SUSTAINING DEVELOPMENT GOAL 14 – LIFE BELOW WATER

TARGET 14.1. REDUCE MARINE POLLUTION

Marine pollution is defined as the introduction of substances from humans into the marine environment resulting in such harmful effects as harm to living resources, hazards to human health, a hindrance to marine activities including fishing, impairment of quality for the use of seawater and the reduction of facilities. The majority of pollutants that make their way into the ocean come from human activities along the coastlines and far inland. One of the biggest sources of pollution is nonpoint source pollution, which occurs due to runoff. Nonpoint source pollution can come from many sources, like septic tanks, vehicles, farms, livestock ranches, and timber harvest areas. Pollution that comes from a single source, like an oil or chemical spill, is known as point source pollution.

One of the major objectives of SDG # 14 is to prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution by 2025. The following are some of the major accomplishments of the Applied Research Center for Environment and Marine Studies (ARCEMS) of the Research Institute of King Fahd University of Petroleum and Minerals (KFUPM-RI) in reducing marine pollution.

14.1.1. Compliance monitoring of developmental projects in the Arabian Gulf and the Red Sea to reduce marine pollution

The industrialization of coastal areas of the Saudi waters and related anthropogenic activities are known to have a wide range of potential effects on the coastal ecosystems. Hence, it is mandatory to conduct compliance monitoring to evaluate the environmental impacts of the operations in connection with any development activities in the coastal/marine areas concerning mitigation criteria and guidelines prescribed in the environmental impact assessment (EIA) report.

The ARCEMS has been contracted with many clients, including Saudi Aramco, to monitor environmental compliance in connection with the many development projects in the Arabian Gulf and the Red Sea. One of the important ongoing monitoring projects is The Red Sea Project (TRSP) on the western Red Sea coast of the Kingdom of Saudi Arabia.

The Red Sea Developing Company (TRSDC) is developing a luxury tourism and real estate project on the western Red Sea coast of Saudi Arabia referred to as The Red Sea Project (TRSP). The Red Sea Project aims to develop high-quality tourism facilities and experiences based around a group of islands within the Al Wajh Bank area, as well as terrestrial sites for tourism. TRSP site encompasses an archipelago of over 90 islands (Figure 1), 22 of which are planned to be developed over two phases. Of these islands, the three islands of Ummahat Alshaykh (9-3, 9-4 and 9-5) and Sheybarah South island are an integral part of TRSP's island assets that are planned to be built in its first phase and are planned to welcome tourists by the end of 2022.

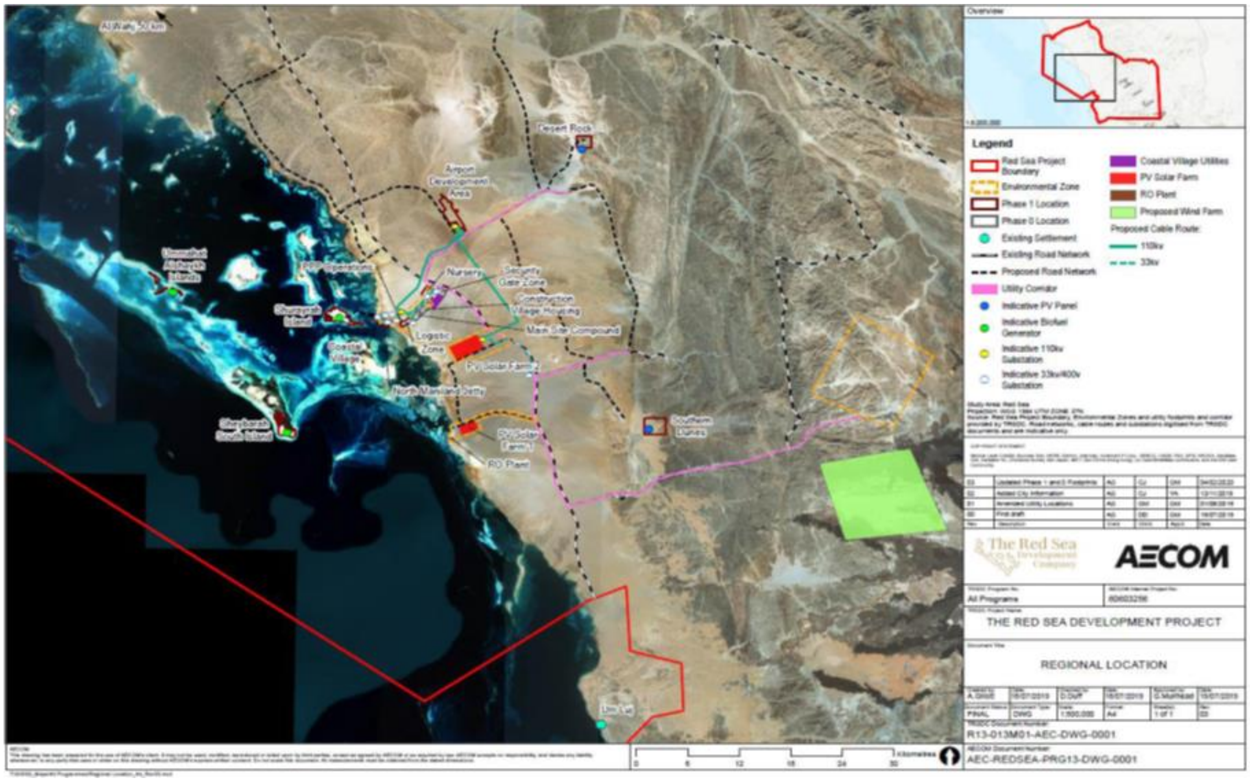


Figure 1. **Map showing the location of the project area on the Red Sea coast of Saudi Arabia.**

China Harbour Engineering Arabia Company Ltd (CHEAC) has been awarded the contract for dredging, reclamation, ground improvement and piling activities at Ummahat and Sheybarah islands by TRSDC. These activities are likely to negatively impact the air, terrestrial and marine environments and generate liquid and solid wastes. Therefore, conducting an Environmental Monitoring during construction period is required.

CHEAC contracted the ARCEMS to conduct the environmental compliance monitoring during construction to comply with the requirements and mitigation measures as stated in the Construction Environmental and Social Management Plan (CESMP), and Environmental and Social Impact Assessment (ESIA), and other local and regional environmental regulations. The objective of this study is to protect the environment in the vicinity of the construction activities in accordance with the environmental rules, regulations and standards of the Kingdom of Saudi Arabia and TRSDC environmental policies.

The ARCEMS, which has extensive experience in conducting environmental monitoring for similar projects, proposed to conduct the monitoring study in accordance with the monitoring plan ad CESMP recommended and approved by TRSDC. The construction activities are in progress at Sheybarah Island. The KFUPM and CHEAC environmental monitoring teams have been carrying out compliance monitoring in and around Sheybarah Island daily. The details of the major monitoring tasks are summarized in Table 1.

Table 1. Details of various monitoring tasks, description of the tasks, and monitoring frequencies being implemented by KFUPM/RI

Tasks	Description and parameter	Frequency and stations
Sea Water and sediment quality	Continuous in situ - mooring buoys	Continuous
	Compliance in situ water quality	Daily
	Turbidity and TSS	Weekly
	Contaminants	Biweekly
	Chl, Nutrients and total coliforms	Biweekly
	Sediment trap	Monthly
	Grain size	Biweekly
Intertidal walk surveys	Walk surveys for litter, scum, sheen, erosion, mangal habitats, turtle etc.	Weekly
Shoreline Ecology Watch and Surveys	Watch surveys for terrestrial flora, fauna, mammals etc.	Monthly
Marine ecology	Macrobenthos	Quarterly
	Corals	Quarterly
	Seagrass	Quarterly
	Mangroves	Quarterly
	Habitat mapping	Once
	Mammal survey	Daily
Waste management	Visual inspection	Daily
Air quality	Visual check for smoke, dust, off-road driving etc. Air quality measurement for fugitive dust and emissions	Biweekly
Noise	Onshore noise	Biweekly
	Underwater noise	Monthly
Environmental Awareness Training	Environmental awareness training	Monthly

KFUPM monitoring team has a lead role in protecting the environment in the development site. The compliance monitoring confirmed minimum or no impact on the environment due to the construction related activities. The sensitive habitats including corals are in healthy conditions (Figure 2) at the site.

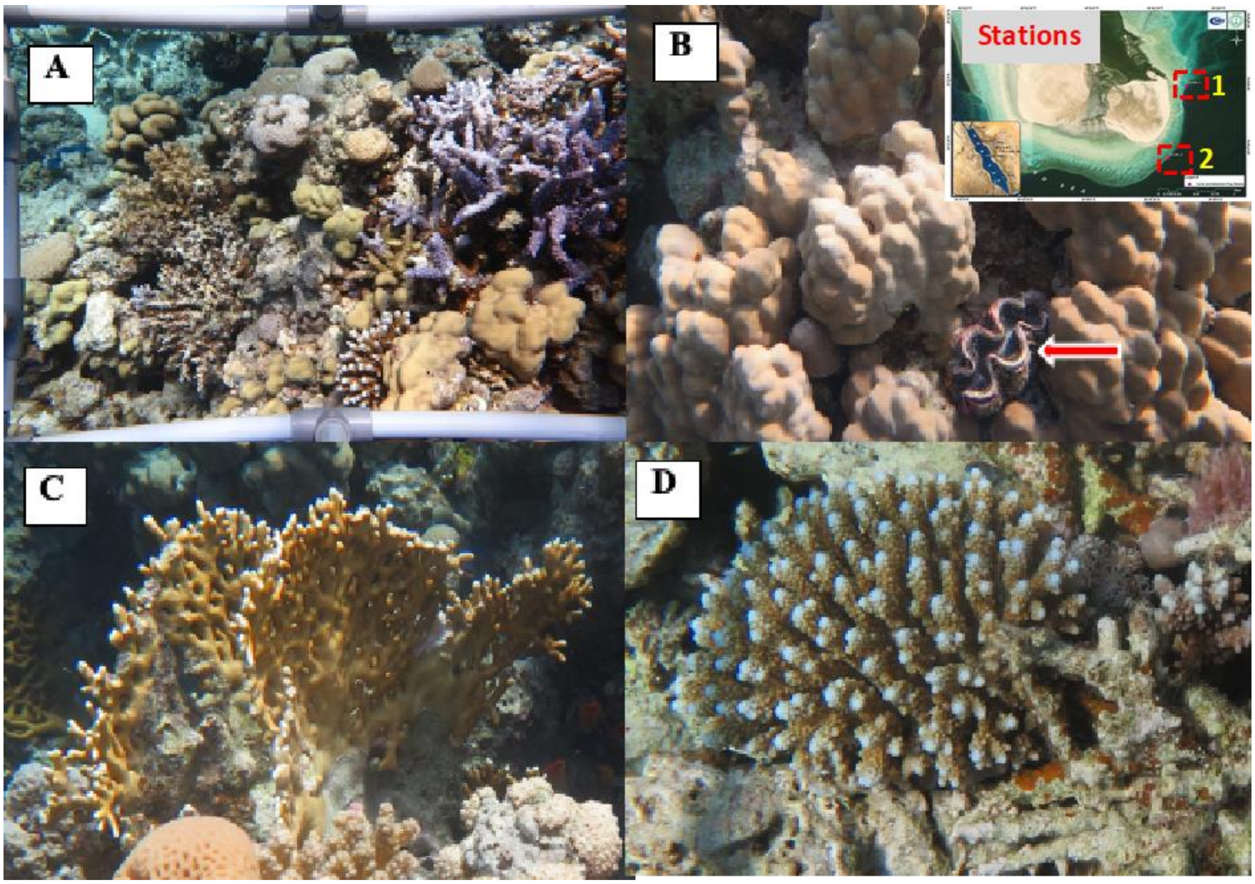


Figure 2. Underwater photographs showing Coral Reefs in the development area

14.1.2. Conducting regular toxicity tests of drilling muds to avoid disposal of toxic drilling mud

Offshore oil-well drilling has been a subject of great interest to environmental regulatory agencies worldwide. The drilling fluids used in this process involve a complex mixture of chemicals and are discharged mainly into the ocean. Different kinds of drilling fluids may be used, including water, bentonite mud, cutting oil, and polymers, which are categorized (according to their main component) as water-based fluids (WBFs), oil-based fluids (OBFs), or synthetic-based fluids (SBFs). Particles and other chemical components present in the formation cuttings may be incorporated into the drilling fluid. These become the primary type of waste related to drilling fluid due to the large volumes that are generated and discharged. For this reason, the toxicity of drilling fluids is of concern to regulatory agencies, which require biological testing of the effect of the whole mix and the individual components of drilling fluids. Toxicity tests are important for assessing the effects of complex chemical mixtures, such as waste drilling mud, on aquatic ecosystems. When waste drilling mud is released into the marine environment, strong ocean currents perhaps separate the drilling mud into a solid phase (SP) and a suspended particulate phase (SPP). The ARCEMS is conducting toxicity assays of SPP using mysids (Figure 3). Only those mud samples that have passed the test are allowed to be discharged, thereby reducing the release of contaminated mud into the water column.

