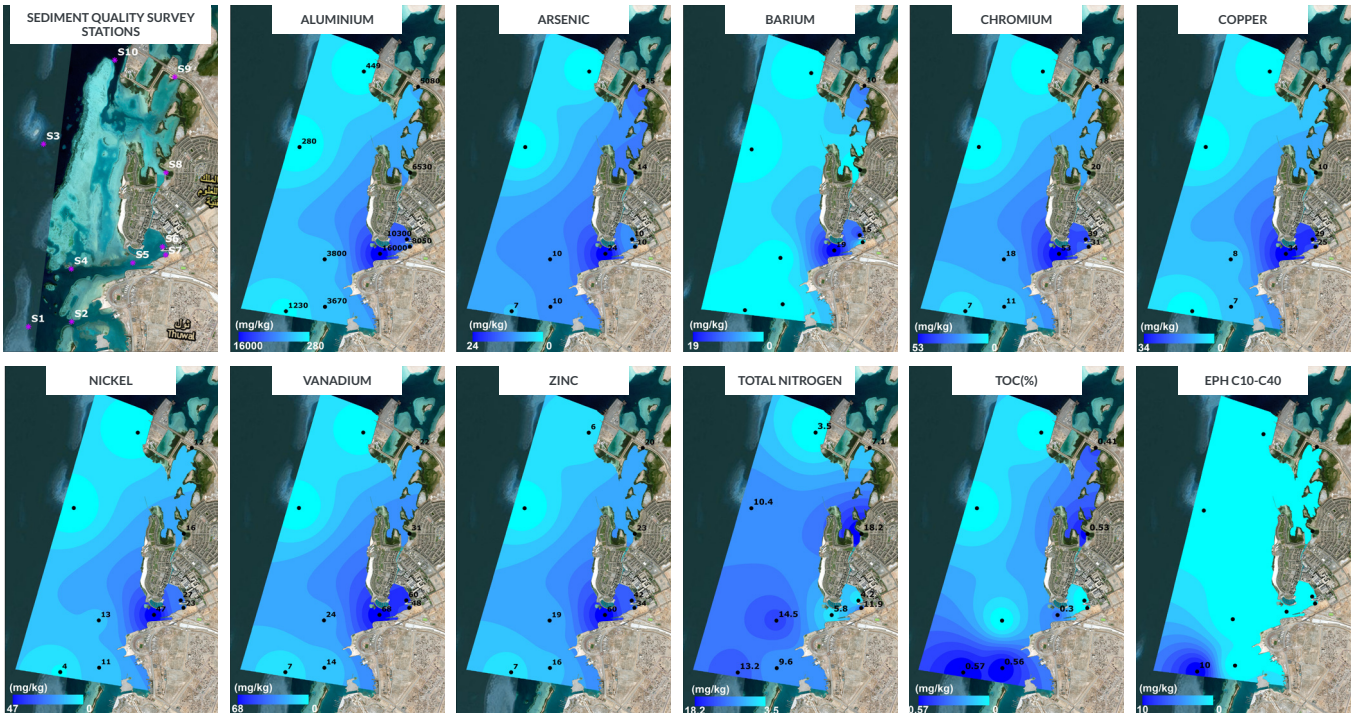
Total Petroleum Hydrocarbons were split into two fractions for analysis; Volatile Petroleum Hydrocarbons (VPH; C6 – C9) and Extractable Petroleum Hydrocarbons (EPH; C10 – C40). Volatile Petroleum Hydrocarbons were undetected in sediment samples from all sampling sites, with a limit of detection of 0.025 mg/kg. Extractable Petroleum Hydrocarbons were also undetected (LoD 10 mg/kg), with the exception of site S1 where a concentration of 10 mg/kg was recorded.



3.2.3 // Heavy & Trace Metals

Living organisms require varying amounts of certain trace metals for normal functioning, however the accumulation over time of some metals can be toxic to organisms. Monitoring heavy and trace metals in sediments can help to provide not only an indication of the source of any increases in metal concentrations (i.e. whether it is naturally derived from weathering of local geology, or a likely anthropogenic source), but also whether concentrations of certain metals are likely to cause damage to the marine flora and fauna over time. Several metals exceeded one or more of the criteria used for comparison, with highest concentrations of all metals recorded with the approach channel, adjacent to the marina. Local factors including the accumulation of fine sediments (and associated metals) are considered to influence these high concentrations, with anthropogenic inputs remaining a possibility.

The distribution of metals in sediments highlighted several which exceeded one or more of the criteria used as the basis for determining existing status: Arsenic, Chromium, Copper, Nickel, Vanadium and Zinc. These metals were widely distributed, indicating significant geological inputs in most instances. Arsenic was present in concentrations ranging from 7 mg/kg to 24 mg/kg. Chromium was detected in sediments from most areas ranging from 7 mg/kg to 53 mg/kg. Copper was detected in sediments from the majority of samples ranging from 7 mg/kg to a maximum of 34 mg/kg. Nickel was detected in sediments from eight sites, with detected concentrations ranging from 4 mg/kg to 47 mg/kg. Vanadium was detected in sediments from eight sites, with detected concentrations ranging in concentration from 7 mg/kg to 68 mg/kg. Zinc was detected in sediment samples from all sampling stations except one, ranging from 6 mg/kg to 60 mg/kg. In all instances the upper most concentrations were recorded within the samples collected at S5, within the main approach channel, adjacent to the marina. Local factors associated with the main approach channel were thought to influence accumulation. These factors were considered to include the build-up of fine materials in the area, which tend to accumulate metals, whilst anthropogenic inputs could not be discounted. Aluminium, Barium, Cadmium, Lead and Mercury had no inferred toxicity implications and were mostly undetected in samples (with the exception of Aluminium was ubiquitous and considered non-toxic).



3.3 // Infauna

Marine infauna defines the animals living in the sediments of the seabed, rather than on the surface. It includes Annelids, Crustaceans, Molluscs, Echinoderms etc. The composition of the infauna community can provide an idea as to how stressed the infauna community is; a very low diversity, or substantial numerical dominance by a single group can indicate a stressed or disturbed environment, whist a high diversity and evenness within the community indicates a healthy, non-stressed community. Low diversity or abundance may also simply indicate that an area is not of regional importance or significance for infauna. In general, infauna was evenly distributed, with little dominance by a single species; infauna was notably absent from sediments within the area adjacent to the marina (S5), suggesting a negative effect from sediment conditions and presence of metals on the infauna community.

158 Individuals

42 Species

12 The highest number recorded at one station

27 Specimens represented at two individual stations

A total of 158 individuals were collected, belonging to 42 species. The highest number of species recorded at one station was 12. In terms of numbers of individuals, two stations were represented by 27 specimens.

Sediment samples highlighted the presence of invertebrate communities at nine of the ten stations surveyed. Most notably the sample collected in the location adjacent to the marina, where sediment toxicity was at it's highest, was the only sample with no infauna recorded.

The annelid worms were the best represented phylum, both in terms of number of species, at 19 and number of individuals, at 89. Crustacea were also relatively well represented with 12 species and 19 individuals.

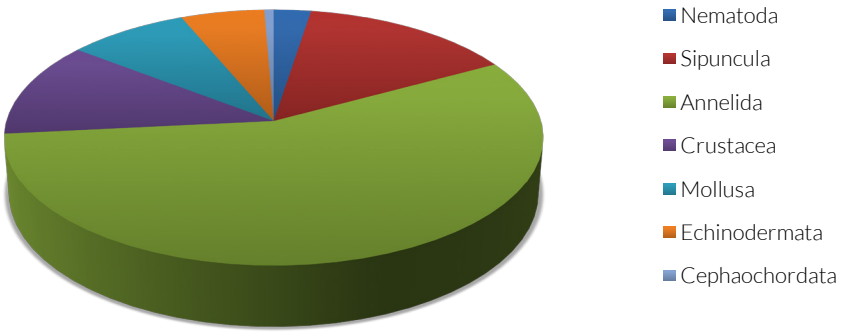
Species Richness peaked at 3.46 and Shannon-Weiner diversity was highest at S7. Species Evenness was highest at S1, although with relatively low abundance figures, these parameters should not be over-interpreted.

// Footnote

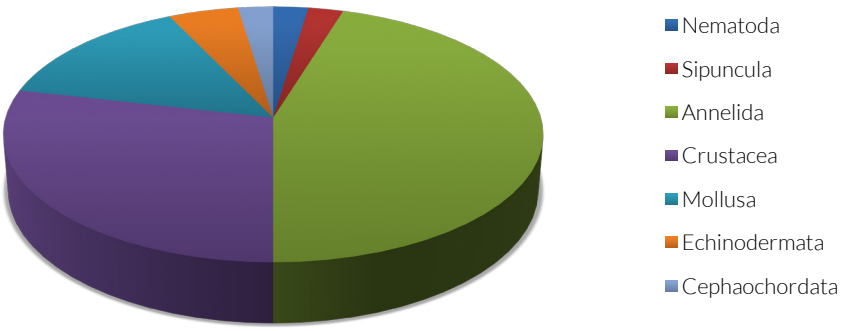
Shannon-Weiner Diversity; A quantitative measure reflecting on how many different types of organisms (i.e. species/families) are present in a dataset, taking into account how evenly the total number of individuals are distributed between these different species/families.

Species Richness; Species richness takes into account the number of species represented in the infaunal community, without taking into account the abundances or relative distribution of the species within the overall community.

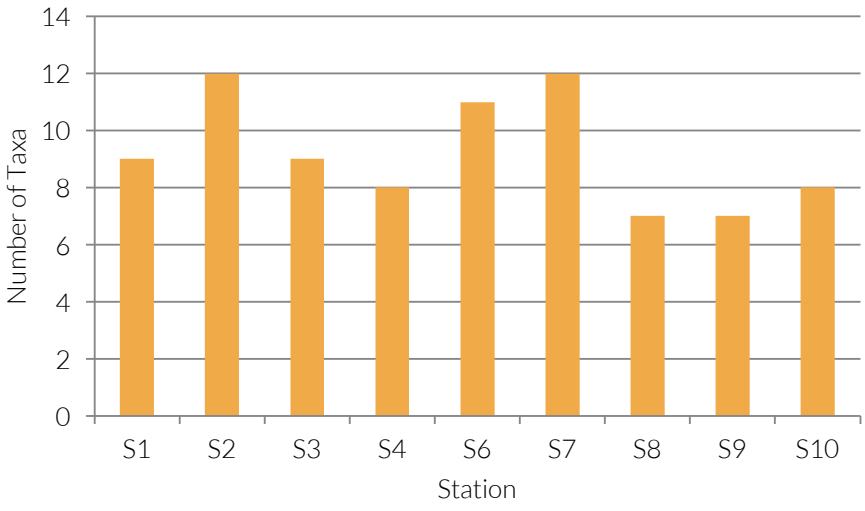
Species Evenness; How numerically balanced or close each species within the infaunal community is, quantifying how 'equal' the community is.



