TARGET 14.A. 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.

Passive samplers

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.

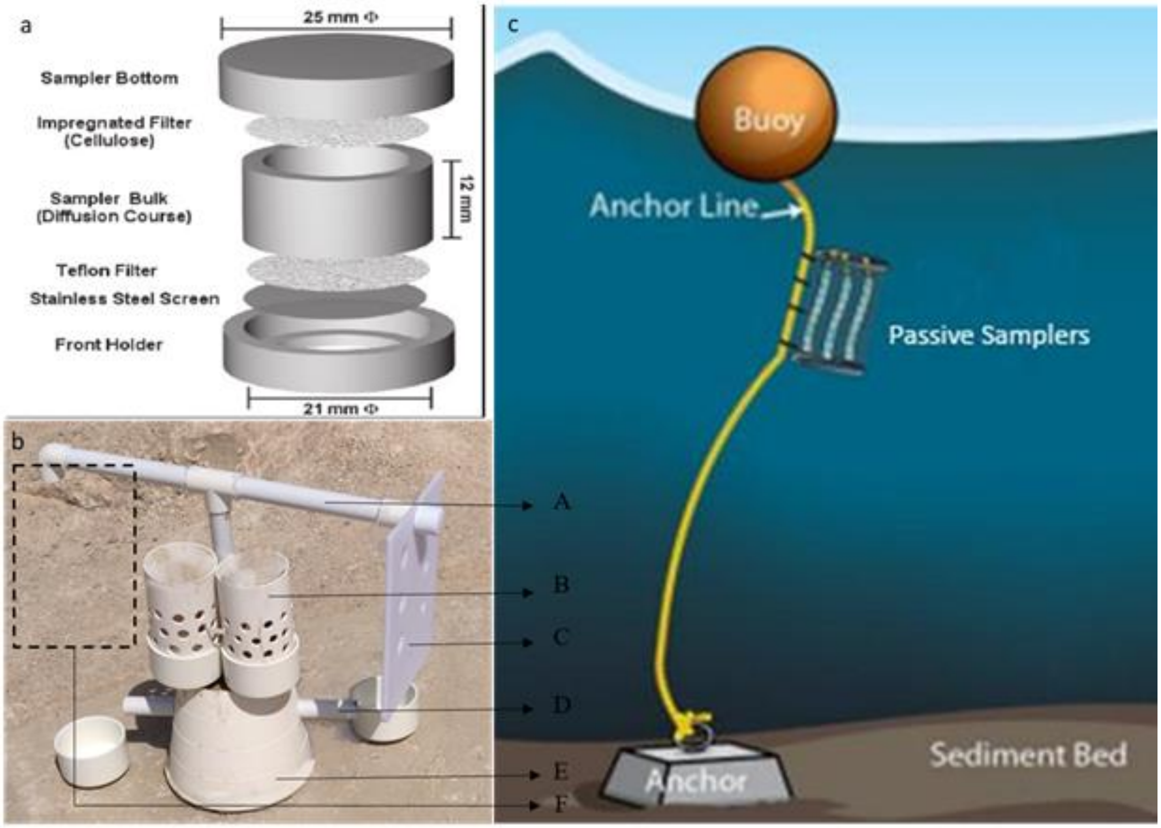


Figure xx. a) The passive sampler, b and c) Structure for the deployment of passive samplers: (A) supporting frame; (B) clam holder; (C) passive sampler holder for metals; (D) lifting handle; (E) sinker and (F) provision for organic passive samplers.

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).