Figure 3. Ecotoxicology laboratory conducting SPP tests using mysids.

14.1.3. Environmental monitoring buoy and mooring with telemetry: continuous monitoring of crude oil

Instrumented moorings (hereafter referred to as moorings), which are anchored buoys (Figure 4) or an anchored configuration of instruments suspended in the water column, are highly valued for their ability to host a variety of interchangeable oceanographic and meteorological sensors. The ARCEMS, with funding from Saudi Aramco, deployed mooring buoys in two strategic locations covering the coastal areas (north and south) of the Arabian Gulf. In addition to sensors for measuring pH, temperature, salinity etc. these buoys continuously monitor the concentrations of oil in water from the surface.

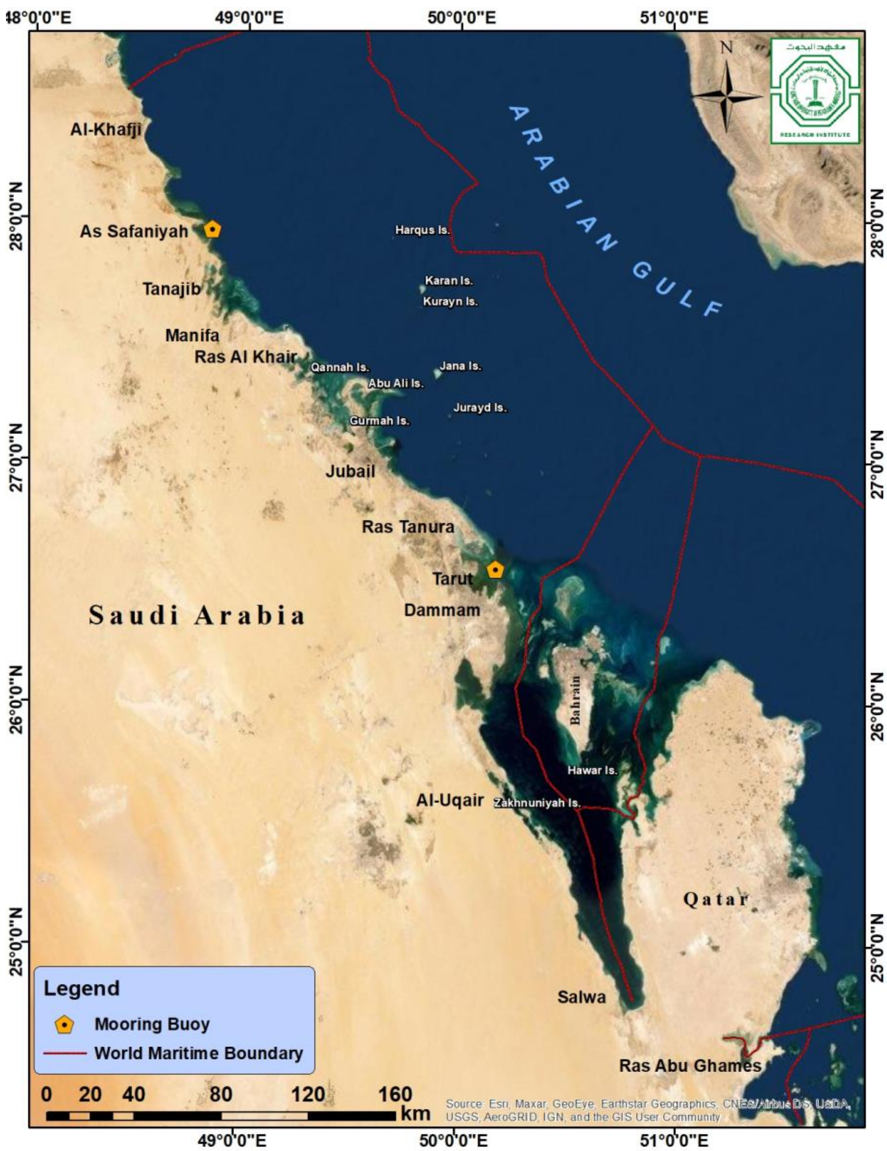


Figure 4. Mooring Buoy locations in the Saudi waters of the Arabian Gulf

14.1.4. Monitoring and assessing the Marine environment in the vicinity of offshore facilities in the Arabian Gulf

Saudi Arabia operates offshore facilities in the Arabian Gulf for oil extraction, production, and transportation. These offshore operations present a potential risk of polluting the marine environment with crude oil and chemicals. Regular monitoring serves to detect adverse conditions on time to allow for mitigation measures. The ARCEMS commenced this study in 2013, and continued with annual surveys until 2018 to monitor the environmental conditions in the vicinity of offshore facilities in the Arabian Gulf, as well as in the coastal areas close to some discharges. The main aim of this study was to ascertain whether the installations in the nearshore and offshore areas of the Arabian Gulf (Saudi waters) cause any changes in the marine environmental quality, among others, as a result of their presence and functioning. The study involved the collection of seawater, sediment, and biological samples at selected stations located in the vicinity of these facilities as well as along the coast and the determination of environmental contaminants such as trace metals and organic contaminants. Around 19 offshore sampling areas constituting offshore gas oil separation plants (GOSPs) and offshore oil well, platform clusters were included for the sampling.

TARGET 14.2. PROTECT AND RESTORE ECOSYSTEMS

Life on the planet depends on oceans. They hold almost three-quarters of the planet and hold 97% of the Earth's water. The phytoplankton that live on the oceans' surface produce half of the oxygen in the atmosphere. Oceans are a vital source of food and other resources, and an economic engine for many communities. For all the oceans provide us, we have not always been so responsible in our stewardship. Human activities are having a negative impact on many of the world's oceans, jeopardizing marine life, habitat, and ecosystems. These threats include overfishing or destructive fishing, coastal development, pollution and runoff, and the introduction of non-native species. Climate change is also having a big effect by causing warming seas and ocean acidification.

The coastal zone of Saudi Arabia, in particular, is a valuable resource, which is increasingly stressed by the activities of man. Marine ecosystems, and in particular nearshore coastal ecosystems, are subject to a variety of physical and chemical stressors, both natural and anthropogenic (Adams, 2005; Khan, 2007). The anthropogenic stressors include pollutants, nutrients, increased turbidity and suspended sediments, and altered habitats and hydrologic regimes. Natural stressors include seasonal temperature and salinity changes, as well as overall increased water temperatures due to global warming. These stressors, acting singly, cumulatively and/ or synergistically can affect biota and ecosystems. Urbanization, related coastal development, dredging, land reclamation, the growth of oil, power, desalination, and petrochemical industries and shipping pollution are all potential stressors on the coastal environment (Hoepner and Lattemann, 2002). All of these factors impact on the marine ecosystems of the Saudi Arabian coastal zones and territorial waters in the Arabian Gulf. Furthermore, global warming and climate change can be expected to affect the Gulf marine ecosystems. Unfortunately the management structures of the Gulf region are highly sectorial and fragmented, both within and beyond national boundaries.

The Kingdom has formulated the needed environmental organizations, particularly with the recent formation of the Ministry of Environment, Water and Agriculture (MEWA). The Kingdom has also signed relevant marine international treaties and has developed adequate environmental regulations with the required laws and framework to protect marine and coastal resources. The Kingdom is also an active member in most of the regional and international organizations concerned with marine protection, such as ROPME, FAO and IMO.

At the voluntary level, there are several ecosystem restoration initiatives conducted by governmental organizations and Saudi Aramco, e.g., the long-lasting mangrove plantation efforts conducted by Saudi Aramco, Saudi Wildlife Authority and MEWA in the Kingdom's coastal areas. Another coastal restoration program was conducted under the United Nations Compensation Commission (UNCC) of the Gulf War to restore key shoreline habitats damaged by the 1991 Gulf oil spill. Under this program, more than 20 coastal locations were remediated by in situ tilling and mixing techniques in addition to mangrove plantation in these locations.

To protect the coral reefs of the Gulf, Saudi Aramco deployed the coral reef buoy anchoring systems in offshore areas. Also, Saudi Aramco has deployed artificial reefs in many areas of the Gulf to reduce diving pressure on natural coral reefs and to enhance biodiversity. The company has also planted two million mangrove trees throughout the Gulf 's coastal areas. In addition, there are many organized activities to restore critical habitats such as the cleanup of offshore islands, and wildlife rehabilitation plans during oil spills. Saudi Aramco also has designated “Biodiversity Conservation Areas” that contain important coastal biodiversity.

The Applied Research Center for Environment and Marine Studies (ARCEMS) of KFUPM works closely with Saudi Aramco through sustaining environmental research projects and other applied research projects in the protection and conservation of the marine environment of Saudi Arabia.

Some of the efforts are summarised below:

14.2.1. Mangrove Ecopark - creating awareness to protect the Gulf’s mangroves

Mangroves are intertropical coastal forests whose trees – also known as mangroves – grow with their roots in the water. Between 1980 and 2010, mangrove forests shrunk by 35% worldwide, with the biggest losses in Southeast Asia and Africa. Currently, an area equivalent to 150,000 soccer stadiums is destroyed each year. The world’s 150,000 square kilometers of mangroves are home to many animal and plant species, including crabs, fish, crustaceans, birds, snakes, monkeys, algae and shrubs, which risk disappearing with the forests. Mangroves also filter water and inhibit coastal erosion. And the sediment in their soil has an unparalleled ability to absorb greenhouse gases, helping to limit global warming. In order to raise awareness of this unique ecosystem and the essential role it plays, the ARCEMS, with funding from Saudi Aramco involved in the development of the first mangrove eco-park in the Kingdom, protecting 64 km2 of marine habitats, including mangrove forests, salt marshes and seagrasses – all important nurseries for fish and shrimp. This eco-park will help foster knowledge and appreciation of this fragile ecosystem and consists of a visitor center, trails, and boardwalks, with various observation and education points. A portion of the park is also designated for research activities.

Figure 6. Mangrove Ecopark in Ras Tanura, Saudi Arabia

14.2.2. Silt screens (Turbidity Curtains) – mitigation measures

The largescale coastal and marine development activities in connection with the oil and gas and other anthropogenic activities in the Saudi waters of the Arabia Gulf and the Red Sea are prone to impact the marine environment. Ongoing industrial development continues to cause concern to marine environment quality.

The major construction activities like dredging, trenching, or reclamation in these development projects are likely to negatively impact the marine environments by increasing the turbidity and suspended sediment load. Hence, as a part of the mitigation measures to reduce turbidity, silt curtains are recommended in the construction area.

A turbidity curtain (Figure 1) is a flexible, impermeable barrier that traps sediment in water bodies. This curtain is generally weighted at the bottom to ensure that sediment does not travel under the curtain, which is supported at the top through a flotation system. Turbidity curtain/barriers are used in dredging, marine construction, and environmental remediation projects to control the sediment and silt in a body of water.