DISTRIBUTION OF INDIVIDUALS AMONG THE PHYLA FOR ALL STATIONS SAMPLED

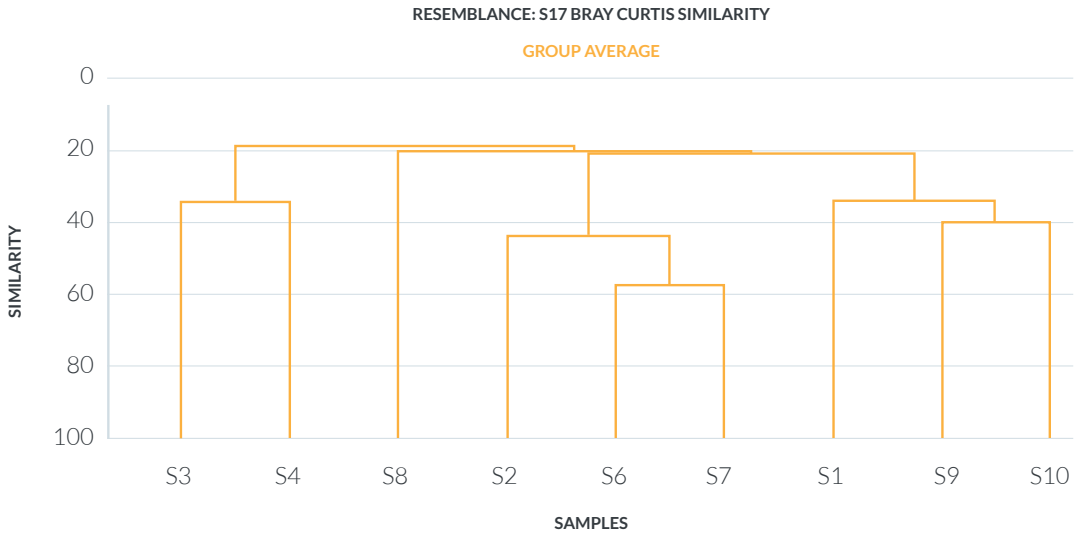


DISTRIBUTION OF SPECIES AMONG THE PHYLA FOR ALL STATIONS SAMPLED

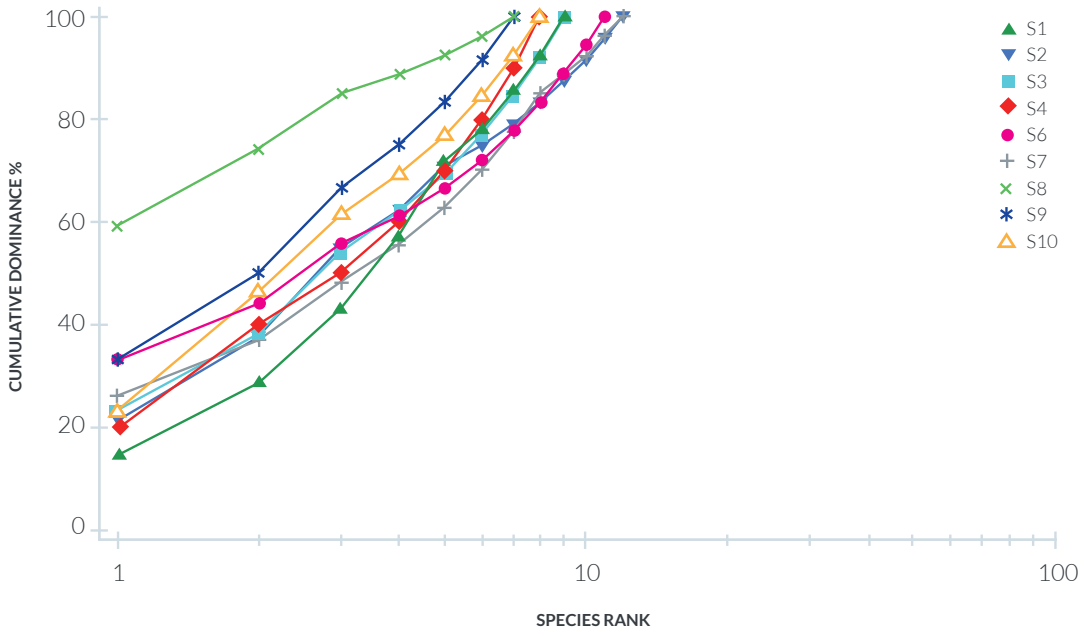


NUMBER OF SPECIES RECORDED AT EACH STATION

A dendrogram of Bray Curtis Similarity shows the two most similar stations were in the basin area of the main channel (S6 and S7). This pair were also relatively similar to S2. S3 and S4 are relatively distinct both from one another and from other stations. The station adjacent to the marina is notably absent due to the lack of specimens recorded.



The vast majority of stations show a very even spread of abundance between the species, with little dominance by a single species (as indicated by the relatively steep plots, which start low on the y-axis). Overall the data suggested that sediment conditions and potentially the presence of contaminants may be affecting infauna in the area near to the marina (S5). Elsewhere, the species present were all well-known from previous studies.



3.4 // Shoreline & Intertidal Habitats

3.4.1 // Habitat Types

Marine habitats are the ecological or environmental area inhabited by organisms. Marine habitats can generally be divided into coastal (shoreline) and open ocean habitats. Coastal/shoreline habitats can be further divided to include sandy or rocky shore habitats, mangrove and salt marsh habitats, mudflats, estuaries, seagrass habitats or coral reef habitats. These habitats are influenced by the dynamic nature of the coastal environment, and due to their proximity to land are at increased risk of damage from anthropogenic inputs such as construction discharges, pollution sources etc. in addition to physical disturbance or loss of habitat due to coastal construction, increased tourism etc. Habitats were mostly sand-based, with varying amounts of rubble and rock present. Mangroves and seagrass habitats were identified at three sampling stations each, whilst macroalgae was recorded at all habitat sampling sites.

Prior to the surveys a review of the project area, using ARC View GIS 9.1, was undertaken based on imagery and previous reporting. Next, a selection of stations were allocated to be re-surveyed to allow for change determination following the construction of the KAUST facility. Stations names have been retained from the 2007 survey for continuity. The survey included the supra-littoral zone, where tidal inundation occurs on only a few days each year; the littoral fringe or upper intertidal, where submersion only occurs during spring tides; the eulittoral or intertidal zone, where substrates and habitats are exposed during the daily tidal cycle; and the sublittoral fringe or lower intertidal which is only exposed during spring tide lows.

The substrate type in most areas was sand overlying a rock platform, with deeper accumulations of sandrecorded above the strand line, or in sheltered bay. Areas where the intertidal zone was relatively exposed tended to be defined by flat bedrock platforms, with thin veneers of mobile coarse sand. Most areas supported at least some combination of sand and rock based substrate conditions, with boulders and rubble also a feature in some areas. The major categories applied are shown in the table and map opposite.

Location of shoreline survey stations (Imagery: Google Earth)

Areas above the strandline tended to be classified as hypersaline soil environments or 'sabkha'. Most of these areas were adjacent to recently constructed infrastructure. Sabkha supported halophytic vegetation in some instances, which was considered noteworthy due to the lack of halophytic vegetation following construction.

Distribution of shoreline and intertidal habitats (Imagery: Google Earth)

SABKHA SUPPORTING HALOPHYTIC VEGETATION

Sandy shores and beach areas were shallow in gradient, consisting of coarser sand. In places the beaches back mangrove stands or give way directly to intertidal rock platforms. The main beach area appeared to have been subject to beach nourishment whereby sand from elsewhere has been used to enhance the amenability of the area. These areas supported virtually zero vegetation or associated ecology.

Tidal sand and mud flats form the backdrop to sheltered lagoons behind the protective fringing reef line. These were low energy areas allowing for the deposition and accumulation of finer sand, silt and mud materials. The thickness of the layers within these areas varied considerably, ranging from a few centimetres of well mixed sediments of varying grain size, to thick deposits of anoxic clay materials, the latter the most impoverished in terms of fauna.

True rocky shore habitats were virtually absent from the project area. All hard ground, rock founded habitats occurring in the area were associated with manmade structures such as coastal protection features, jetty bases and boundary fences. These areas represented locations where previous naturally occurring habitats existed – typically as beaches or where hypersaline compacted sands shelve gently into the intertidal area.

3.4.2 // Flora and Fauna

Marine Flora and Fauna relates to the plant life (flora) and animal life (fauna) found within the marine environment; collectively, they are referred to as the marine biota. As with infauna, the composition, abundance and variation over time of the marine flora and fauna (including the presence or absence of certain species) can provide indications as to the overall health of the shoreline habitats in an area.

HALOPHYTE: *ZYGOPHYLLUM COCCINIUM*

MANGROVES: *AVICENNIA MARINA*

MIXED MACROALGAE COLONISATION ON AN EXPOSED ROCK PLATFORM

A COMMONLY OCCURRING MACROALGAL COMMUNITY IN THE LOWER INTERTIDAL ZONE: *HALEMIDA, PADINA, ACANTHOPHORA* AND *PALLISADA.*

Vegetation in the supra-littoral zone was restricted to a handful of halophytes, primarily *Zygophyllum coccinium*. These halophytes were largely absent from the surveys, only recorded in the central site areas, where no reclamation or construction works have occurred. Within the intertidal zone mangrove stands were widespread dominated by small to medium sized *Avicennia marina*. In lower intertidal areas macroalgae were abundant and diverse, with *Acanthophora spicifera*, *Palisada papillosa*, *Halimeda* sp., *Padina boryana* and *Hypnea* sp. the most commonly recorded species. Other algae such as *Ulva* sp., *Dictyosphaeria* sp., *Avrainvillea amadelpha* and *Acetabularia* sp. were also widespread.

Fauna were dominated by gastropods (snails). Species number were relatively low and were not overly abundant for the most part. *Cerithidea cingulata* was the most widespread, with *Umbonium* sp., *Rhinoclavis* sp., *Nassarius* sp. and *Volema paradisiaca* also recorded in sand substrates, tidal flats and mangrove areas.