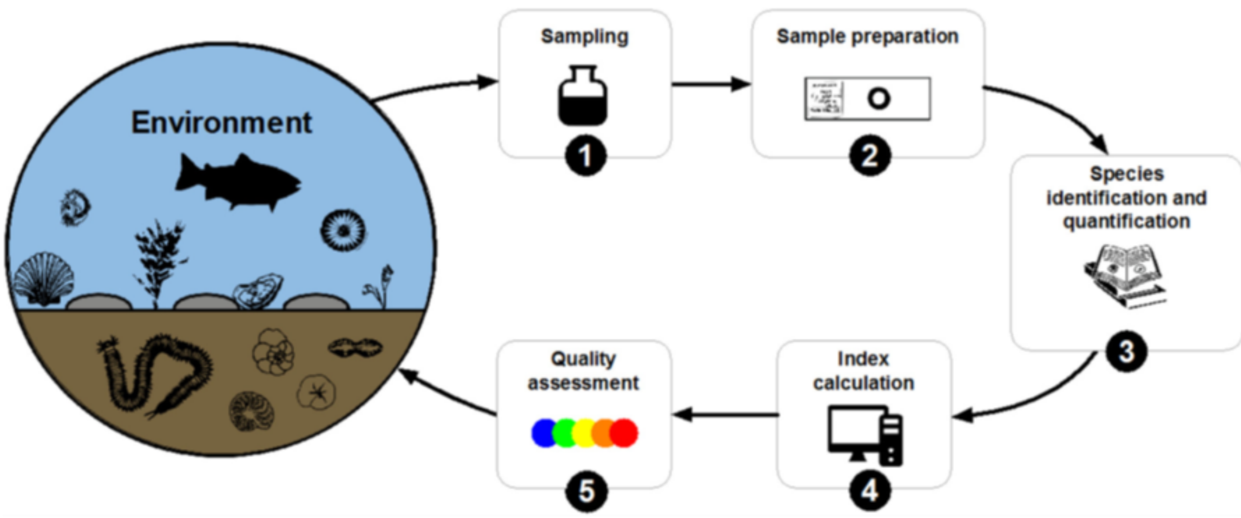


Figure 2.1. Scheme of key steps in traditional biological monitoring and assessment procedures (Source: Pawlowski et al., 2018).

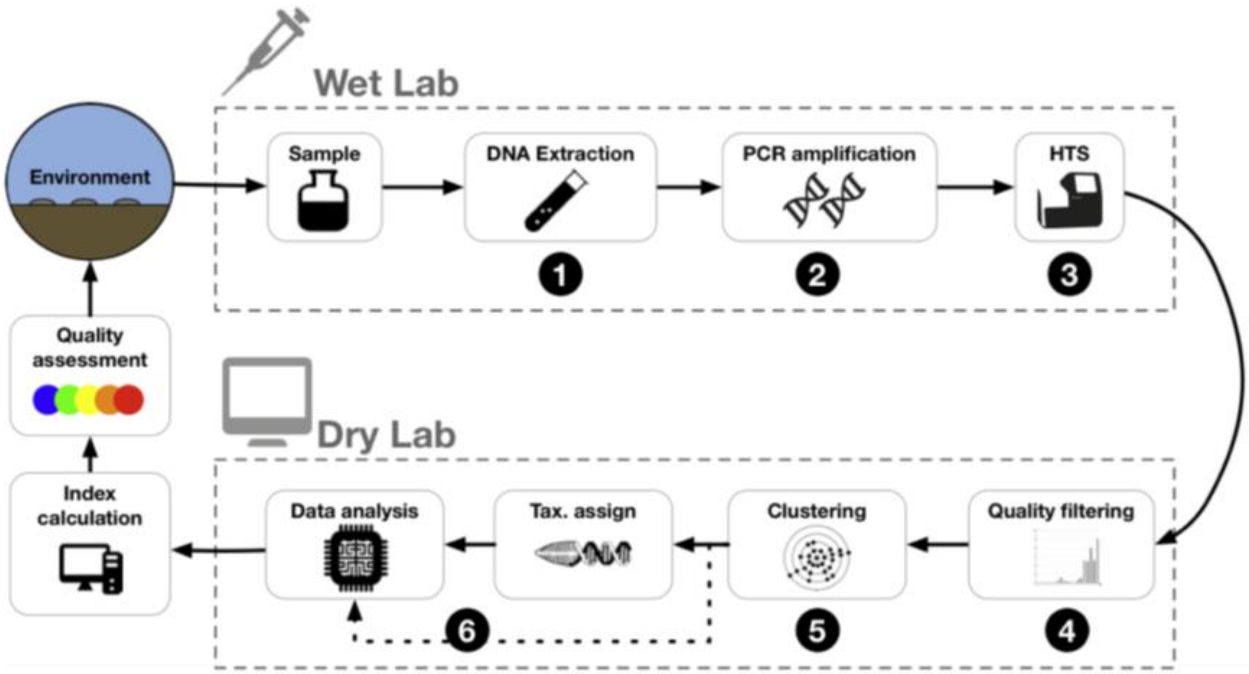


Figure 2.2. Scheme of key steps in DNA metabarcoding applied to bioassessment (Source: Pawlowski et al., 2018).

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).