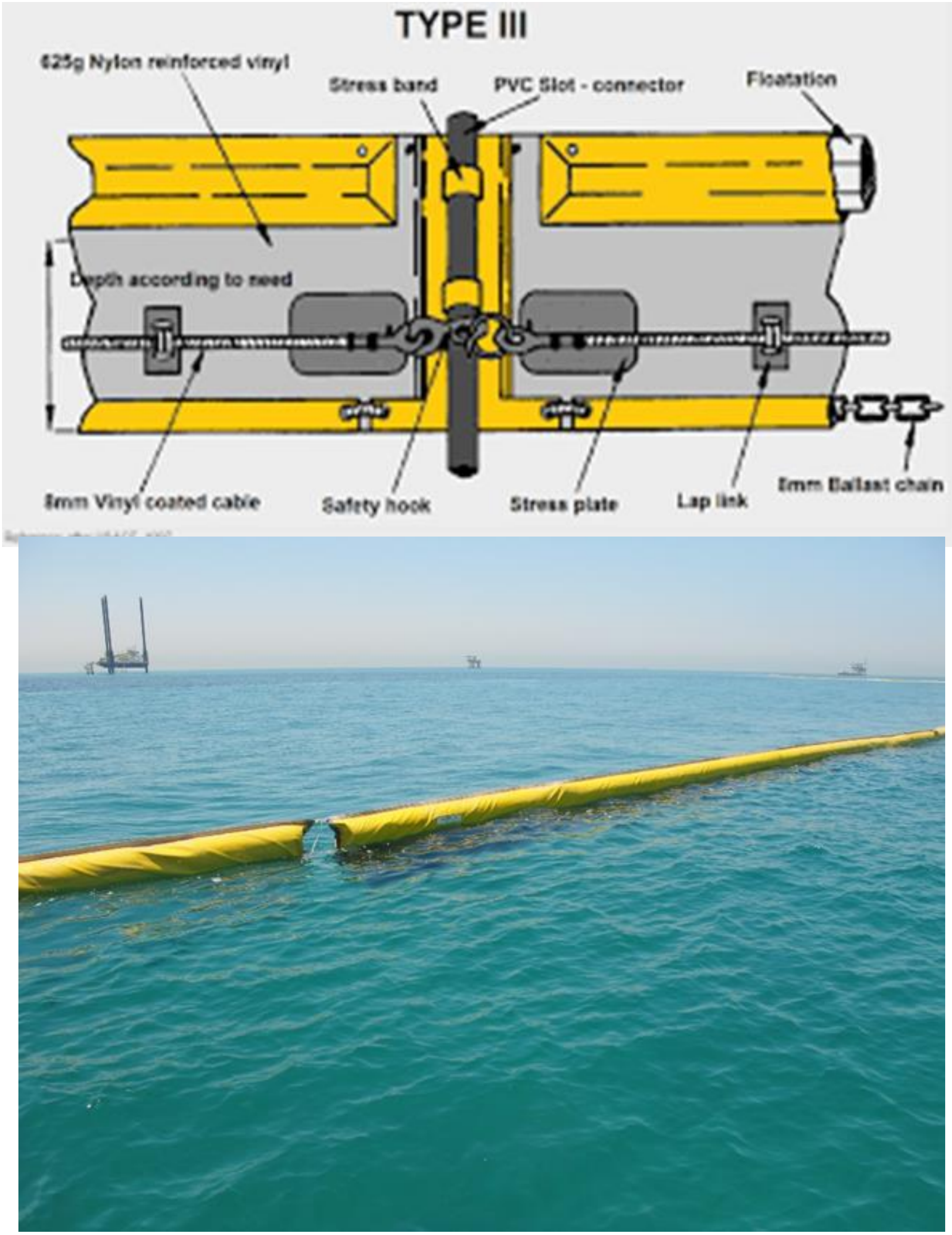


Figure 1. A Silt Curtain (top) and a silt curtain in Safaniyah (Bottom)

Deployment of silt curtains is one of the most reliable and effective methods to control the spread of the turbidity plume from the activity areas. So as part of the mitigation measures, silt curtains of different lengths and sizes will be recommended to deploy on the construction sites before dredging/trenching or similar activities. During the compliance monitoring visits, the KFUPM monitoring team inspects the location of the silt curtain, size, length, depth and effectiveness of the silt curtain and inform the contractor if it notices any noncompliance issues. The monitoring team will also measure the turbidity level inside and outside the silt curtain and verifies the effectiveness of the silt curtain.

Figure 2. A view of the deployed silt curtain around the trenching site in Safaniyah

Figure 3. A view of the deployed silt curtain around the trenching site in Abu Ali

14.2.3. Recommending offset programs

In recent years, biodiversity offsets have gained increasing attention as both the public and private sectors strive to protect biodiversity from the loss caused by development projects and activities. Since the 1970s, biodiversity offset programmes have been used in several countries to mitigate damage to wetlands. Over 100 countries have laws or policies that require or enable the use of biodiversity offsets or are considering their use. Therefore, it is important to examine the lessons from the experience of biodiversity offset programmes to date and how they can be improved in the future.

The concept of biodiversity offsets refers to measurable conservation outcomes that result from actions designed to compensate for significant, residual biodiversity losses resulting from the implementation of developmental projects. They are intended to be implemented only after reasonable measures have been taken in order to prevent and minimize the biodiversity loss at a development site. A biodiversity offset is an approach based on the premise that the impacts of development can be mitigated by protecting, enhancing, or establishing habitat elsewhere. The biodiversity offsets are economic instruments and are based on the polluter pays principle. Their objective is to internalize the external costs of biodiversity loss associated with development projects by placing a cost on activities that cause adverse effects on biodiversity. A common objective of offset programmes is to achieve No Net Loss (for example, of habitat, species, ecological status, or ecosystem services), although some programs have adopted a more ambitious goal of Net Gain.

14.2.4. A case study from the Western Arabian Gulf Coast (Saudi Arabia):

An Environmental Impact Assessment (EIA) study was conducted by the Center for Environment and Marine Studies (CEMS), KFUPM, for a Saudi Aramco oil and gas development project located in the Marjan field, Saudi Arabia, in 2019. The proposed trenching route (for burying submarine pipelines/cables) overlaps extensive areas of dense seagrass communities (mean cover of 58%). It was predicted that seagrasses would be destroyed along the trenching route and in the sidecast area. As a result of the loss of seagrass feeding grounds in the area, green turtles in the area will suffer a similar impact. Seagrasses are expected to gradually recover over the course of the Project's lifespan (more than 40 years), possibly within five years. The residual direct and indirect impacts are estimated to around 345 Quality Hectares of seagrass bed, and for associated Green Turtles – for which this is the key habitat.

14.2.5. Recommendations for voluntary seagrass offsets

A quantified offset may not be required for this project under Saudi Aramco policy as there is expected to be full recovery to seagrass within the 40-year Project lifetime. However, the Project may still want to undertake offset measures to identify an appropriate level of compensation required under national regulations and to account for uncertainty in the scale of impacts and efficacy of mitigation measures.

Therefore, in the EIA, it was recommended to establish a Biodiversity Protection Area (BPA) to cover 2,250 ha of the extensive seagrass beds off Safaniyah (Figure 1), aligned with an existing requirement for the nearby Safaniya Project as voluntary offset mitigation. The designation will enhance the long-term security and value of this area as a Partner Protected Area in the future. An offset of this type could be aggregated for several projects in the area, including those in Marjan, Zuluf, and Safaniya, which would reduce costs and increase the likelihood of achieving a positive outcome for marine biodiversity.

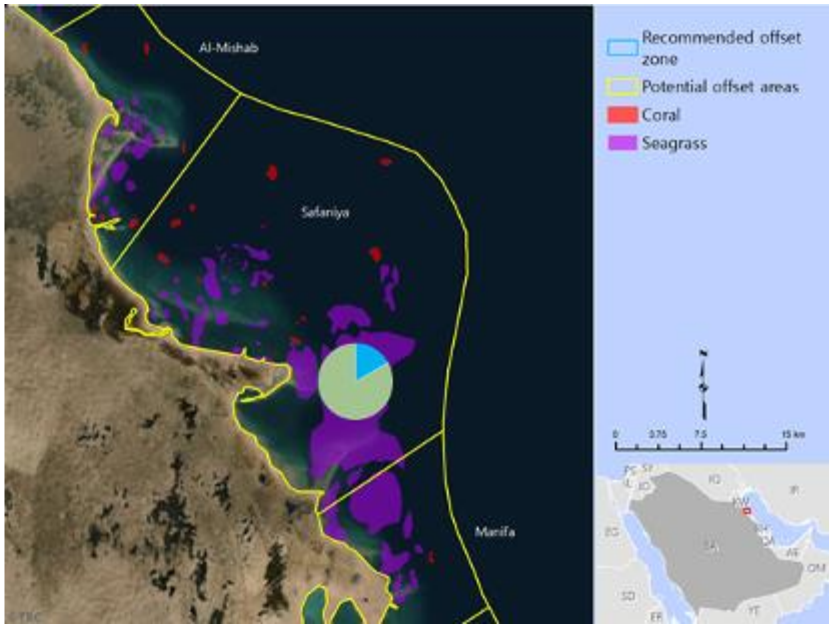


Figure 1. Recommended zone and indicative area for the establishment of a seagrass protection offset. The pie chart sections indicate the relative offset area for Safaniya Project (blue) and Marjan Project (green).

14.2.6. Long term Coral reef monitoring - **Mr. Reylindo**

14.2.7. Annual Comprehensive marine monitoring of Petro Rabigh

Rabigh is home to Rabigh Refining and Petrochemical Company (Petro Rabigh), located 165 kilometers north of Jeddah on the Red Sea coast. With its deep-water port, the company utilizes the opportunity of the easy reach of the Asian and European markets. Loading and offloading petroleum and petrochemicals through its marine terminals and increased shipping activities make the Rabigh marine ecosystem vulnerable to environmental impacts.

Figure 1. Stations occupied for Annual compliance monitoring in Petro Rabigh.

Monitoring Petro Rabigh was imperative for the company. Hence a long-term contract was established between Petro Rabigh and the ARCEMS in 2010 covering five years (2011-2015) period in order to perform annual environmental compliance surveys and bioaccumulation studies. Subsequently, a similar contract with the same objectives was awarded to the ARCEMS for another five years (2016-2020). The annual studies were conducted to assess the present condition of seawater, sediment, and sensitive ecosystems and its biota within the vicinity of Petro Rabigh coastal and marine waters. Studies were conducted to detect and characterize any releases of contaminants into the sea due to the operation of Petro Rabigh. The health status of mangrove, saltmarsh, intertidal and coral ecosystems were assessed based on surveys and studies conducted at permanent monitoring stations. Bioaccumulation of environmental contaminants such as trace metals and petroleum hydrocarbons were studied using shell fishes and reef fishes collected from the study area. The survey and studies helped Petro Rabigh assess the changes in baseline conditions and also identify potential problems due to operational activities and take corrective actions.

TARGET 14.3. REDUCE OCEAN ACIDIFICATION

14.3.1. Temperature and Salinity data loggers

By the year 2100, climate change is projected to be associated with an increase in oceanic surface temperature of more than 3 °C and a decrease in the global mean sea surface pH of up to 0.32 units. Ocean warming (OW) and acidification (OA) are two of the main stressors causing significant changes in marine environments, posing a major threat to species that generate and accumulate calcium carbonate structures, such as corals, and decreasing the socioeconomic value of ecosystems dependent on calcifying organisms. The nearshore coastal ocean is one of the most dynamic and biologically productive regions on our planet, supporting a wide range of ecosystem services. It is also one of the most vulnerable regions, increasingly exposed to anthropogenic pressure. In the context of climate change, monitoring changes in nearshore coastal waters requires systematic and sustained observations of key essential climate variables (ECV), one of which is sea surface temperature (SST). As temperature influences physical, chemical and biological processes within coastal systems, accurate monitoring is crucial for detecting change. SST is an ECV that can be measured systematically from satellites. Yet, owing to a lack of adequate in situ data, the accuracy and precision of satellite SST at the coastline are not well known. The center has deployed temperature data loggers in strategic coral reef locations such as Jana, Manifa and Abu Ali. The data from these loggers will help researchers understand the dynamics of sea surface temperature in the Arabian Gulf.

TARGET 14.4. SUSTAINABLE FISHING

14.4.1.

Dr. Rommel’s

TARGET 14.5. CONSERVE COASTAL AND MARINE AREAS

The coasts of the Arabian Gulf and Red Sea are witnessing rapid industrialization and urbanization that contribute to the degradation of naturally stressed marine ecosystems. Coastal and marine environments are affected by intensive dredging and reclamation activities, and several sources of pollution. Due to its unique environmental setting, the Red Sea and Arabian Gulf are increasingly receiving international scientific interest to study the effects of environmental extremes on marine organisms, and to investigate the potential impacts of future climate change on the ecological integrity of marine ecosystems. The following are the initiatives from the Center in protecting the fragile coastal and marine ecosystems in the Red Sea and Arabian Gulf.