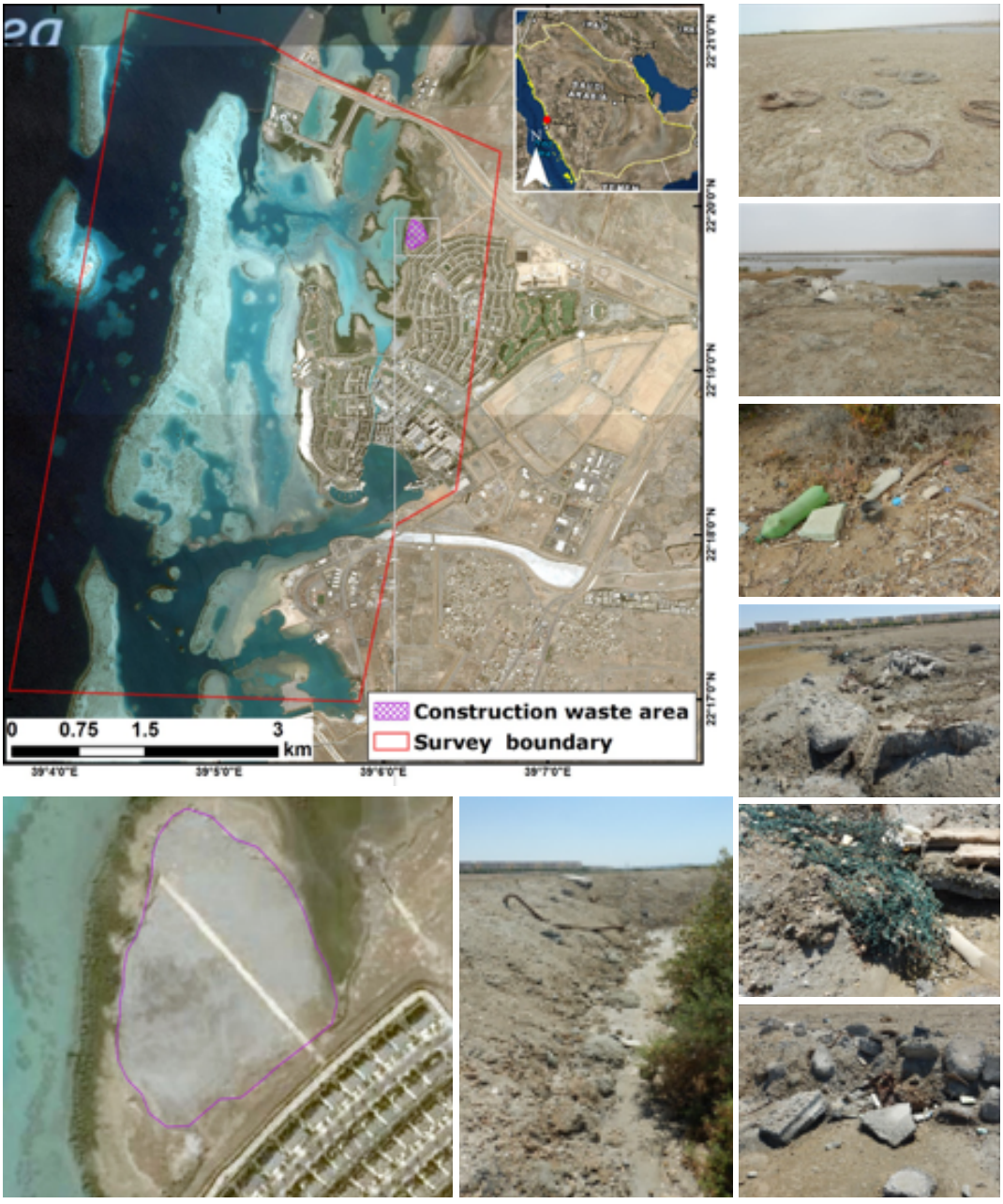
GASTROPODS RECORDED DURING THE SURVEYS. LEFT: *CERITHIDEA CINGULATA*, RIGHT: *NASSARIUS DESHAYESIANUS*

GRAPSID CRABS (*METOPOGRAPSUS MESSOR*) RECORDED IN MANGROVE AND ROCKY SHORE AREAS; HERMIT CRABS (*DIOGENES* SP.) WERE WIDESPREAD.

3.4.3 // Shoreline Waste Survey

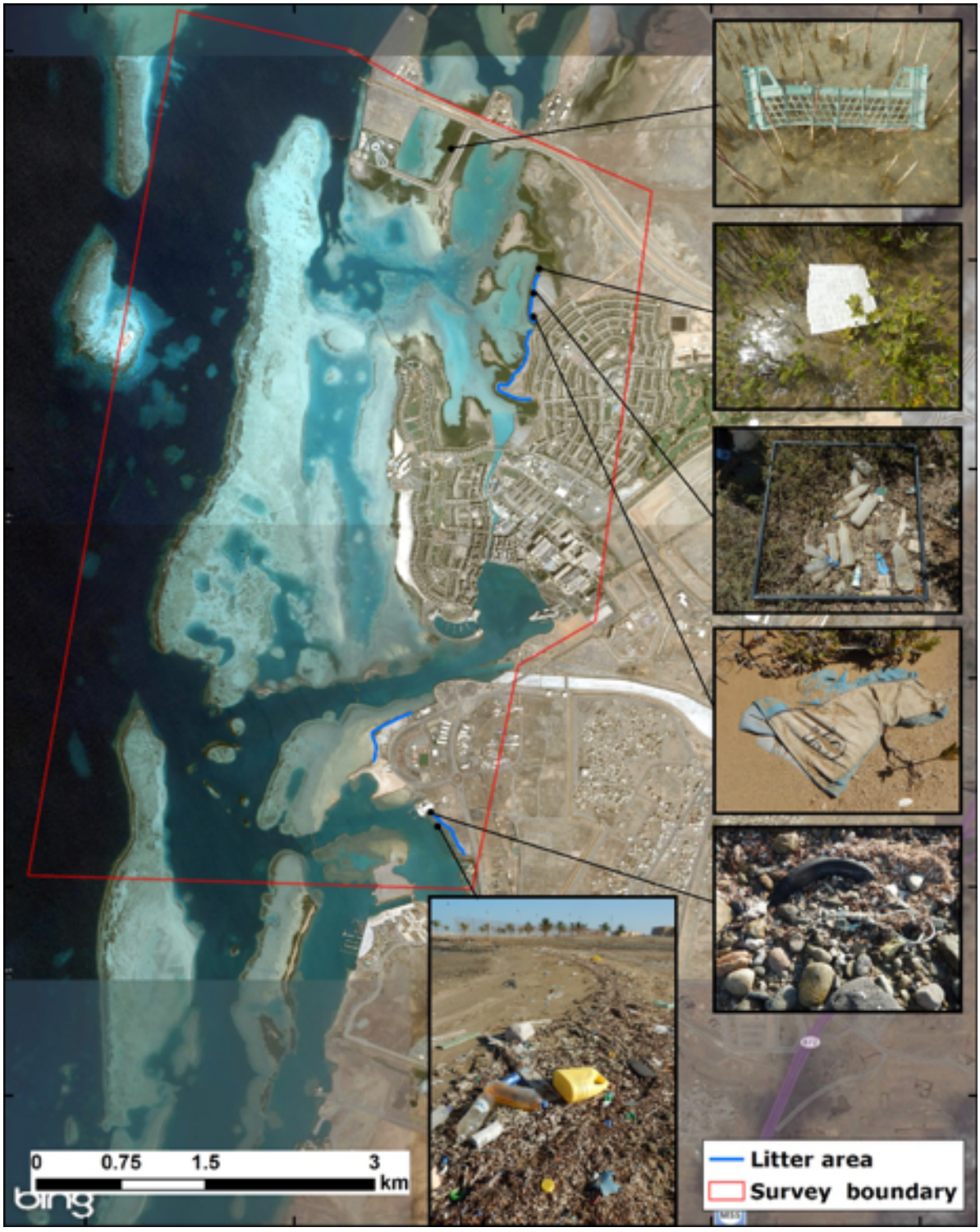
The primary purpose of this survey was to highlight any areas of significant waste and litter accumulation resulting from the construction phase of the project (construction waste), disposal of construction materials, or litter accumulation in areas which were unlikely to be covered by the operational waste management services.

Surveys were undertaken in shoreline areas following a rapid assessment of the site. Where waste issues were identified the type and weight of material was quantified based on measured area collections, counts of individual items and classifications of litter by weight.



Areas of landfilled and left over construction materials (Imagery: Google Earth)

Areas included within the survey, highlighting areas for further clean-up activities (Imagery: Google Earth)



Areas of significant litter accumulation (Imagery: Google Earth)

3.5 // Mangrove Surveys

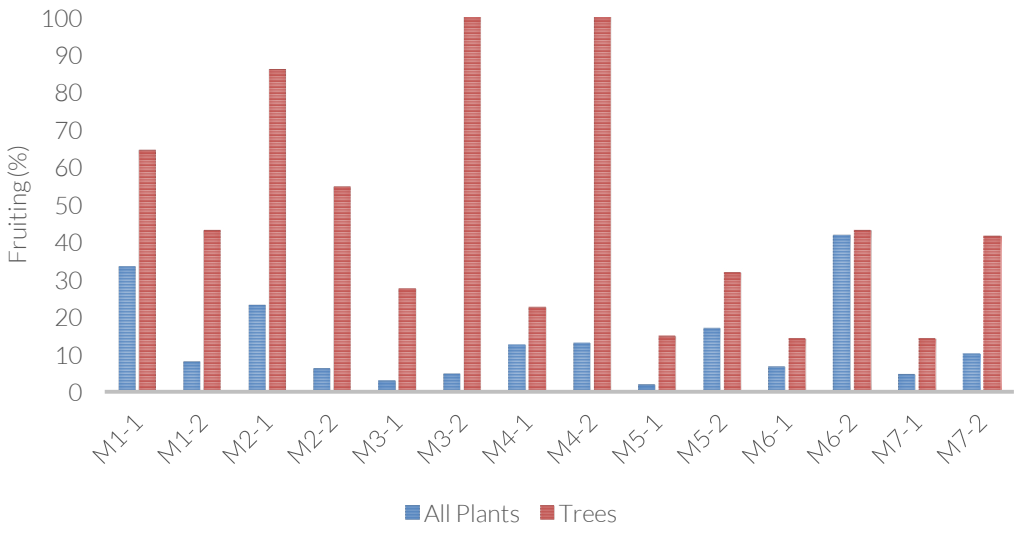
3.5.1 // Trees & Saplings

Measurements of tree heights, girths and density were made based on the allocation of plots within the mangrove stands. Measurements were all made within 10mx10m mangrove plots. Two plots were established at each survey station, as depicted in the map below.