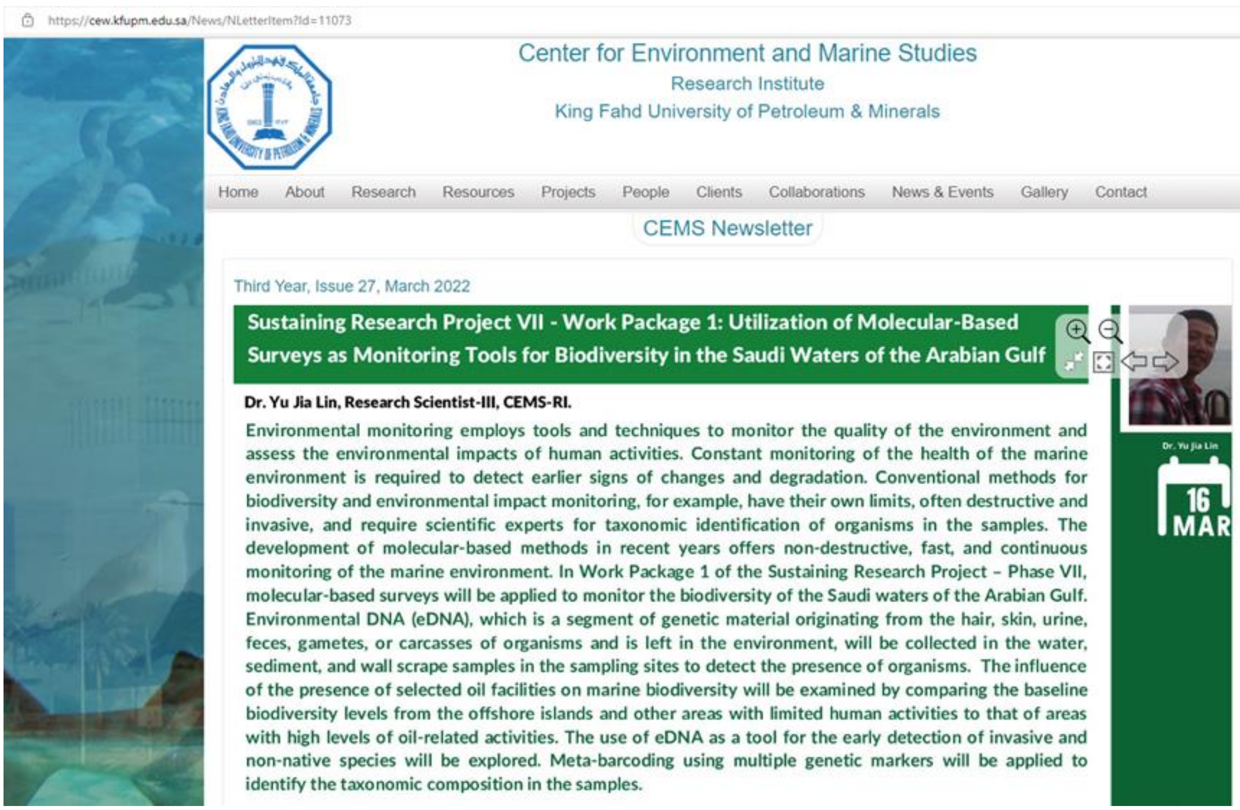
(4) eDNA methods can be applied to monitor organisms at different life stages in a variety of environments (Beng and Corlett, 2020; Wang et al., 2021).

(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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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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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).