14.5.1. Design changes for Manifa Causeway (Manifa Bay protection)

Background: Saudi Aramco proposed the construction of a Causeway to access the drilling sites at the mouth of Manifa Bay (Fig. 1). The main Causeway, which is about 20 km long, connects with drilling site islands through subsidiary routes. The total length of the lateral Causeways and coastal offshoots is about 23 km. Manifa Bay is an ecologically sensitive region and is known to be a nursery for shrimps, and various species of corals and seagrass. The modeling study was, thus, envisaged to estimate the impact of the construction activities. Likely impediments the artificial structures can cause to the local circulation can best be studied by developing computer models that simulate flow conditions when the structures are in place. KFUPM undertook modeling studies covering hydro-dynamics, sediment transport, and water quality aspects before and after the Causeway construction.

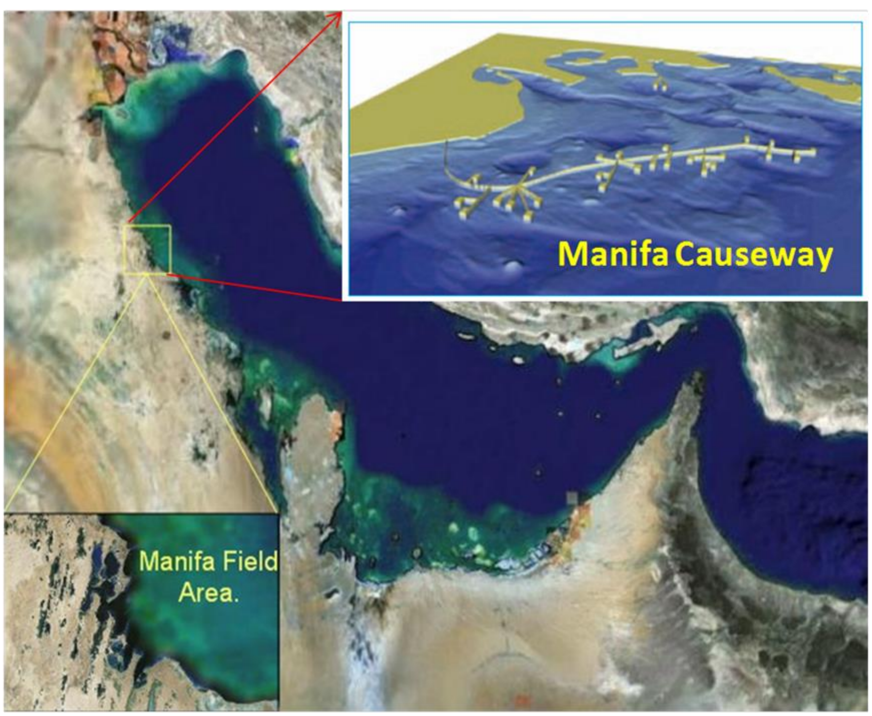


Fig. 1. Manifa Causeway site.

Model details: The DHI modeling package was utilized to investigate coastal circulation, waves and sediment transport in the Manifa Bay with a flexible grid (Fig. 2). The DHI modeling suite includes state-of-the-art modeling tools such as Mike-21 for 2D hydrodynamic and wave modeling and ECOLAB for modeling environmental conditions. Modeling and monitoring studies components were:

- Circulation (Hydrodynamics)
- Waves
- Sediment transport
- Water quality

For the Causeway design purpose, hypothetical tracer concentration initial fields (Fig. 3) were generated. Simulation for 16 days was performed as a control run to identify the distribution of the tracer concentration in the absence of the Causeway. Subsequently, simulations were performed for the same period with different Causeway designs (Table 1). Later, realistic modeling studies were carried out, for the optimal design of the Causeway using data obtained from surveys during the design phase and post-construction period.

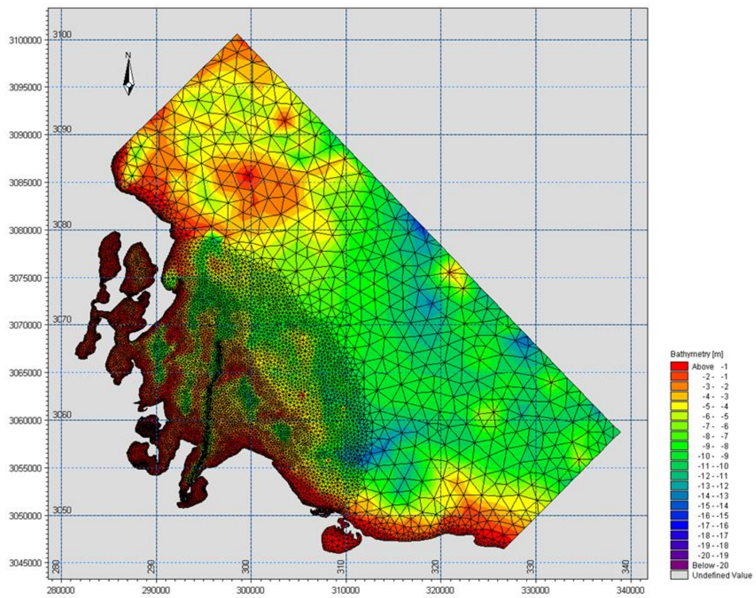


Fig. 2. Modelling domain and grid.

Table 1. Causeway design criteria.

Case	Description
A	No Causeway
B	Causeway with no openings
C	20% opening as main culverts only

D	Long bridge in the southeast (2 m contour depth (CD) to drill sites 21/22)
E	Short bridge in the southeast (3 m CD to drill site 20)
F	With 20% openings in the main Causeway as in case D
G	5% openings in the main Causeway and 1 km short bridge in southeast
H	A short bridge in the southeast (3 m CD to drill site 20) and 5% openings in the main Causeway
I	2.5 km short bridge in the southeast and openings in the form of short bridges (150 m) and culverts (50 m)

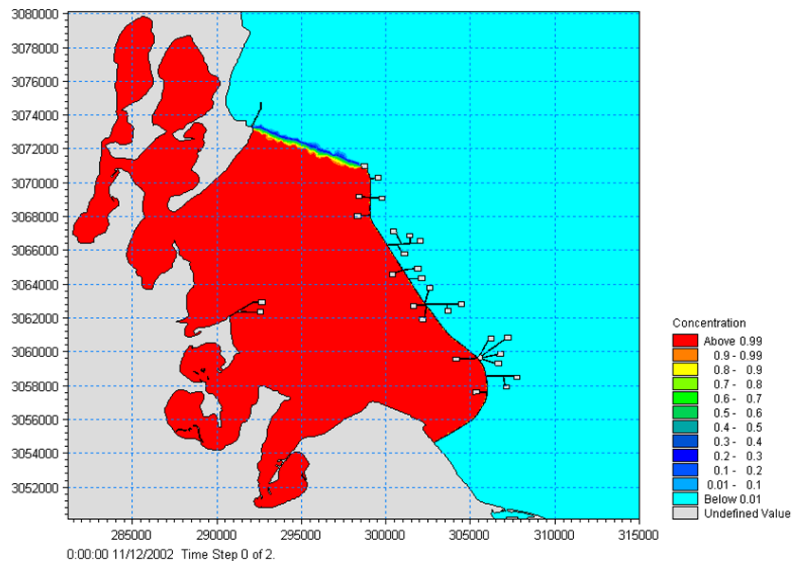


Fig. 3. Initial tracer concentration

Results: Optimization of Causeway Design:- Case A estimates the ideal tracer concentration pattern in the absence of any Causeway. Different Causeway designs alter the model circulation in the region and hence tracer concentration field and flushing time of the bay (Fig. 4). In the optimal design (case I) the concentration field closely resembles that of the control run. Furthermore, the modeling study predicts quick flushing of the bay after the construction of the Causeway (Table 2).

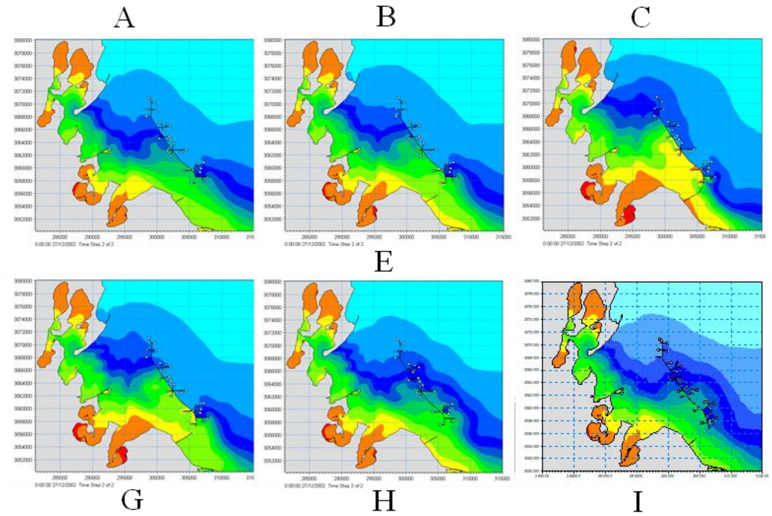


Fig. 4. Tracer concentrations after 16 days for different Causeway designs.

Table 2. Mean tracer concentration and residence time.

Case	Mean	$T_{50\%}$*
A	0.52	17
B	0.85	71
C	0.57	20
D	0.56	19
E	0.61	22
F	0.71	33
G	0.66	26
H	0.58	20
I	0.48	15

Environmental impact of causeway: The salinity difference predicted during the design phase was lower compared to that obtained in the post-construction modeling investigation (Fig. 5). The residual surface current intensifies at the Causeway openings. However, its impact on the flushing rate was minimal (Fig. 6). The Causeway also modifies the sedimentation rate. Modeling investigation shows that the seabed thickness could change by more than 5 mm at some locations over a year (Fig. 7).

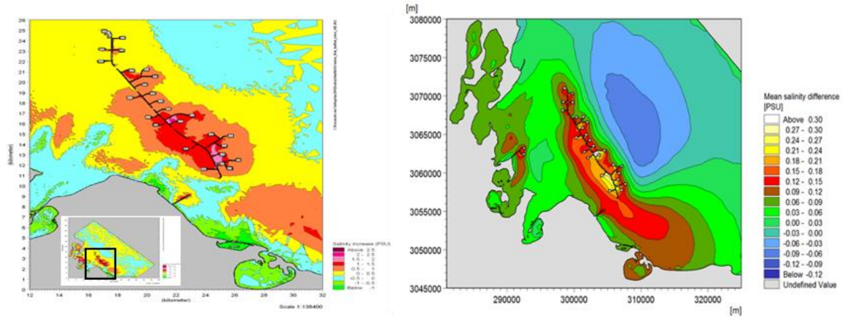


Fig. 5. Salinity difference predicted during the EIA (left) and after the construction (right).

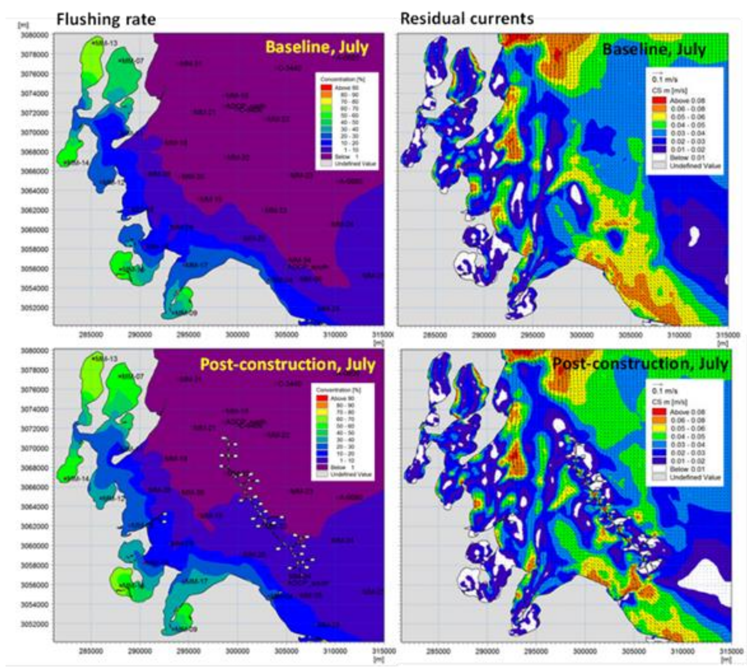


Fig. 6. Model-predicted flushing rate (left panels) and Residual current (right panels) before (top panels) and after (bottom panels) the Causeway construction.