Most areas supported relatively dense stands of mangroves with large numbers of mid-sized tree (2m-3m). Areas of larger trees were restricted to mid-intertidal zones, with the tallest trees reaching 4m – 5m in height. All areas supported large numbers of relatively young trees and saplings, with those less than 1m in height particularly abundant in some areas.

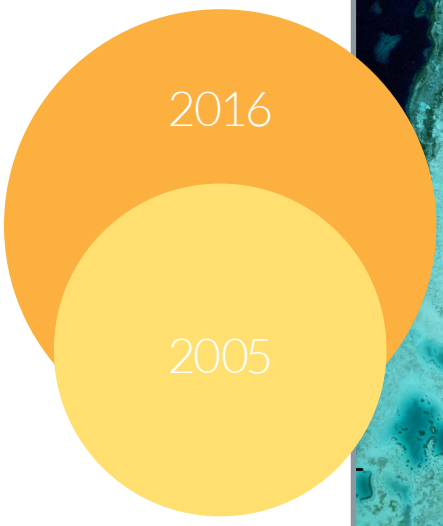
The majority of trees were fruiting at the time of the survey, with high proportions evident at a number of locations.

MANGROVES FRINGE A LARGE PROPORTION OF THE SHORELINE OF THE SITE. THE PHOTOGRAPH ON THE BOTTOM RIGHT SHOWS RIPENING FRUIT, WHICH WAS COMMONLY OBSERVED DURING THE COURSE OF THE FIELD SURVEY.



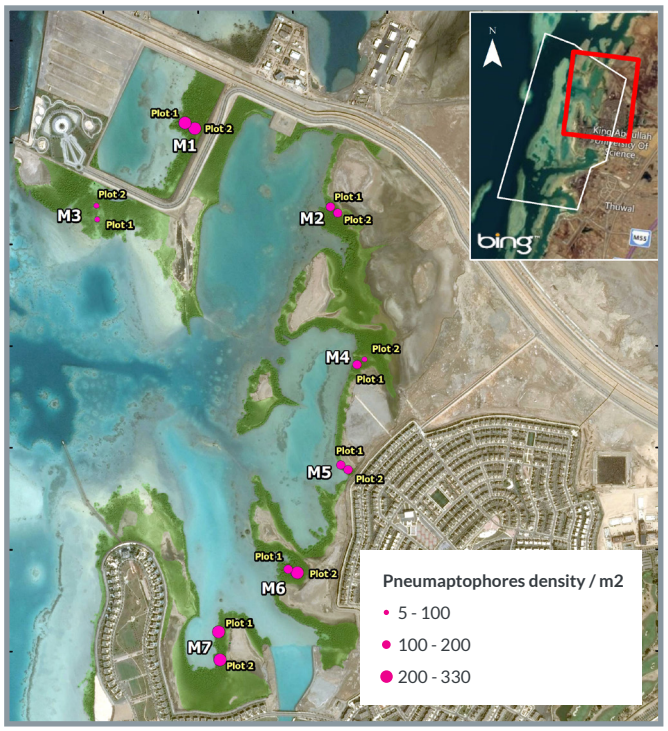
3.5.2 // Area

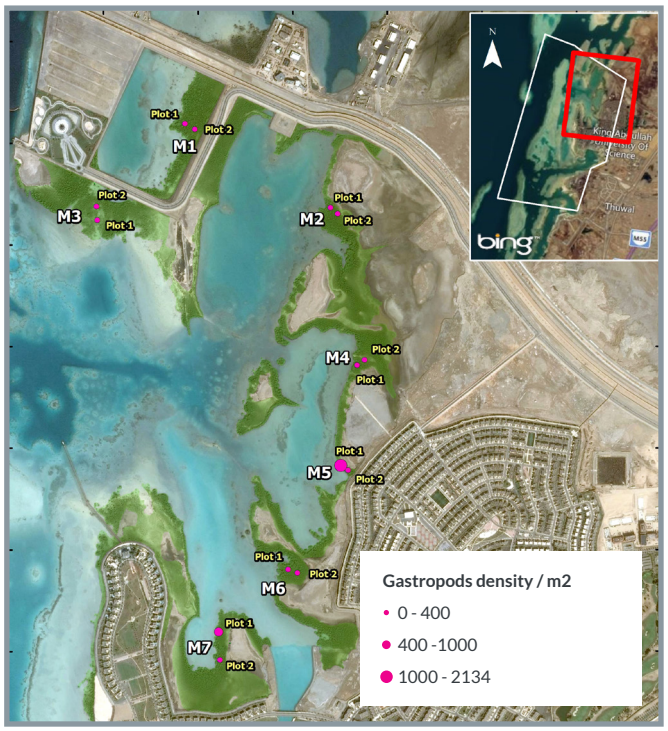
The area of mangrove present was 91.2 hectares, based on estimates derived from satellite imagery and on-site boundary verification', an increase in total area at least 16 hectares since 2005. The areas were broken down into units to allow for future monitoring of changes in total cover on smaller scales.



3.5.3 // Other Indicators

Within the mangroves, counts of pneumatophores, crab burrows and gastropods were also recorded as the basis of future monitoring of mangrove 'health'. (Text links to the fig below). The densities varied considerably between areas, influenced by the location of the survey plots, the depth and type of substrate overlying the rock platform, as well as factors related to hydrodynamics.





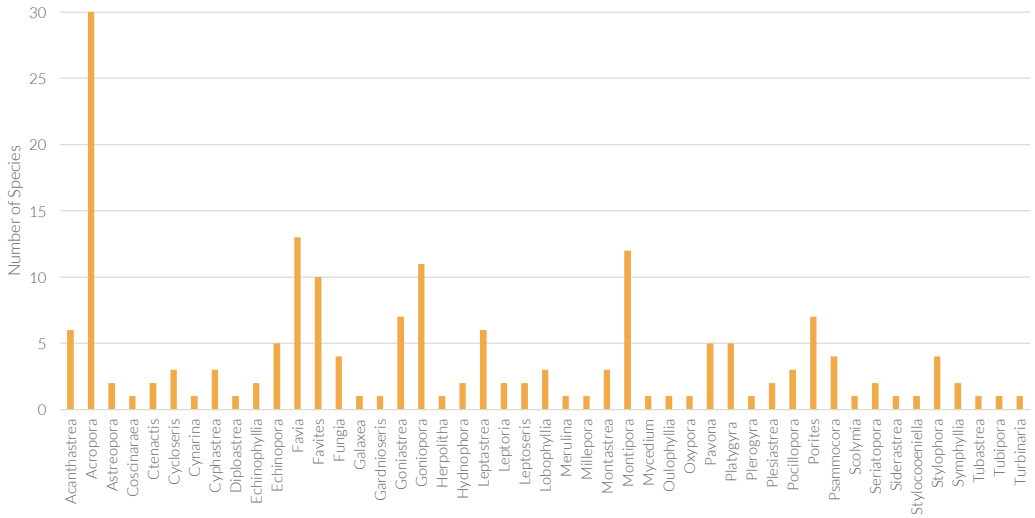
3.6 // Coral Reef Surveys

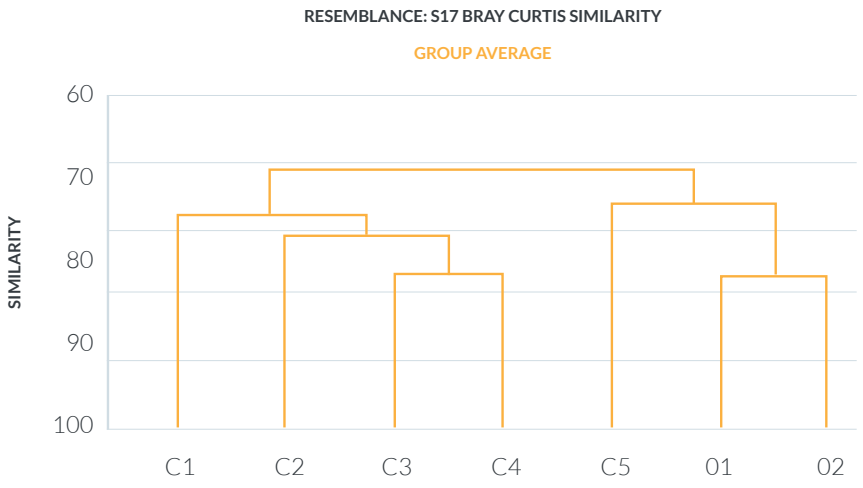
3.5.1 // Distribution

Coral reefs were wide spread, consisting of large areas of fringing and outer reefs. A total of 181 species from 44 genera were recorded, dominated by *Acropora*, *Dipsastrea* (formerly *Favia*), *Montipora*, *Goniopora* and *Favites*.