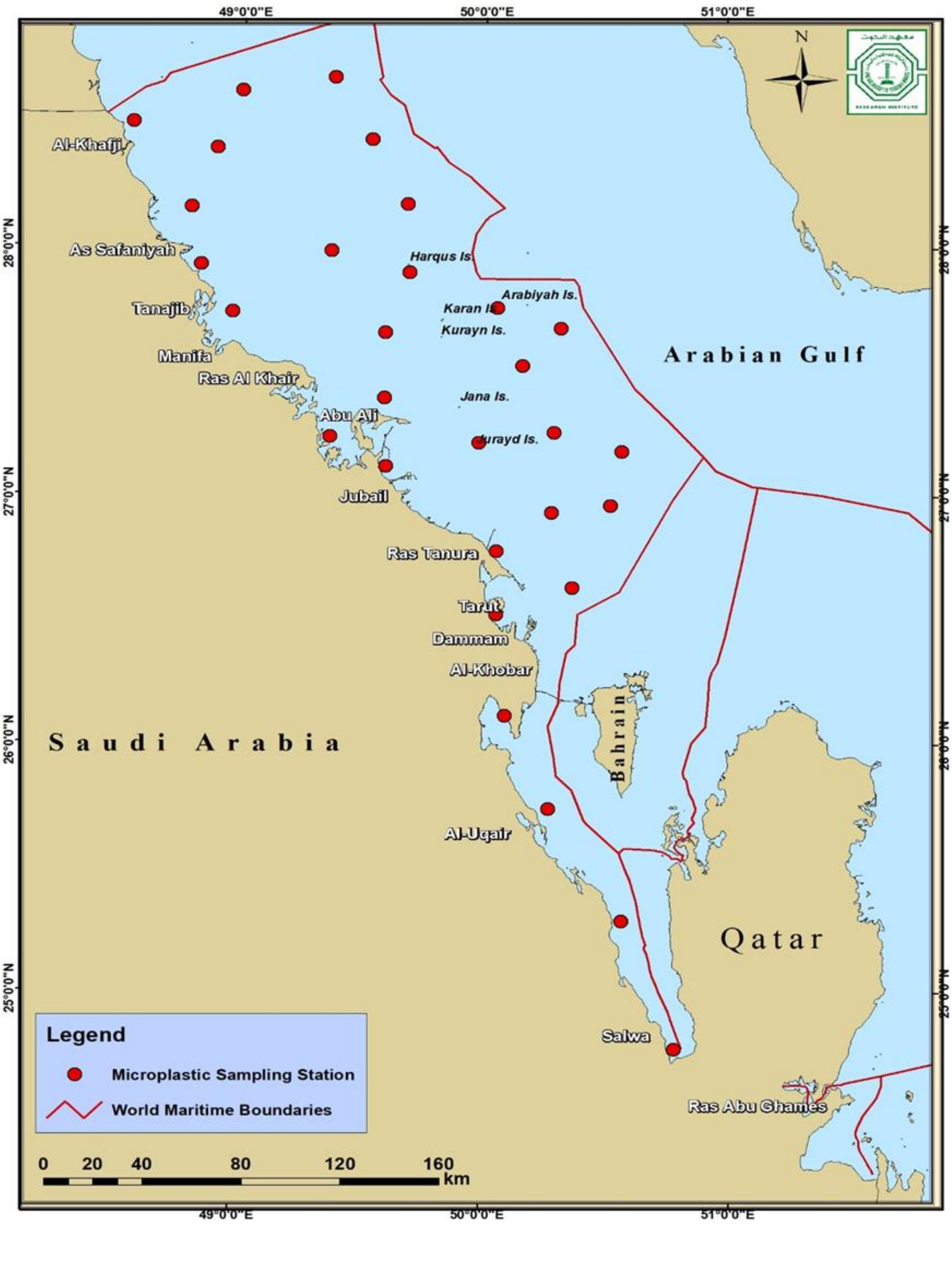

Figure 1. Proposed sampling stations for Microplastic study.

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.