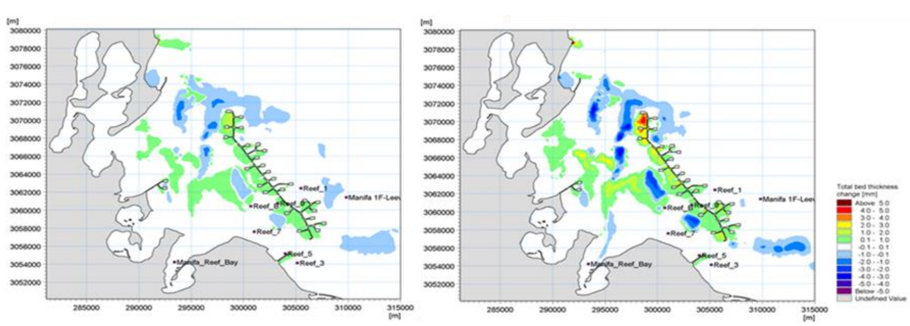


Fig. 7. Model-predicted changes in sediment deposition after 6 months (left) and 1 year (right).

Conclusion: The model simulations predicted that the maximum current speed will increase from 25 cm s-1 to about 50 cm s-1 at the 2.4-km southern bridge. The surveys conducted during 2013-2015 confirmed the same. The residual current speeds at the Causeway openings can exceed 10 cm s-1. The modeling study reveals that the Causeway has only a minor impact on the overall flushing rate. Modeling investigations suggest an increasing trend in the seabed thickness at the northern edge of the Causeway. The modelled thickness increase is approximately 5 mm a year.

14.5.2. Avoiding Biodiversity Hotspots from developmental activity (Northern Red Sea)

The Center was approached by Saudi Aramco to conduct an EIA at a site for exploratory drilling in the northern Red Sea. Upon studying the baseline of the site, the project area was notable for the presence of several ecologically sensitive coastal marine biotopes. Among them, the coral reefs are the most abundant, occurring as shallow fringing reefs near the shore and the islands and as a barrier-like formation across the mouth of the bay leading to the open sea. As is the norm, these reefs are home to a wide variety of marine life including fishes and macro-invertebrates. Next in importance, the seagrasses were found along the shallow sandy intertidal areas and reef flats. Numerous seaweed patches were found on sandy-rocky areas of the back reefs. In addition, several sea turtles and sting rays were also observed adjacent to the seagrass beds and coral reefs.

The Center proposed that the present location chosen for the drilling operations was unsuitable based on three considerations. The first is that it is located amidst a high density of sensitive marine habitats. The second is that, because of its proximity to the coast, any impact that may arise will reach the shores quickly (ex. Oil spill, favoured by tidal currents). The third is the shallow nature of the site, which requires dredging for navigational channels with attendant negative environmental and ecological consequences.

The recommendation of the Center was, therefore, a fresh location, away seaward from the present site, may be identified for the exploratory drilling, which would have to be sited as far away as possible from sensitive biotopes.

14.5.3. Optimal design of cooling water Discharge from Jizan Refinery

The Applied Research Center for Environment and Marine Studies (ARCEMS) at King Fahd University of Petroleum and Minerals (KFUPM) conducted an Environmental Impact Assessment (EIA) for the Cooling Water Discharge of Jazan Refinery and IGCC Plant, Jazan, Saudi Arabia based on the request received from Saudi Aramco. The objective of this EIA was to prepare an expert assessment of the potential environmental impacts due to the Cooling Water Discharge of Jazan Refinery and IGCC and suggest suitable mitigation measures to avoid or reduce the potential environmental impacts.

Saudi Aramco intended to construct a grassroots 400 thousand barrel per day refinery and hydrocarbon terminal facility, as well as a new power plant in its vicinity, within Jazan Economic City (JEC) premises on the south-west Red Sea coast of Saudi Arabia. The proposed facilities will generate significant amount of heat as a result of the cooling/processing of crude oil, which is intended to be moderated using seawater as the heat exchanger. The expected increase in temperature of the cooling water is about 8ºC. Continuous disposal of this warm water into the sea is expected to entrain impacts on coastal hydrography, biota, and habitats, which need to be minimized and/or mitigated. This requires the preparation of an EIA, detailing the prevailing baseline conditions and the expected impacts of construction and operation of the facilities.

As part of the EIA for the proposed development, ARCEMS collected baseline environmental, oceanographic, and biological data near the proposed refinery site. The components chosen to reflect environmental impacts were hydrodynamics of the study area, physical, chemical, and biological properties of the seawater, benthic organisms, sediment properties and contaminants therein, sensitive biotopes, and fishery. The likely dispersion of sediments associated with trenching for the installation of offshore discharge pipelines and the probable dispersion of cooling water during the operation of the refinery were assessed with the help of modeling studies. The potential impacts and environmental risks associated with the construction of the offshore discharge pipeline and the operation of the seawater intake and cooling water discharge facilities were systematically assessed and suitable mitigation measures were identified to avoid or reduce the potential environmental impacts. An environmentally suitable discharge layout option was recommended after analyzing 16 options. An EIA report was prepared based on the survey and studies conducted and as suggested in the scope of work.

TARGET 14.8. INCREASE SCIENTIFIC KNOWLEDGE, RESEARCH, AND TECHNOLOGY FOR OCEAN HEALTH

Approximately 71% of the Earth's surface is covered by the ocean, which regulates our climate and contains vast and in some cases untouched resources. It provides us with basic necessities such as food, materials, energy, and transportation, as well as a variety of recreational and religious activities. In today's world, more than 40% of the population lives within 200 kilometers of the ocean, and 12 out of 15 megacities are located along the coast. Over the past 50 years, the world's population has doubled, industrial development has increased rapidly, and human affluence has grown. Several factors threaten the productivity and health of the ocean, including climate change, non-sustainable resource extraction, land-based pollution, and habitat degradation. Against this backdrop, scientists and societal actors have organized a bottom-up movement in recent years, leading to the United Nations General Assembly declaring a Decade of Ocean Science for Sustainable Development (2021-2030).

Governments, industry, and scientists have raised awareness about the rapid degradation and overuse of the oceans during this process. In its final document, “The future we want”, the Rio+20 summit made extensive reference to the ocean, and the Global Ocean Commission called for the development of more effective global ocean policies. Additionally, the 2030 Agenda for Sustainable Development includes an explicit ocean goal (SDG14), which led to the first-ever UN Ocean conference. This decade of ocean science intends to use this momentum to mobilize scientists, policy-makers, business, and civil society around a program of collaborative research and technological development.

Here we briefly explain how CEMS has used scientific knowledge, research, and technology for knowing the status of local coastal seas and enhancing the ocean health.

14.8.1. Passive samplers - Dr. Rajaneesh

The ARCEMS has a research project entitled, "Environmental monitoring studies for the Arabian Gulf using novel technologies: passive samplers and biomarkers" funded by Saudi Aramco through the five-year Sustaining Research Program VII.

Technology for marine environmental monitoring is constantly advancing to improve collecting high-resolution data that are reliable for regulatory purposes. Next-generation compliance utilizes new tools, technologies and approaches which are smaller, smarter, cheaper and faster to strengthen the enforcement of environmental law. Monitoring programs which are best suited to generate a broader and more representative picture of water quality and the potential for deleterious impacts are those which use a variety of integrative sampling approaches and matrices (Allan et al., 2006). Environmental passive samplers were first developed in the 1930s, although they were not mathematically described until the 1970s (Hazrati and Harrad, 2007). Soedergren (1987) originally created passive samplers that could be used to assess volatile organic chemicals in water, using a dialysis membrane containing hexane to imitate the absorption of contaminants by aquatic creatures.

Passive techniques have received significant attention in recent years, thanks to researchers looking for effective ways to monitor organic and inorganic compounds in the natural environment. Passive samplers are reliable, cost-effective tools that can be used to determine the time-weighted average concentration of target compounds, allowing for the integration of spot pollution occurrences. The ability to accumulate analytes at ultra-trace concentrations is another advantage of passive sampling devices. They can be used in the field without electricity or any specific equipment. These are significant advantages over spot sampling approaches, in which analyte concentrations are frequently below instrument detection limits, preventing the identification of ultra-trace environmental micropollutants. Conventional methods of analyte determination in samples collected from the field are comprised of many steps such as point sampling, transferring samples to the laboratory, extraction of analytes from the sample matrix, purification and concentration of target chemicals, and instrumental analysis. The adoption of spot sampling to monitor pollution has several drawbacks. The most significant disadvantage is that spot sampling will only indicate the contaminants present at the moment of sampling. Because contamination can disperse before the next test period, incidents like storms, water leaks, or runoff will go undetected. It would require sampling numerous times to account for episodic events, which would be a tedious job, especially in remote locations. Moreover, time-weighted average concentrations of target substances may not be established without sufficient sample repeatability. Regardless of the media being tested, the ideal model of a passive sampler has a basic design, is inexpensive and straightforward to prepare, apply, and analyze, and is selective and sensitive enough for a wide range of chemical substances. In practice, sampler designs are created for a variety of applications, and no single device is ideal for all of them. Single-phase polymer samplers are the most basic passive sampling devices, with the polymer formula and surface area-to-volume ratio adjustable to improve sampler performance. In contrast, two-phase passive samplers have a receiving phase and diffusion membranes. Membranes are used to lengthen the kinetic phase by slowing diffusion between the receiving and water phases. Another major advantage is that passive samplers can provide more representative information on the occurrence of contaminants, particularly where concentrations fluctuate markedly with time. They are simple to deploy and have been found to be robust in the environment. Extraction and analysis of these devices have also proven to be a straight forward procedure with the use of performance reference compounds providing in-situ calibration. The accuracy of the passive sampling technology is generally considered to be on par with traditional techniques.

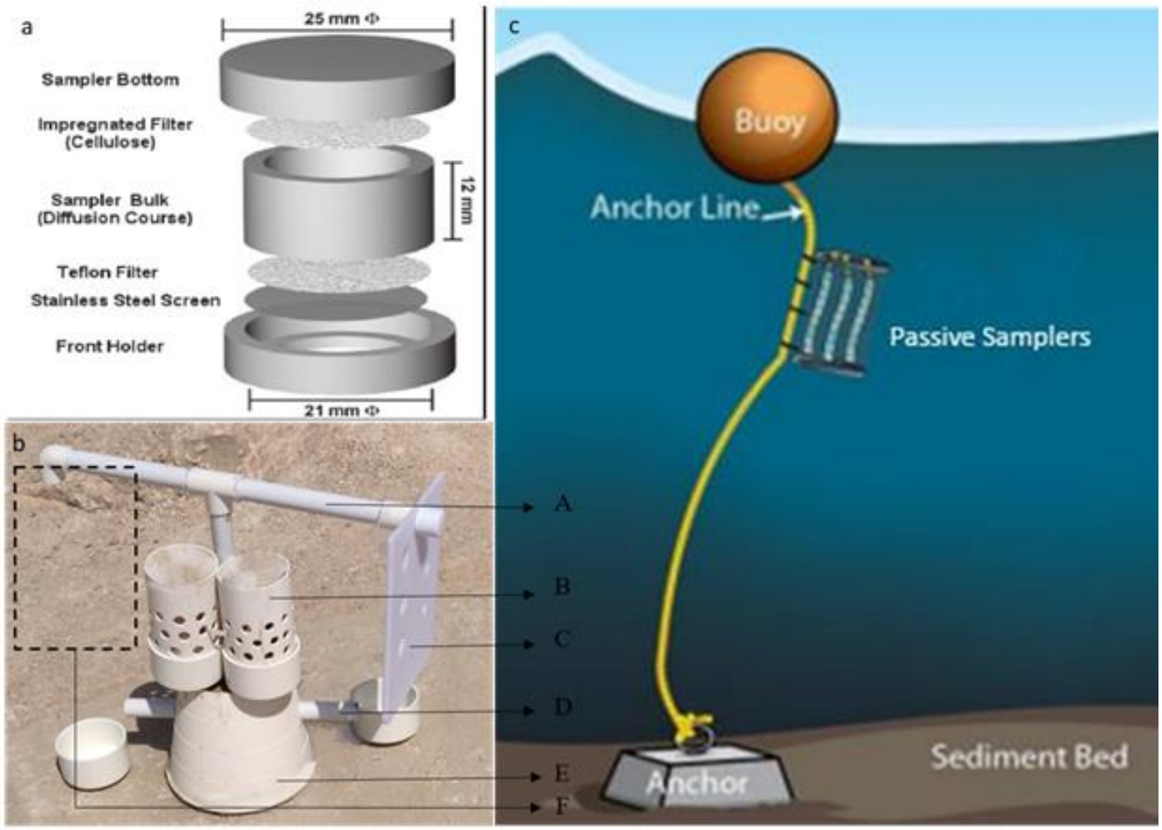


Figure xx. a) The passive sampler, b and c) Structure for the deployment of passive samplers: (A) supporting frame; (B) clam holder; (C) passive sampler holder for metals; (D) lifting handle; (E) sinker and (F) provision for organic passive samplers.