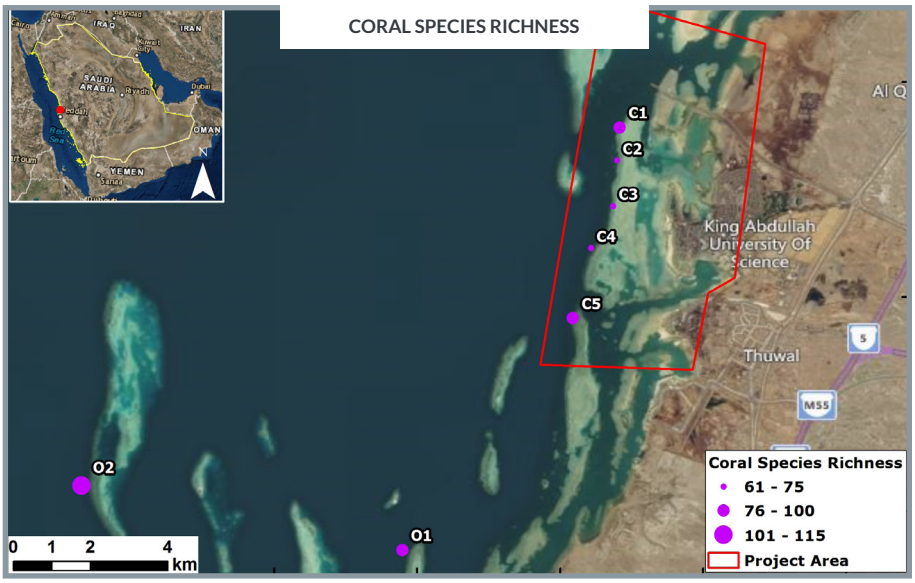
181
species

44
genera

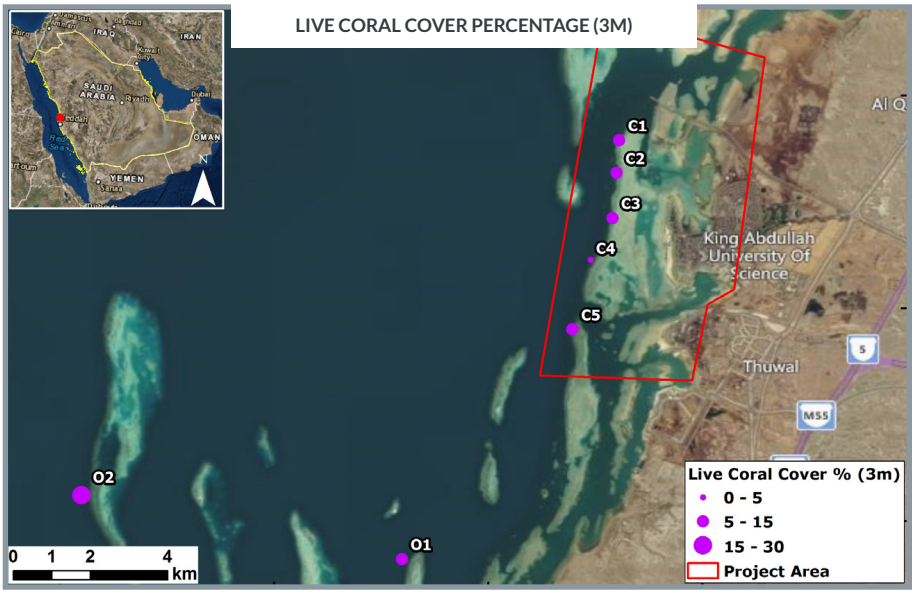


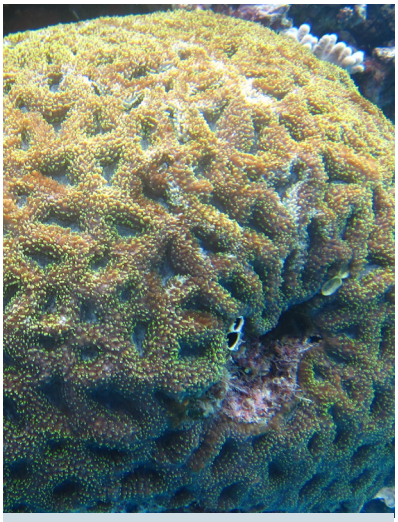


Live coral cover followed a similar pattern to the distribution of diversity, with higher covers at the most outer reef areas, with areas immediately in front of the University being the most degraded. (fig below). Reductions in live coral cover were most pronounced in shallow areas, although all areas, and especially along the fringing reef have suffered some decline in recent years.

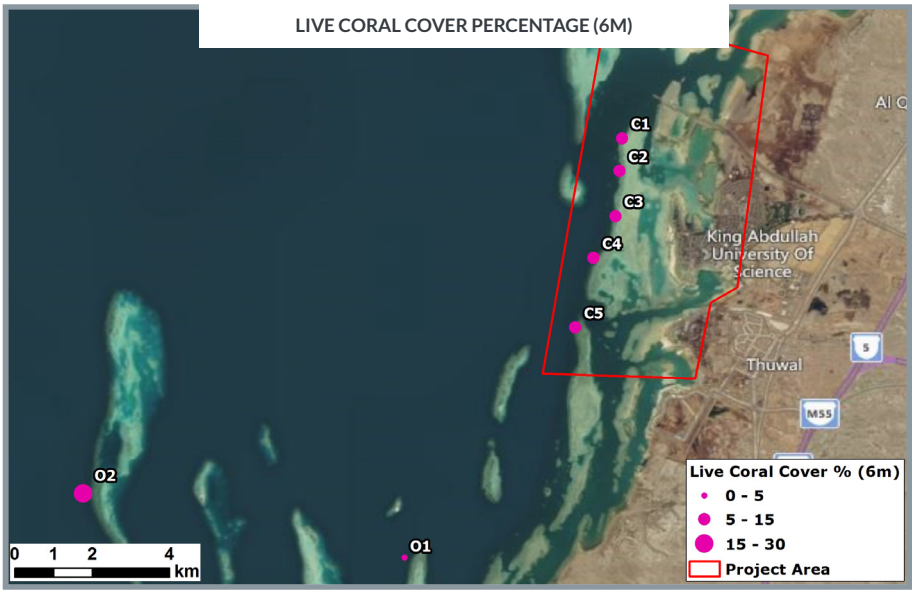


BRANCHING CORAL OF THE GENUS *ACROPORA*

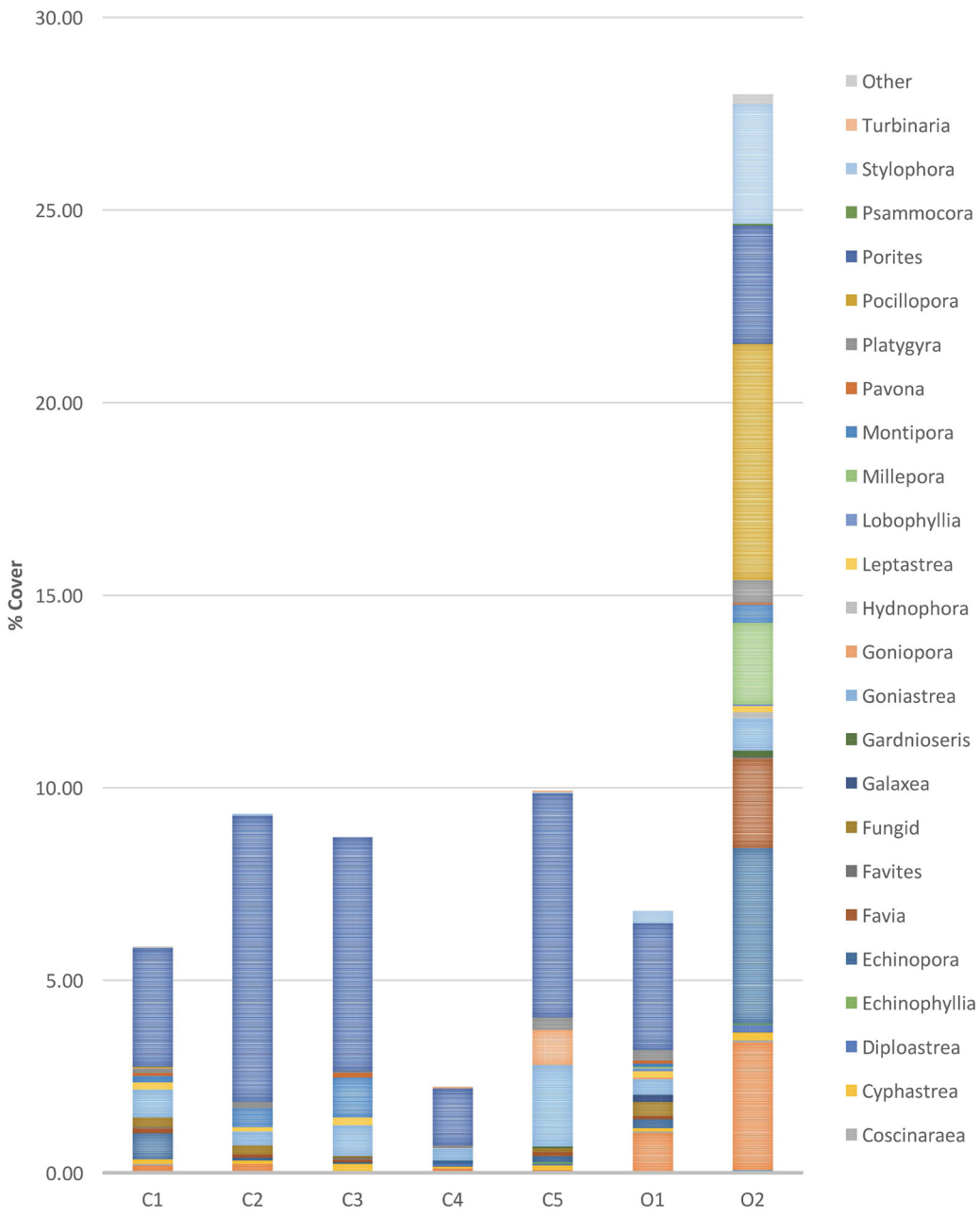


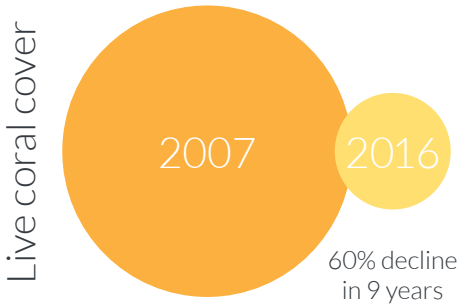


SUB-MASSIVE CORAL OF THE GENUS *DIPSASTREA*

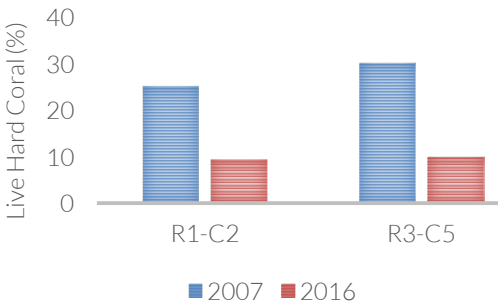


ENCRUSTING CORAL OF THE GENUS *PLATYGYRA*

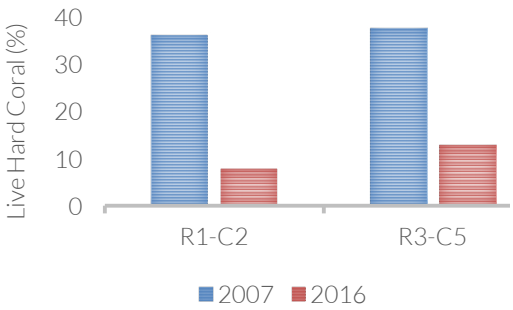




Outer reef locations supported the highest numbers of species, whilst the northern and central areas of the fringing reef were the least diverse and also had the lowest remaining live coral cover. Significant reductions in live coral have occurred since the pre-construction baseline survey, with coral cover changes demonstrated by a comparison of two locations surveyed in 2007 and again in 2016, which demonstrated at least a 60% decline in live coral.