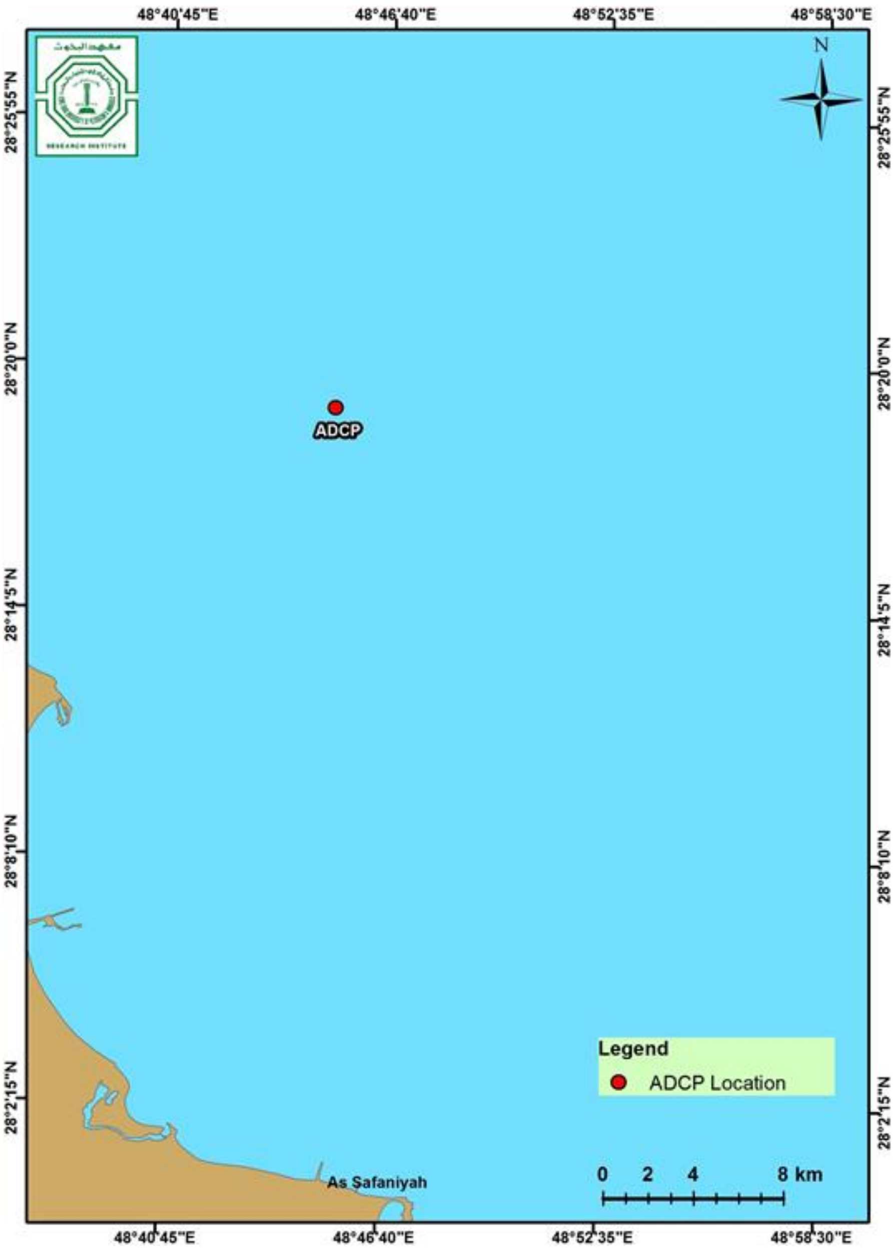

Figure 1. ADCP deployment location in Safaniyah

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.

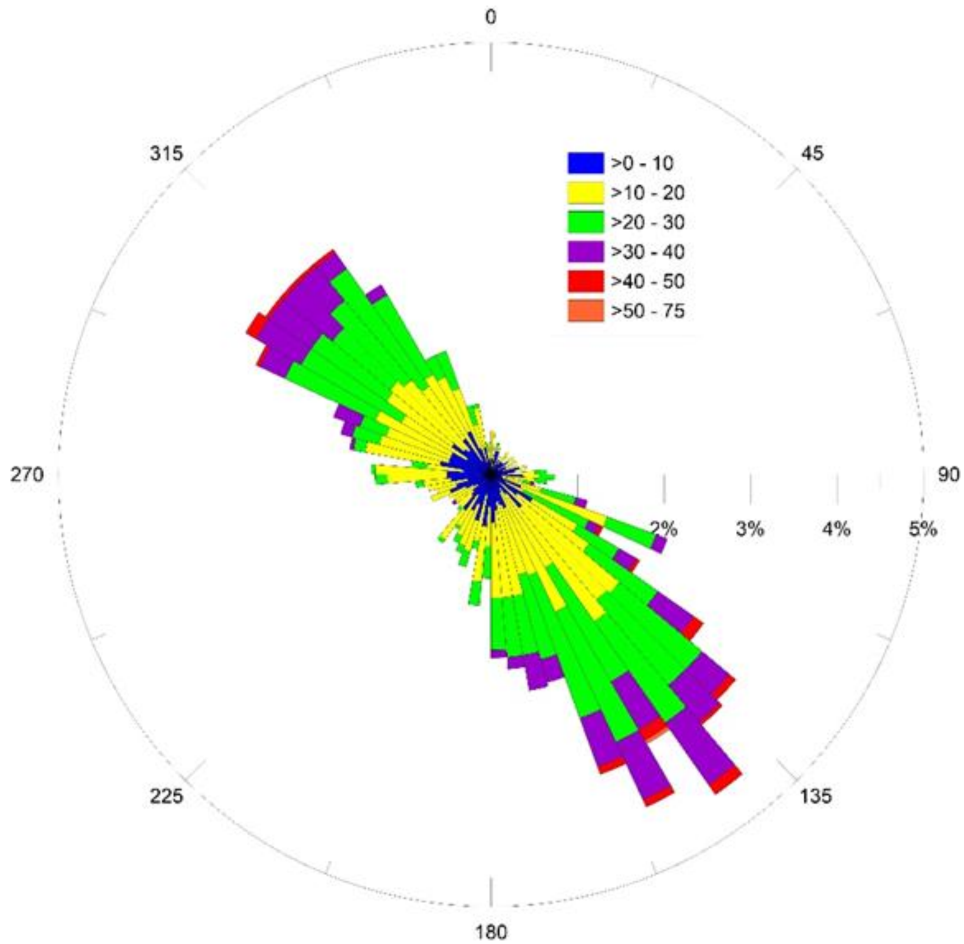

Figure 2 Directional rose plot of current at 5 m depth at Safaniyah

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.

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