14.8.2. Environmental DNA (eDNA)

The ARCEMS has a research project entitled, "Utilization of molecular-based surveys as biodiversity monitoring tools in the Saudi waters of the Arabian Gulf" funded by Saudi Aramco through the five-year Sustaining Research Program VII.

Background of the project: Regular monitoring and management are required to maintain and improve the health and quality of the marine environment. Conventional monitoring methods vary among target organisms. For example, capture-based methods are usually applied for small vertebrates or invertebrate taxa. For marine megafauna, such as sharks, sea turtles, and dolphins, a combination of both observational and capture methods is often applied. For surveys of microscopic biota, such as bacteria, algae, fungi, and viruses, a variety of laboratory-based methods may be applied, such as microscopy, heterotrophic plate counts, flow cytometry, or quantitative polymerase chain reaction analysis.

These methods have their own logistic requirements and limitations, and conducting several methods in a monitoring program would be very costly and require a great amount of taxonomic expertise. However, it is usually necessary to include multiple taxa for effective assessments of the marine ecosystem. Therefore, there is a need to have an economical method to cover a wide range of taxonomic groups with minimal requirements for sampling and analytical efforts. The molecular-based metagenomics surveys, which analyze the genetic materials extracted from environment (water and sediment) samples, serve as rapid and cost-effective tools for monitoring the marine environment. These approaches serve as alternatives to destructive sampling and monitoring methods and options for a broad range or whole community assessment.

As the most important oil producer in the world, Saudi Arabia has large numbers of oil and gas structures operating in the Arabian Gulf. The marine environment may be impacted during the installation and construction of these oil-gas structures. On the other hand, by creating additional hard-structures and reef-like habitats and restricting fishing pressure nearby, these structures are considered as another type of artificial reefs with enhanced marine productivity and attract various marine organisms [Robinson et al., 2013; Rabaoui et al., 2015].

Saudi Arabia, as the largest exporter of oil-related products and shipping traffic in the Arabian Gulf, is one of the main threats for the introduction of marine invasions to the region. However, little is known about the current state of marine invasive species in Saudi Arabia. Therefore, a detection and early warning system for biological invasion from non-native species [van den Heuvel-Greve et al., 2021] will have a real impact on the environmental performance of the company as well as the protection of biodiversity in the region.

Monitoring the marine ecosystem by molecular-based surveys will be very informative for examining current ecological effects on the surrounding marine environment around the Aramco drilling operations, as well as early detection of invasive and non-native species.

The primary objective of eDNA project package is to contribute to the understanding of the marine environment and ecosystems of the Arabian Gulf, and examine the anthropogenic influences on the Gulf marine ecosystem and its biodiversity.

The specific objectives of the study are:

i. Monitor the impact of selected Saudi Aramco drilling operations on the biodiversity of the marine environment by analyzing water and sediment samples using molecular-based surveys.

ii. Apply molecular-based surveys to analyze water and sediment samples at selected Saudi Aramco ports for early detection of invasive and non-native species.

iii. Reveal the biodiversity baseline of the offshore islands by using molecular-based surveys.

iv. Evaluate the relationship between biodiversity and anthropogenic environmental stress factors, particularly metal and hydrocarbon contamination in seawater and sediments at study sites.

v. Elucidate seasonal changes in biodiversity patterns using molecular-based surveys at studied sites.

vi. Assess the potential of employing molecular-based surveys as fast and economic tools for monitoring and evaluating the marine environment in the region.

vii. Develop a strategy or protocol for detecting invasive, non-native species using molecular techniques.

eDNA as a promising tool in assessing diversity

Quantifying biodiversity and monitoring historical and contemporary biodiversity trends are important tools that can help marine researchers maintain the health of marine ecosystems (Patrício et al., 2016; Canonico et al., 2019; Lin et al., 2021a). Conventionally, marine biodiversity can be measured using various methods, including data collection through observation, catching marine organisms using nets, hooks, and traps, sediment collection with grab samplers, and analysis of acoustic, chemical, and electrical properties using different instruments (Costello et al., 2017). All these methods are selective and have limitations, such as being invasive, destructive, time-consuming, labor-intensive, and dependent on a declining number of taxonomic experts to identify specimens (Thomsen and Willerslev, 2015).

The recent development of molecular-based techniques using DNA or RNA sequencing, however, has made the assessment of marine biodiversity more economical and affordable. These techniques have been applied as alternative methods of monitoring biodiversity (Stephenson, 2020). By comparing sequences found in the sample to those of known taxa (Box 1: DNA barcoding, Zemlak et al., 2009), these molecular-based methods have significantly improved the monitoring of marine biodiversity by overcoming challenges of traditional, labor-intensive surveys, offering the opportunity to characterize marine biodiversity more efficiently in terms of time and space (Figure 2.1 and 2.2) (Zemlak et al., 2009; Thomsen and Willerslev, 2015; Pawlowski et al., 2018; Wang et al., 2021).

Environmental DNA (eDNA) is a segment of genetic material originating from the hair, skin, urine, feces, gametes, or carcasses of organisms which are shed in the environment, such as water or sediment (Thomsen and Willerslev, 2015). The procedure for monitoring biodiversity using eDNA techniques consists of the following steps: (1) capture of eDNA, (2) extraction of eDNA, (3) sequencing of eDNA, (4), comparison of eDNA sequences with a reference database, and (5) community analysis of eDNA (Wang et al., 2021). First, once environmental samples (e.g., water or sediments) have been collected, eDNA is commonly captured by collecting genetic material from the samples through filtration, precipitation, and centrifugation. Fixatives are usually added to prevent degradation of genetic material. Next, DNA is then isolated from the captured genetic material. After this, the DNA is amplified and sequenced. Usually, certain genetic markers such as Cytochrome c oxidase subunit 1 (COI) and 16S ribosomal DNA (16S) are sequenced. Next, DNA sequences obtained from the environmental samples are compared to reference databases. These databases can be public reference databases such as the GenBank, the National Centre for Biotechnology Information database (NCBI) (http://www.ncbi.nlm.nih.gov), and the Barcode of Life Database (BOLD) (https://www.boldsystems.org/), or specific reference databases constructed for other studies (Rabaoui et al., 2019). In the end, the output of the eDNA analysis is usually an array of the presence of taxa, which can be further analyzed by multivariate community analysis (e.g., Cordier et al., 2019).

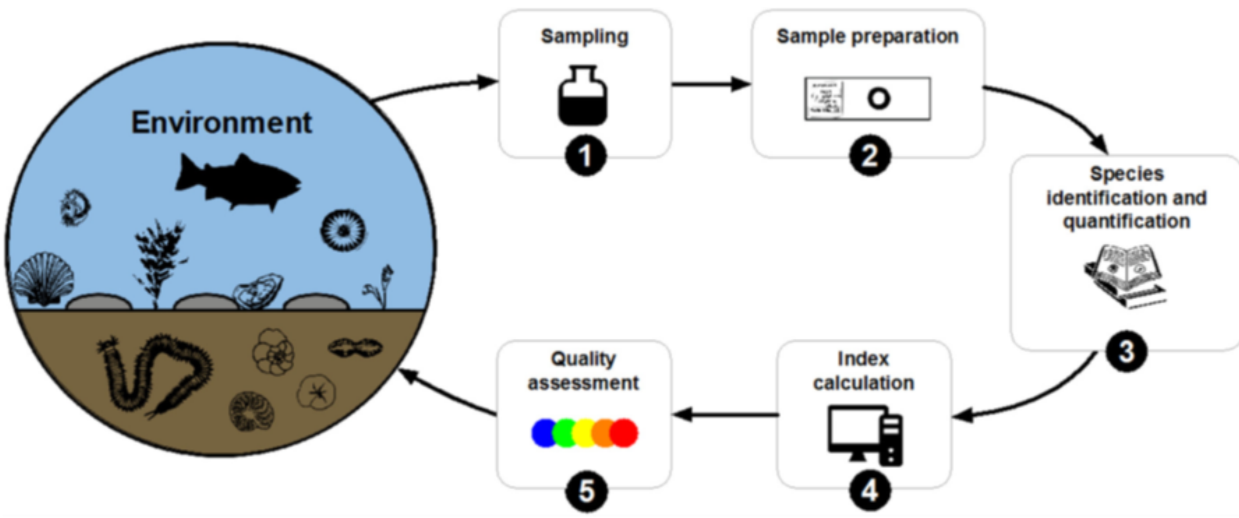


Figure 2.1. Scheme of key steps in traditional biological monitoring and assessment procedures (Source: Pawlowski et al., 2018).

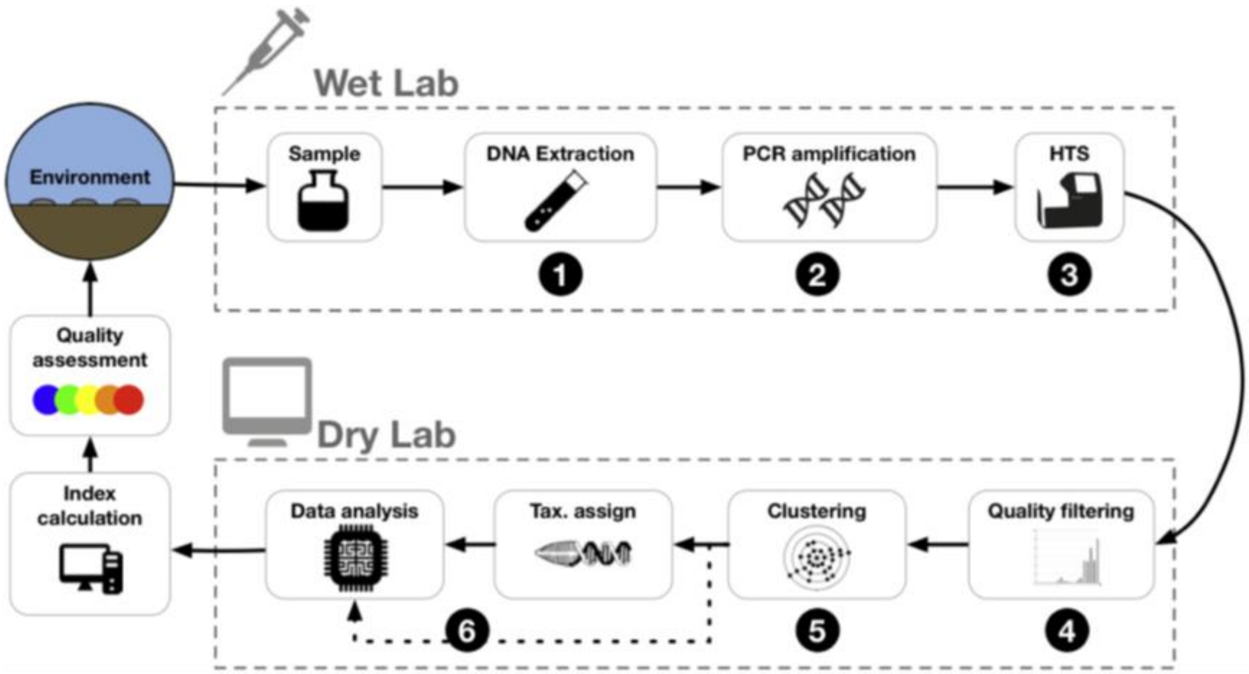


Figure 2.2. Scheme of key steps in DNA metabarcoding applied to bioassessment (Source: Pawlowski et al., 2018).