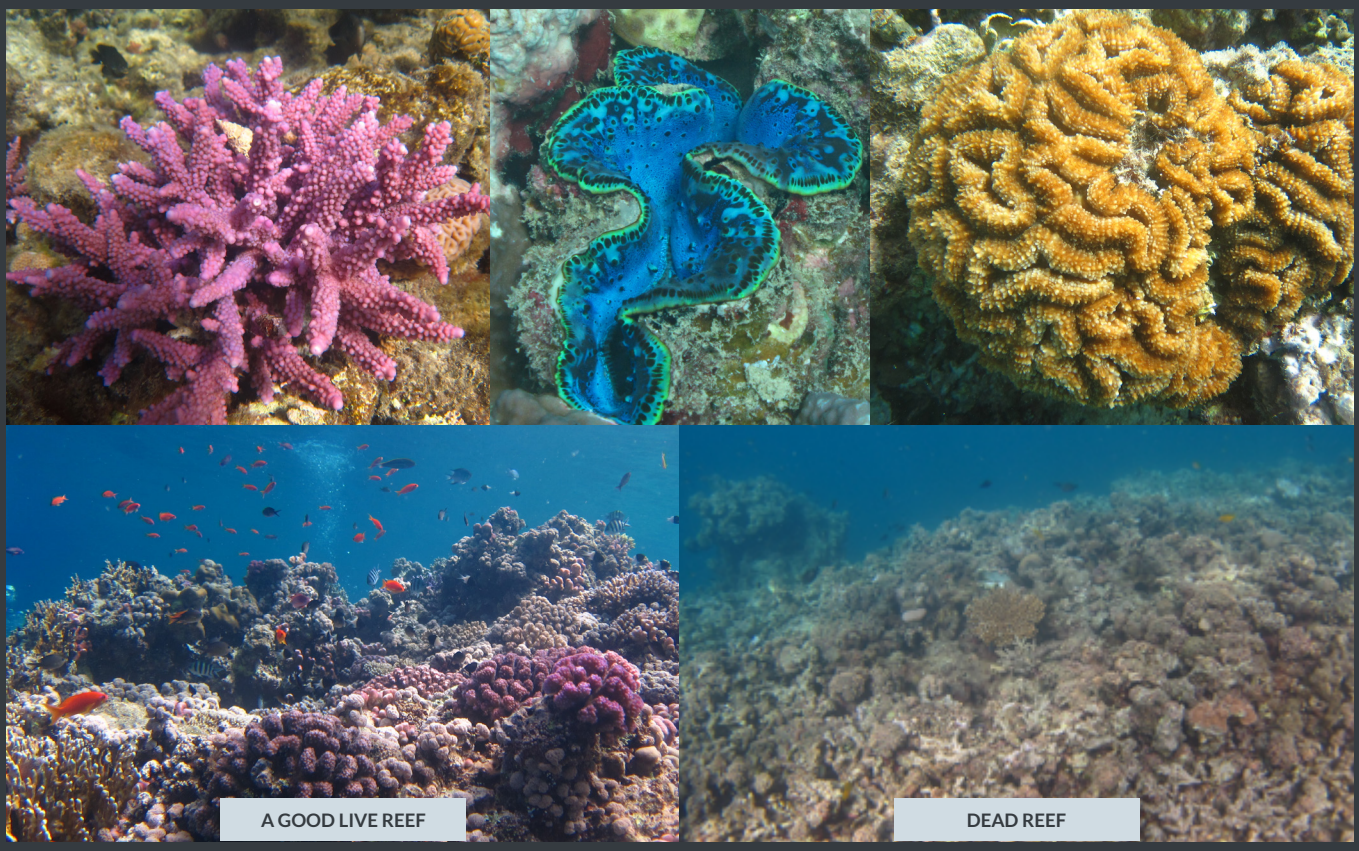
CHANGES IN REEF CREST CORAL COVER (3M)



CHANGES IN REEF SLOPE CORAL COVER (6M)

CHANGES IN LIVE CORAL COVER 2007 TO 2016

The reduction in live coral has taken place over a relatively large geographic area due to a combination of regional and local scale impacts, which are particularly pronounced along the central fringing reef where historical coral bleaching impacts are compounded by other factors which likely include predation by *Drupella* (a corallivorous snail), competition by sponges, disease, and potentially reduced water quality and increased sedimentation rates associated with the project.

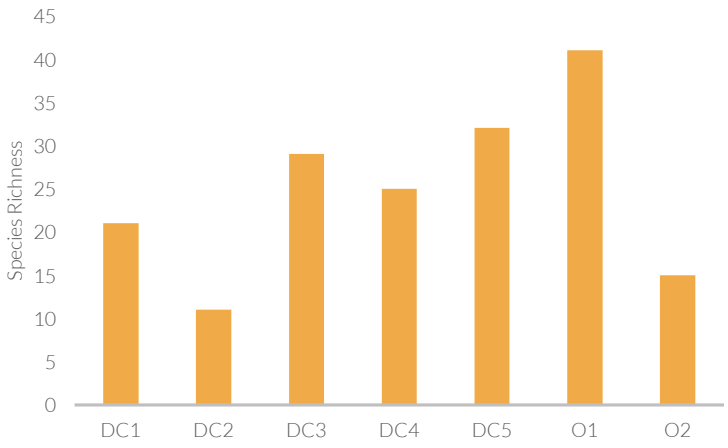


A GOOD LIVE REEF

DEAD REEF

3.7 // Other Benthic Fauna

The coral reef surveys also included non-coral invertebrates: sponges (Porifera), soft corals (Anthozoans), hydrozoans (Hydrozoa), bryozoans (Bryozoa), molluscs (Bivalvia and Gastropoda), echinoderms (Echinoidea and Holothuroidea) and ascidians (Ascidiacea). These fauna did not form the primary focus of the survey, with data collected incidentally using the methods applied to the coral survey. As a result a more detailed survey of cryptic fauna would likely result in an increase in the number of species recorded. In some instances species identification was also limited by available published reference material, or the limitations of using underwater photography to describe species, (as opposed to the collection and taxonomic determination which may sometimes be required to provide a comprehensive determination), particularly with regards to poorly described groups such as sponges. Species richness varied between locations, although no clear distinction existed between outer and fringing reef areas, although there was significant variation along the fringing reef itself.



At least 29 species of sponges were recorded number of which a number of genera were widespread: *Acanthella*, *Callyspongia*, *Hemimiycele*, *Hyrtios*, *Phyllospongia*, *Piona*, and *Siphonochalina*. There was no clear pattern in the distribution of species richness, with the outer reef and some fringing reef areas having similarly high numbers of species. The abundance of sponges was noted as high along the fringing reef, potentially indicating favourable conditions for sponges.

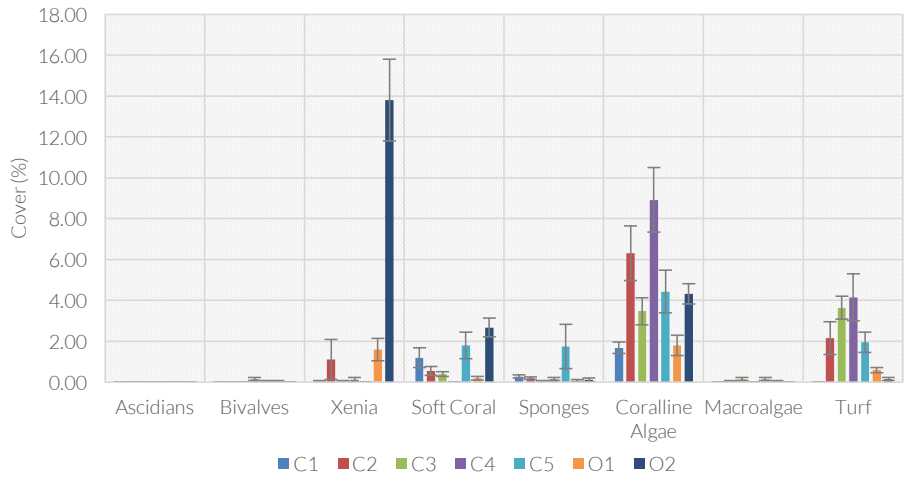
Soft corals were not overly abundant or diverse in the areas included in the survey. A total of 14 species of were recorded from 4 genera: *Sarcophyton* and *Sinularia* were relatively widespread in their distribution, along with *Xenia*, *Tubipora*, *Entacmaea* and *Palythoa*. Other genera were less well represented with *Capnella*, *Dendronephthya* and *Litophyton* rarely recorded. The highest number of species were recorded in outer reef areas, where up to 14 species were identified. Fringing reef areas typically had lower numbers of species ranging from 4 to 10 species. Hydrozoans were widespread with a total of 6 species identified. *Distichopora* and *Dyamena* were recorded at most stations. *Millepora* (fire coral) was less widespread and abundant than expected (typically *Millepora* are widespread and abundant components of Red Sea reef assemblages), with other hydroids also less well represented. Bryozoans were infrequently recorded with *Alcyonidium* present at one location.

Two classes of molluscs were recorded: bivalves and gastropods. Only 5 bivalves were recorded. the most widespread of which reef associated clams, (*Tridacna*) with *T.maxima* present at all but one of the survey locations. Other taxa including oysters were less commonly recorded. Gastropods were represented by 10 species with *Serpulorbis* and *Hyotissa* the most widespread. Species richness was highest at the outer reef survey location (9 species), with the fringing reef supporting up to 6 species in most locations.

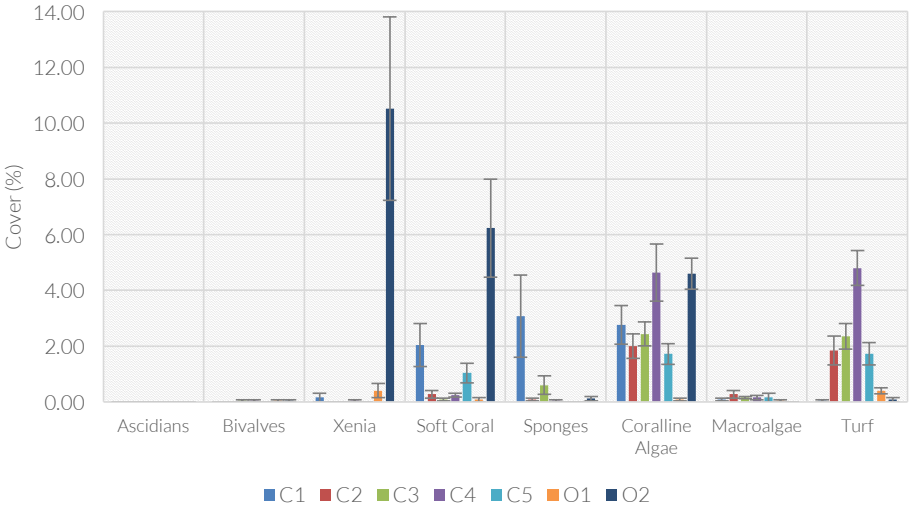
Echinoderms appeared relatively restricted in distribution which may be due to the areas within which the survey was focused: the reef crest and mid-slope, whereas echinoderms often favour reef flat, back reef and lagoon areas, or sand expanses at the base of the reef slope. Only three species were determined: *Diadema setosum*, *Echinometra mathaei*, and *Holothuria fuscopunctata*.

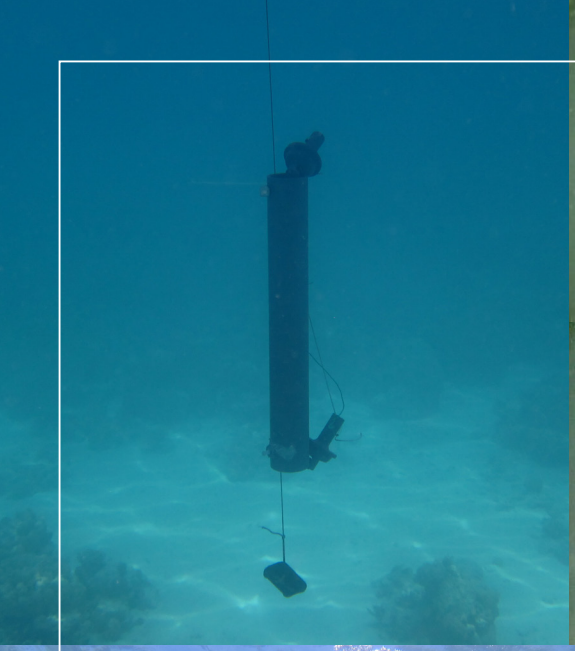
A total of 8 species of ascidian were identified, with betwee n1 and 5 species identified at the locations included. Living, non-hard coral, benthic cover varied considerably, between stations, clearly dominated by coralline algae soft corals, sponges and turf algae.

NON-CORAL COVER WITHIN REEF CREST SURVEYS (3M)



NON-CORAL COVER WITHIN UPPER REEF SLOPE SURVEYS (6M)









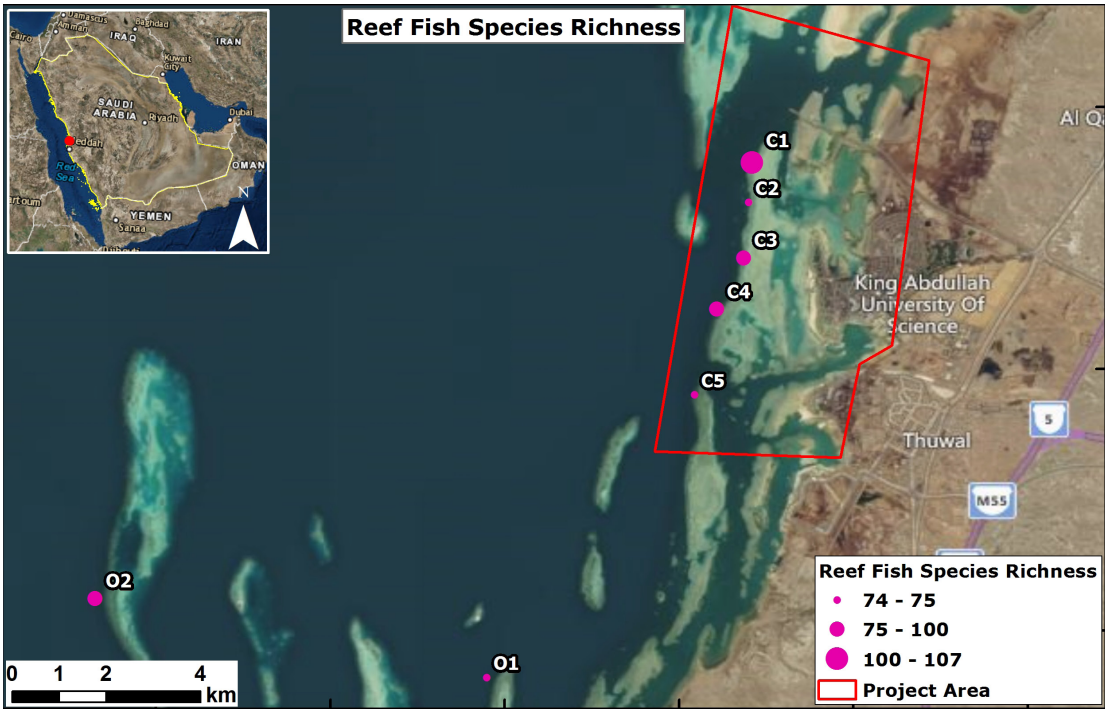

3.8 // Reef Fish

A total of 34 families of reef associated or at least semi-pelagic species found in the vicinity of coral reefs were recorded, accounting for a total of 176 species. Labridae (wrasses) were the most species rich family (n=32), followed by Pomacentridae (damselfish) (n=23), Scaridae (parrotfish) (n=12), Chaetodontidae (butterflyfish) (n=1), Serranidae (groupers) and Acanthuridae (surgeonfish) (n=10). All other families were represented by 7 species or less, with 11 families represented by a single species.

The number of species recorded were high at most stations surveyed, although those areas with the most degraded coral cover typically had the lowest numbers of species. The most species recorded at a single station was 107 (C1), the lowest was 74 (O1).

Large species were represented primarily by sharks (a single large blacktip reef shark was recorded in the centre of the KAUST fringing reef), eagle rays, bumphead parrotfish, juvenile humphead wrasse and some *Epinephelus* and *Plectropomus* groupers, as well as large carangids (golden trevally).

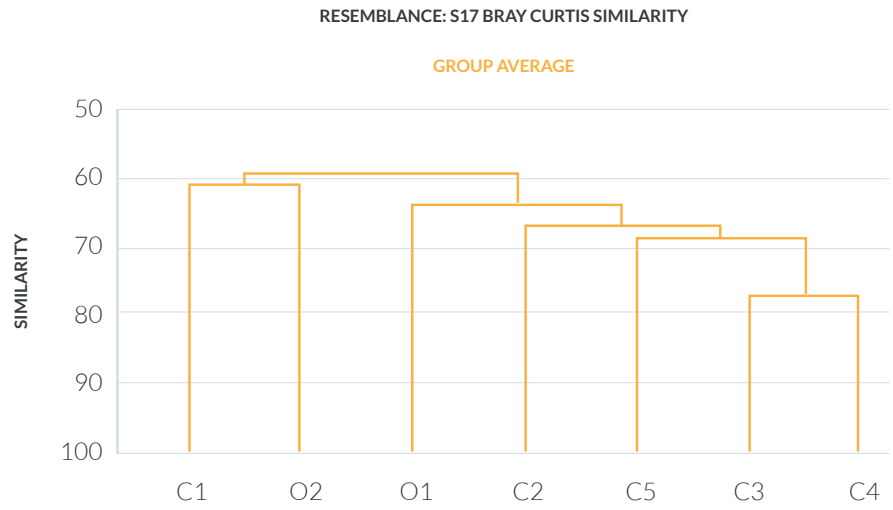
The communities present were largely similar as would be expected within a coral reef survey covering an area of the scale forming this study. The majority of species were recorded across all stations.



ANTHIAS - FAMILY SERRANIDAE

DAMSELFISH - FAMILY POMACENTRIDAE

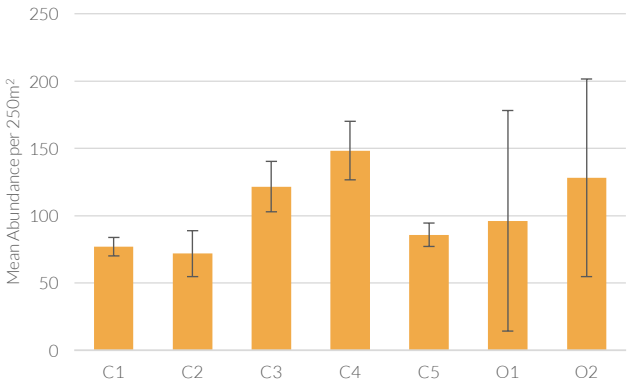
BUTTERFLYFISH - FAMILY CHAETODONTIDAE



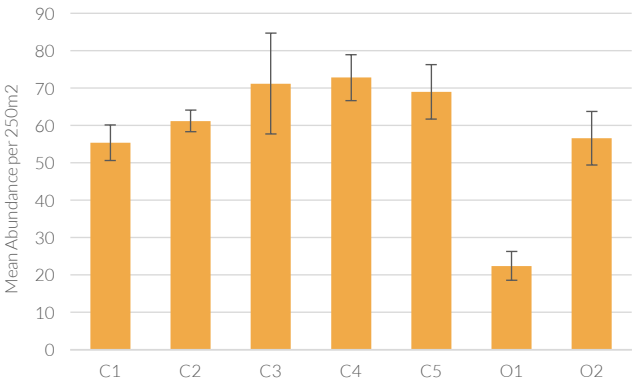
In shallow reef areas (reef crest) the abundances of fish varied considerably, albeit with no clearly defined patterns determined by locations (e.g. fringing versus outer reef locations). The abundances recorded ranged from 77 to 121 fish per 250m2 of reef area. The highest abundances were recorded in the middle of the fringing reef in front of KAUST (C4), with relatively high abundances also recorded at the outer reef (O2) and one other fringing reef location (C3). Abundances at other locations were considerably lower. Where abundances were high the contribution of a handful of species of snapper, emperor, and unicornfish to the counts were typically high, and of these several species *Lutjanus ehrenbergi*, *Lethrinus mahsena* and especially *Naso unicornis* were particularly prevalent.