The utilization of eDNA has the potential to revolutionize conservation science and practice because of the following advantages:

(1) eDNA techniques are fast, efficient, and relatively economical, thus allowing the opportunity to monitor the dynamics of marine ecosystems over large temporal and spatial scales (Beng and Corlett, 2020).

(2) eDNA sampling is simple, nondestructive, and non-invasive, causing no significant damage to the target organisms or their habitats (Smart et al., 2016; Senapati et al., 2019; Wang et al., 2021).

(3) eDNA techniques can be highly specific to targeted organisms and can detect the presence of target organisms in small quantities of genetic material. Therefore, eDNA techniques can be widely applied to monitor rare, cryptic, or elusive taxa (Gargan et al., 2017), or to detect biological invasions at an early stage before invasive species can become fully established (Smart et al., 2015; Davison et al., 2019).

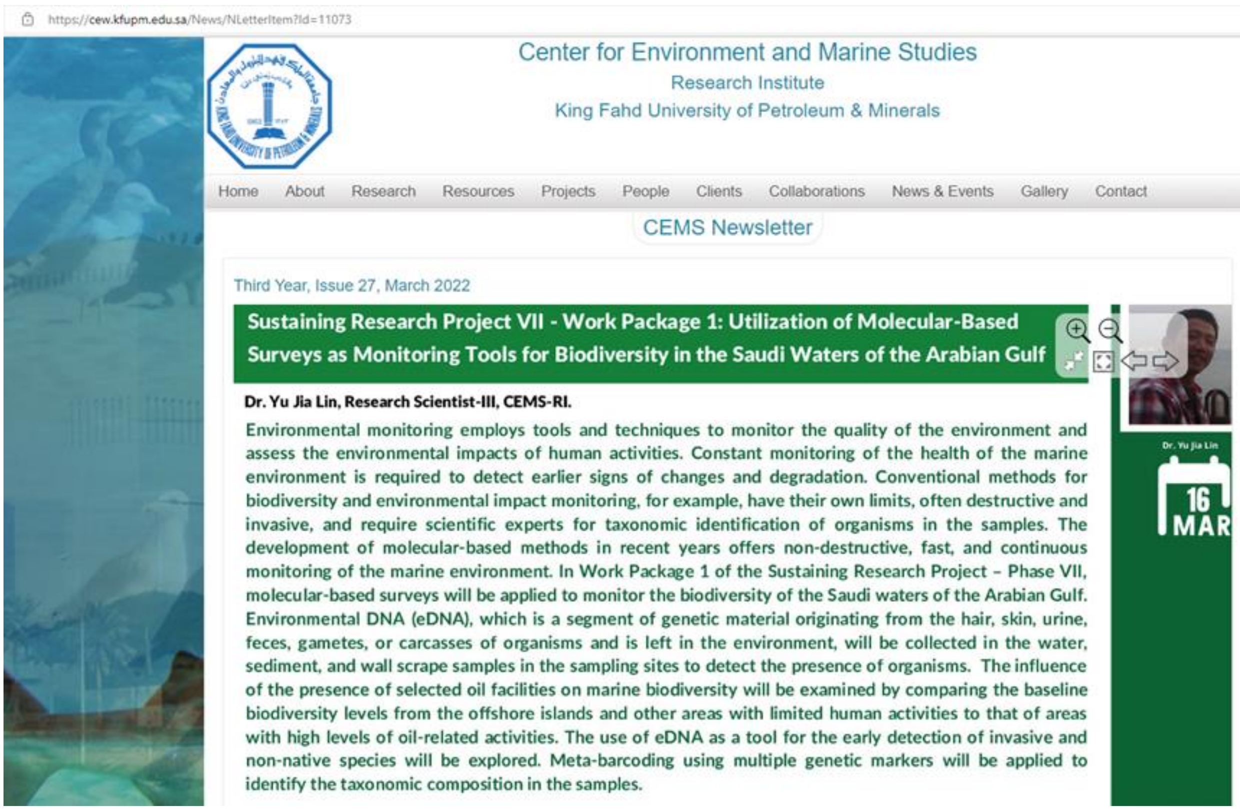
(4) eDNA methods can be applied to monitor organisms at different life stages in a variety of environments (Beng and Corlett, 2020; Wang et al., 2021).

(5) Using metabarcoding (Box 1), eDNA methods make it possible to monitor marine biodiversity across a broad taxonomic range, both micro-organisms and macro-organisms from small metazoans to large vertebrates, simultaneously (Cordier et al., 2019; Topstad et al., 2021).

ARCEMS' awareness programs on eDNA

The ARCEMS has organized seminars and written articles on eDNA to enlighten the members of the center on the applications and prospects of eDNA-based monitoring in the Arabian Gulf. A workshop on "Applications of Environmental DNA (eDNA) in Marine Biodiversity Assessments will be conducted in October 2022.

Two articles appeared in issue 27 (March 2022) newsletter of ARCEMS



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CEMS Newsletter

Third Year, Issue 27, March 2022

Sustaining Research Project VII - Work Package 1: Utilization of Molecular-Based Surveys as Monitoring Tools for Biodiversity in the Saudi Waters of the Arabian Gulf

Dr. Yu Jia Lin, Research Scientist-III, CEMS-RI.

Environmental monitoring employs tools and techniques to monitor the quality of the environment and assess the environmental impacts of human activities. Constant monitoring of the health of the marine environment is required to detect earlier signs of changes and degradation. Conventional methods for biodiversity and environmental impact monitoring, for example, have their own limits, often destructive and invasive, and require scientific experts for taxonomic identification of organisms in the samples. The development of molecular-based methods in recent years offers non-destructive, fast, and continuous monitoring of the marine environment. In Work Package 1 of the Sustaining Research Project – Phase VII, molecular-based surveys will be applied to monitor the biodiversity of the Saudi waters of the Arabian Gulf. Environmental DNA (eDNA), which is a segment of genetic material originating from the hair, skin, urine, feces, gametes, or carcasses of organisms and is left in the environment, will be collected in the water, sediment, and wall scrape samples in the sampling sites to detect the presence of organisms. The influence of the presence of selected oil facilities on marine biodiversity will be examined by comparing the baseline biodiversity levels from the offshore islands and other areas with limited human activities to that of areas with high levels of oil-related activities. The use of eDNA as a tool for the early detection of invasive and non-native species will be explored. Meta-barcoding using multiple genetic markers will be applied to identify the taxonomic composition in the samples.

Dr. Yu Jia Lin

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Third Year, Issue 27, March 2022

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SCIENTIFIC ARTICLE

eDNA AS A PROMISING TOOL FOR MARINE BIODIVERSITY MONITORING

Quantifying and monitoring biodiversity help marine biologists identify historical and contemporary trends in the health of the marine ecosystem. Conventional methods have their limitations. However, they can be invasive, destructive, or overly dependent on a declining number of taxonomic experts to identify specimens. Recent development of molecular-based techniques using DNA or RNA sequencing has made the assessment of marine biodiversity more economical and affordable.

Utilization of eDNA to monitor biodiversity has the following advantages: (1) eDNA techniques are fast, efficient, and relatively cheap. (2) eDNA sampling is simple, nondestructive, and non-invasive, causing no significant damage to the target organisms or their habitats. (3) eDNA techniques can be highly specific to targeted organisms and can detect the presence of target organisms in small quantities of genetic materials. Therefore, eDNA techniques can be widely applied to monitor rare, cryptic, or elusive taxa and for early detection of biological invasions before their full establishment. (4) eDNA methods can be applied to monitor diverse marine organisms at different life stages and in different environments simultaneously across a broad taxonomic range. Because of these significant advantages over conventional methods, the CEMS team has decided to apply eDNA analysis for on-going Sustaining Research Project – Phase VII. eDNA is a promising tool, complementing conventional marine environment monitoring surveys.

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The Speaker invitation to conduct a workshop on "Applications of Environmental DNA (eDNA) in Marine Biodiversity Assessments, which will be conducted in October 2022.

CENTER FOR ENVIRONMENT AND MARINE STUDIES, KFUPM

SPEAKER INVITATION

WEBINAR

OCTOBER

Applications of Environmental DNA (eDNA) in Marine Biodiversity Assessments

Organized by the Applied Research Center for Environment & Marine Studies, King Fahd University of Petroleum & Minerals

Background

Marine biodiversity surveys are the basis of any study that explores the effects of natural or anthropogenic stresses on an ecosystem. Biodiversity surveys used to be very time-intensive, requiring substantial taxonomic expertise for species identification. However, recently Environmental DNA (eDNA) metabarcoding has emerged as an alternative to bioassessments requiring considerably less time and taxonomic expertise. eDNA is genetic material originating from, e.g., the skin, urine, or feces of animals, which is shed in the environment, in this case, water or sediments. eDNA can be analyzed using standard molecular techniques, and the results can be compared against ever-growing global databases of genetic information to identify the organisms in an ecosystem. Only a limited number of eDNA-based monitoring studies have been conducted in the Arabian Gulf. This workshop will serve as a platform for researchers and environmental managers to discuss adopting the eDNA method for biodiversity assessments.

Workshop aim and outcome

This workshop aims to discuss the potential applications and implementation of eDNA in biodiversity assessments in the Arabian Gulf. A key outcome of the workshop will be collaborations between scientists, institutions, and agencies to address the appropriate implementation of the eDNA method in the Gulf region. The workshop will also lead to the development of joint publications by KFUPM and interested speakers, who will involve and support the technical aspects of the forthcoming eDNA project.

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Proposed topics:

The workshop will consist of 6 or 7 talks (20 min + 10 min Q/A each) on:

1. General Introduction to eDNA metabarcoding and its use in environmental monitoring studies
2. Best Practices on eDNA sampling, preservation, and pre-sequencing sample quality verification
3. eDNA study on bacteria, benthos etc. (sedimentary eDNA)
4. eDNA study on plankton, fish, megafauna etc. (seawater eDNA)
5. Applications for identifying and studying invasive species
6. The implementation of eDNA research in the Saudi waters of the Arabian Gulf (by KFUPM)
7. Bioinformatics tools in eDNA analysis

Organizer

Applied Research Center for Environment & Marine Studies, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

Who should attend?

Scientists, engineers, and natural resource managers who are interested in biodiversity and implementation of eDNA in marine environments.

Registration

will start at least 10 days before the day of the workshop

OCTOBER, 2022

ZOOM

(20 min + 10 min Q/A

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14.8.3. Microplastics

The marine environment faces severe threats due to anthropogenic activities, and pollution due to plastic debris is one such activity leading to large-scale ingestion and consumption of plastics by many ecosystem functional groups. Marine pollution due to plastics, particularly Microplastics (MPs), is a topic of global attention due to its potential threat to marine life and ecology. MPs tend to accumulate on the surface of the water column, but they are also transported vertically to the bottom through different mechanisms.

MPs occur in a variety of organisms, including commercially important finfishes and shellfishes. A number of studies positively extracted MPs from mussels, fish, crabs and other organisms. Since humans, directly or indirectly, consume most of these marine organisms, the chance for human exposure to MPs is high. Many studies have already identified health hazards of MPs ingestion in a variety of organisms. These health hazards include blockage of the intestinal tract, inhibition of gastric enzyme secretion, reduced feeding stimuli, reduction in steroid hormone levels, delays in ovulation and failure to reproduce.

MPs research has recently received increased attention in the Arabian Gulf region. A number of studies reported MPs presence in water, sediment and biota of the Arabian Gulf. Despite the evident effect of MPs pollution on marine ecology and life, no serious attention has been given to initiate studies of MPs pollution in the seawater, sediment and biota of the Saudi waters in the Arabian Gulf. A number of ecosystem functional groups, ranging from plankton to apex predators in diverse forms, support a productive marine life in Saudi Arabian waters. Most of these resources, particularly fish and shrimps, are economically important and support livelihoods in many coastal communities. Similarly, it is essential to know microplastic contamination in salts, which form an essential ingredient in food items and in food preservations. It is vital to know that these resources, including salts are pollution free and an efficient study is therefore essential to assess MPs contamination in the marine environment and its associated fauna.