Surveys of the reef slope highlighted that abundance was typically lower away from the reef crest, with the depth profile of the reef and the nature of the slope also influencing the overall abundances recorded (shallow reef where the slope meets the sea-floor tend to concentrate fish on the slope, whilst offshore locations which reach deeper depths may disperse fish over a greater reef area).

The highest abundance per reef area was recorded in the middle of the fringing reef, with very similar abundances (69 – 73 fish per 250m2) recorded at three of the stations (C4, C3, C5). Abundances at the nearest of the outer reefs (O1) was similar to those recorded at the two lower fringing reef stations (C2, C1). The outer reef in question was situated on a very shallow shelf with the 6m transect covering the seafloor at the base of the slope and therefore away from coral areas and rocky substrates. Specific details regarding individual families and species can be found within the main survey report.



REEF CREST SURVEYS

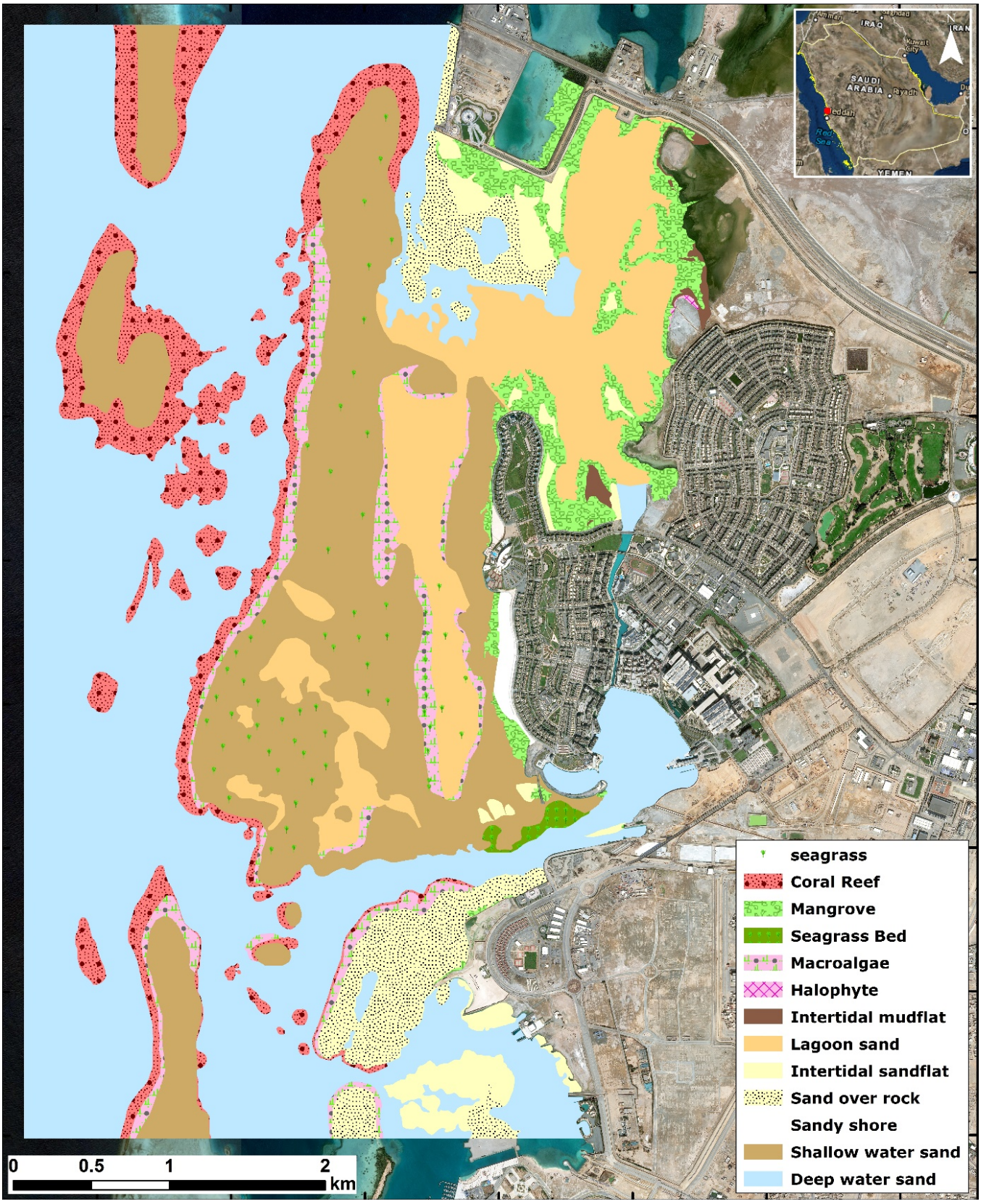


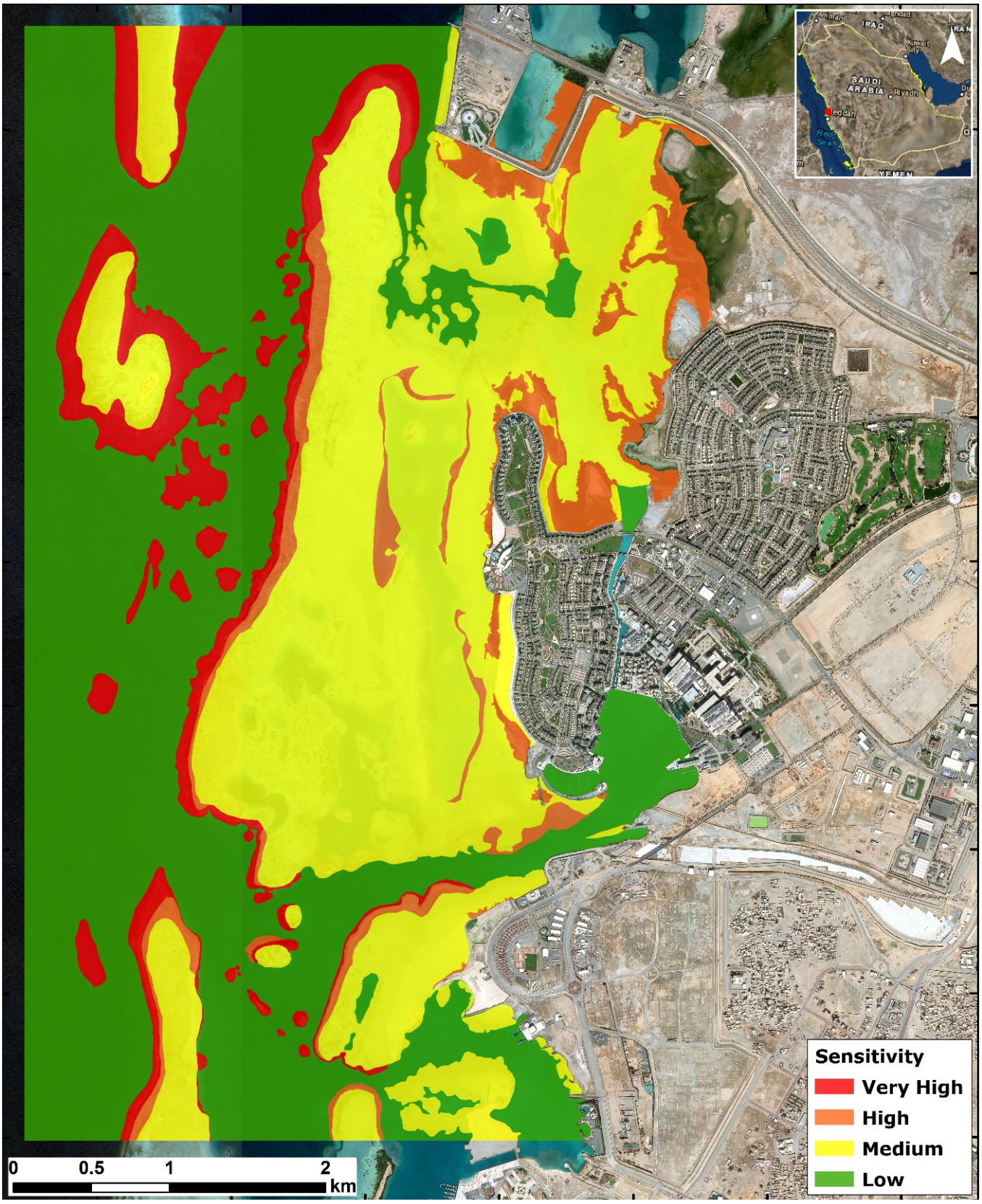
REEF SLOPE SURVEYS

3.9 // Habitat & Sensitivity Maps

The project also produced habitat and sensitivity maps for the area, which underlie the development of Key Ecological Attributes (KEAs) which form the basis of the Environmental Action Plan (EAP) report.

CLASSIFICATION	DESCRIPTION
Halophytic vegetation	A terrestrial habitat classification dominated by halophytes has been included to highlight the last remaining significant area of *Zygophyllum* and similar plant species recorded in the project area coastal zone.
Mangrove stand	Presence of mangrove trees, saplings and seedlings (*Avicennia marina*)
Intertidal sand and mudflats	Shallow gradient areas of sediment material exposed at low tide
Sand shore	Sand substrates at or above the high-water mark
Subtidal sand habitats	Areas below the low water mark where the seafloor is characterised by sand cover of varying thickens and coarseness.
Lagoon	Deeper water areas surrounded by raised fossilised reef matrix typically supporting sand cover with sporadic colonisation by sparse ecology: seagrass, corals or macroalgae.
Coral reefs	Areas where coral communities dominate the substrate: including live and dead coral areas.
Seagrass	Areas where either dense seagrass beds have been determined; or where sparse colonisation of seagrass has been determined alongside a more dominant classification (typically sand).
Macroalgae	Areas where dense macroalgae cover dominates the cover of an underlying rock platform; an area where macroalgae co-occur or border areas which are classified as coral reefs.


seagrass
Coral Reef
Mangrove
Seagrass Bed
Macroalgae
Halophyte
Intertidal mudflat
Lagoon sand
Intertidal sandflat
Sand over rock
Sandy shore
Shallow water sand
Deep water sand
0
0.5
1
2
km
IRAQ
IRAN
SAUDI ARABIA
Riyadh
Jeddah
YEMEN


IRAQ
IRAN
Kuwait City
SAUDI ARABIA
Riyadh
Jeddah
Red Sea
YEMEN
Sensitivity
Very High
High
Medium
Low
0
0.5
1
2
km