Considering the above burgeoning attention on MPs pollution in the region, the ARCEMS has included a research project entitled, “Characterization of Microplastic Pollution in the Saudi Waters of the Arabian Gulf” in the five-year Sustaining Research Program VII funded by Saudi Aramco.

The main objective of this proposed study is to characterize microplastic pollution in the Saudi waters of the Arabian Gulf. The specific objectives of the study are the following:

i. Study spatial variations of microplastic concentrations in sediments and waters of Saudi territorial areas in the Arabian Gulf.

ii. Examine yearly changes in concentrations of microplastics in these waters and sediments, over a three-year period.

iii. Identify and define plastic pollution hotspots in Saudi territorial waters in the Gulf.

iv. Study microplastic contamination of three edible marine species found in Saudi Gulf waters and assess the potential impact of this contamination on human health.

v. Assess the microplastic contamination in salts collected from commercial markets and salt pans.

vi. Set necessary recommendations to establish an efficient management strategy to minimize plastic pollution in Saudi marine waters.

Sampling for MPs study will be carried out in the Arabian Gulf water of Saudi Arabia. The sampling area in Saudi Arabian waters will be divided into three strata: northern, central and southern strata. Annual sampling for seawater will be carried out from 30 pre-determined stations for three years (Figure 5.1).

Figure 1. Proposed sampling stations for Microplastic study.

14.8.4. Wave and current studies

Hydrodynamics play a major role in the ocean ecosystem. The delineation of the hydrodynamic features of the coastal waters is considered one of the major requirements for the enhancement of the scientific knowledge, research, and technology for ocean health.

Hydrodynamic processes such as waves, tides and currents may cause cyclical alterations of natural coastal features. Current and wave regimes may rework nearshore sediment, often with vital biological repercussions. Along the Saudi coast, the impact of hydrodynamic trends on natural coastal features is largely unknown. On the other hand, current and wave regimes may have a tremendous effect on various human activities in the coastal zones. In fact, certain industrial operations are highly dependent on the prevailing hydrodynamic regimes. For instance, the efficiency of dispersion and dilution of effluent discharges may rely heavily on local hydrodynamic conditions, including sea currents and waves. Navigation may be severely disrupted by strong currents and rough sea surface. Wave-induced erosions and sediment dynamics at foreshore zones may cause deleterious impacts on coastal activities and installations. Therefore, a better understanding of sea current and wave regimes in nearshore zones along the Saudi waters serve a major interest. The efficiency of dispersion and dilution of cooling water discharges strongly depends on the current regime, while nearshore structures, such as platforms and harbors, must incorporate wave parameters in their design and construction. Since the foreshore zones afford protection to coastal installations from current and wave actions, shoreline stability is a crucial requirement to ensure the safety of coastal facilities. Sediment dynamics, which affect coastal geomorphology, are highly dependent on ambient sea currents and waves. Hence, adequate knowledge of currents and waves in the nearshore zone of Saudi waters is necessary for structural safety, operational efficiency, and design optimization of future projects.

A NORTEK AWAC 600KHz ADCP (Acoustic Doppler Current Profiler, wave and current meter) was deployed at the northwestern Arabian Gulf in Safaniyah (Figure 1) during May - June 2020 to demarcate the hydrodynamic features of the Safaniyah coastal waters. The depth at the deployed station was 21 m. The data was collected with a bin size of one meter from surface to bottom. The current meter was programmed to acquire data for approximately five minutes at every fifteen minutes intervals for a period of one month. The wave data is available at the one-hour interval for this period.

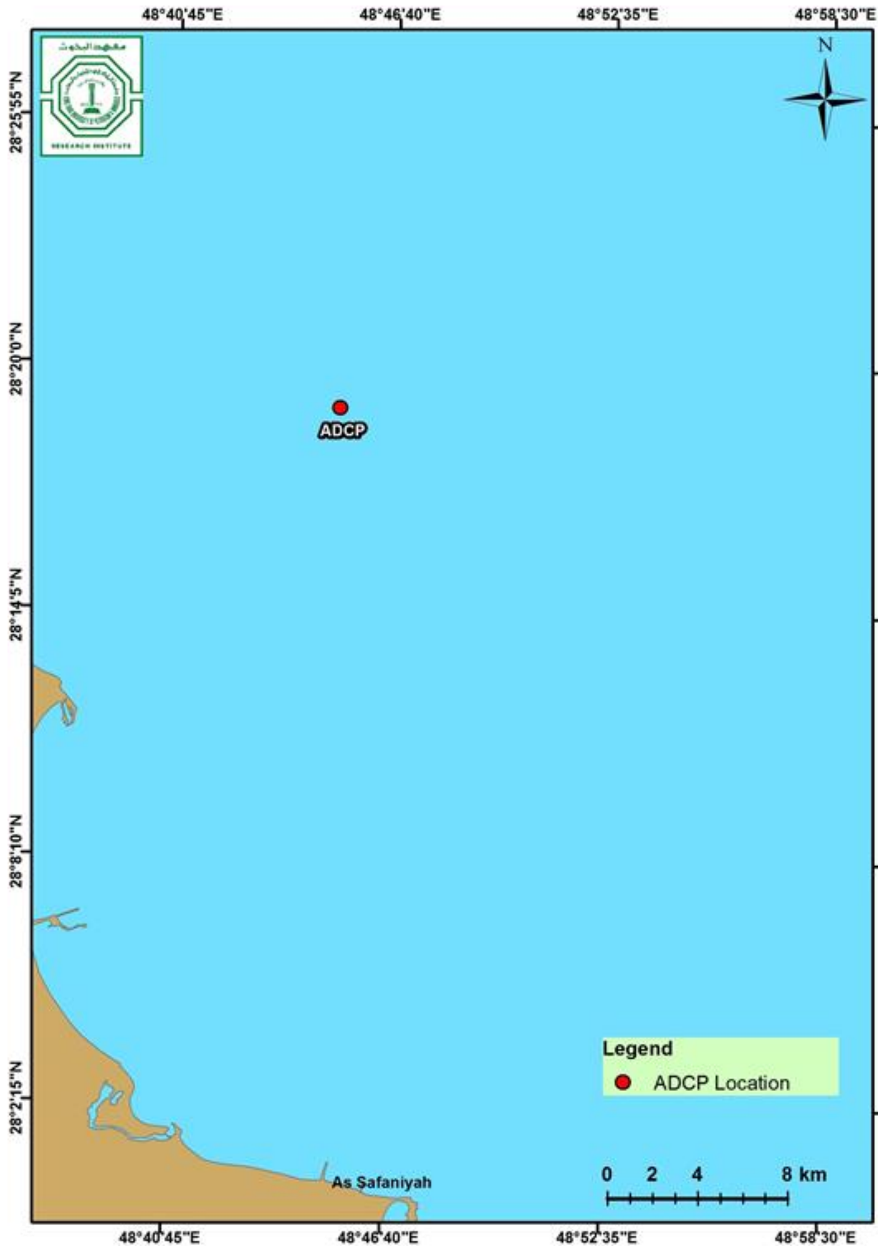

Figure 1. ADCP deployment location in Safaniyah

Tidal currents dominate in the water column and were mainly of mixed type with a semidiurnal component. A moderately strong current was recorded along the entire water column. Surface current was ranging from 0.2 to 70.9 cm/s (average speed of 17.75 cm/s). The magnitude was reduced to 15 cm/s at the bottom (19 m). The year-round northwest "shamal" wind triggers a southeastward current in the surface layers. Tide dominant, bidirectional currents were noticed along the mid and bottom layers. The predominant current directions were northwest (flood) and southeast (ebb) at the water column (Figure 2), flowing parallel to the Saudi land mass. The current magnitude during ebb tide was larger than flood tide. This depicts a net southward surface current along the study area, which could be the part of the southeastward flowing coastal jet along the west coast of the Arabian Gulf.

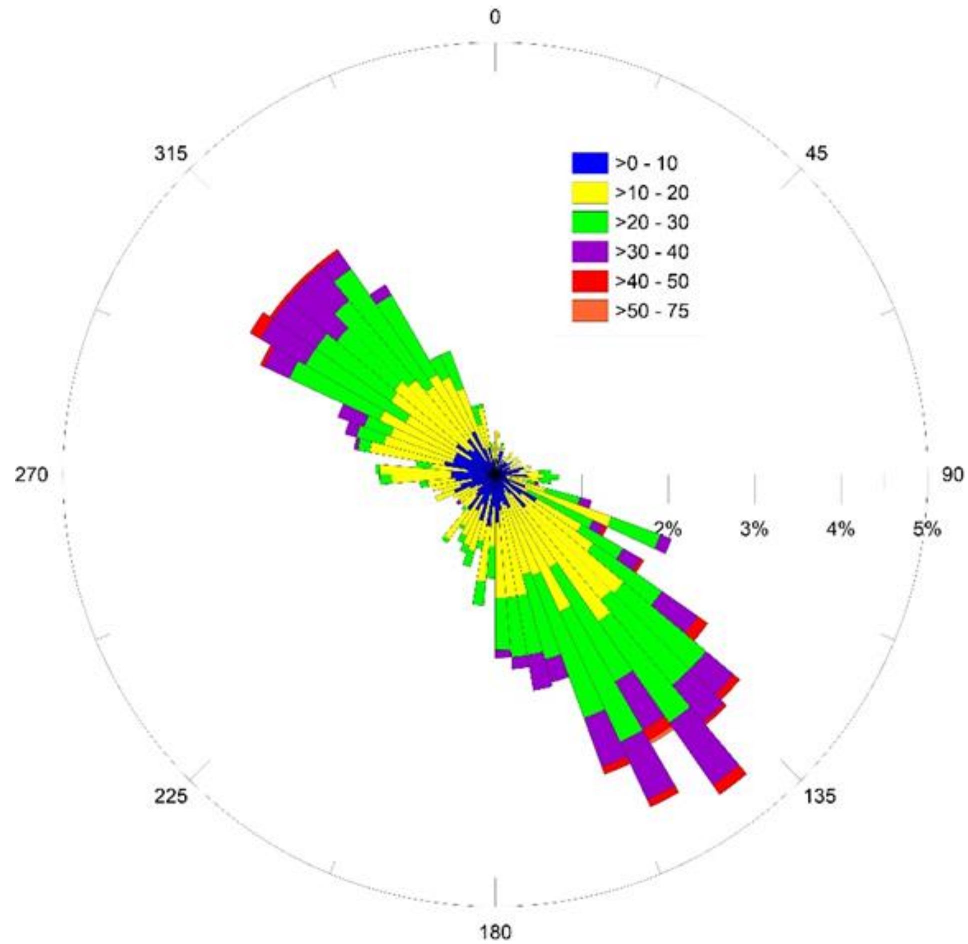

Figure 2 Directional rose plot of current at 5 m depth at Safaniyah

14.8.5. Study on Marine biodiversity using Remote Underwater Cameras

Understanding how marine biodiversity is distributed and what drives these patterns relies on good descriptions of marine ecosystems. This information should inform the protection of biodiversity and guide its management. Remote camera imagery has emerged as an essential tool for monitoring at all scales, from individuals to populations and communities up to entire marine ecosystems. With funding from Saudi Aramco, the center is installing offshore underwater cameras in strategic locations in the Arabian Gulf and the Red Sea to monitor the presence/absence of various animals and their activities in the underwater habitats. The resultant videos/ photographs are a valuable resource for the interpretation of wildlife information by decision-makers and the public.

14.8.6. Implementation of novel technologies for studying coastal circulation patterns

High-frequency radar (HFR) is a unique technology mapping ocean surface currents and wave fields (along with other variables) over wide areas with high spatial and temporal resolution. These radars can measure currents over a large coastal ocean region, from a few kilometers offshore up to about 200 km, and can operate under any weather conditions. They are located near the water's edge and need not be situated atop a high point of land. It is cost-effective, requiring only small manpower and technical costs. It has immense applications such as in the search and rescue system for coastguard, to help forecast and hindcast oil spills or other floating materials and for tidal predictions. The Center, with funding from Saudi Aramco is planning to install 4 HF Radars covering the north to south of the Arabian Gulf.

Figure 14. HF Radars in the Arabian Gulf