Short Report

Sediment Classification Framework for the Indian Ocean Region

~Romit Kaware

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1. Executive Summary:

The Indian Ocean Region (IOR) is a vital geopolitical, economic, and environmental hub, spanning 27 million square miles with a diverse population of over 2.7 billion. As a linchpin connecting Asia, Africa, and Australia, the IOR plays a critical role in global trade, hosting a significant portion of worldwide oil trade and large-scale shipping. Coastal economies rely on the Indian Ocean for fishing and marine tourism, contributing substantially to their GDP. Projected to reach a value of $2.5 trillion by 2030, the IOR holds immense economic significance. Understanding and managing the IOR's characteristics are essential for global security, prosperity, and environmental health.

Oceanographic research, particularly Sediment Classification (SC) systems, provides crucial insights into seafloor topography, geological mapping, and environmental monitoring. SC systems are vital for understanding sediment composition changes over time, aiding in ecological impact assessments and informed management decisions. Additionally, these systems contribute to palaeoclimatology and palaeoceanography by identifying sediment layers from different epochs, facilitating the study of past climate changes. SC systems play a pivotal role in habitat mapping, resource exploration, marine engineering, and coastal zone management, offering valuable insights into benthic ecology, potential mineral resources, and coastal ecosystem dynamics.

The advancement of acoustic technology, particularly sonar, has revolutionized oceanic studies by providing a deeper understanding of ocean basins. Originally developed for submarine detection during World War I, acoustic systems transmit sound waves into the water and capture returning echoes to discern ocean floor topography. In this study, we introduce a sediment classification framework built upon acoustics and the Underwater Acoustic Backscatter Sensor (UABS), enhancing our ability to analyze sediment characteristics and distribution patterns. This framework represents a significant advancement in oceanographic research, contributing to our understanding of seafloor processes, marine ecosystems, and past climate variations.

2. Introduction

The Indian Ocean Region (IOR) holds significant strategic, economic, and environmental importance. This renders it a prominent area of interest for individuals globally. As the third-largest ocean on the planet, it spans approximately 27 million square miles, boasting a shoreline extending over 66,000 kilometres. As a vital link between Asia, Africa, and Australia, the IOR accommodates a diverse population of over 2.7 billion, representing various cultures, languages, and commercial activities. The IOR is pivotal as a significant maritime region, intricately woven into global trade and commerce. Notably, a substantial proportion of worldwide oil trade, around 80% and 33% of large-scale shipping traverses its waters, highlighting its indispensable role in the transportation of energy and trade. Coastal economies rely on the Indian Ocean (IO), with fishing and marine tourism significantly contributing to their GDP. Projections suggest that by 2030, the economic value of the Indian Ocean is anticipated to reach a staggering $2.5 trillion, amplifying its profound significance within the global economic landscape. Given the importance of the Indian Ocean in terms of security, economics, and the environment, it is essential to understand and deal with its characteristics to keep the world safe, prosperous, and healthy.

Current oceanographic research relies on Sediment Classification (SC) systems to get valuable insights into seafloor topography and the distribution of landmasses. These systems hold immense importance for geological mapping and seafloor exploration, shedding light on the ocean basin's historical geology and sediment transport mechanisms. SC systems also serve as crucial tools for environmental monitoring, allowing scientists to monitor sediment composition and distribution changes over time. This aids in understanding ecological impacts and making informed management decisions. Furthermore, sediment classification helps palaeoclimatology and palaeoceanography by identifying sediment layers from different epochs, enabling the study of past climate changes. These systems are integral to various applications, including habitat mapping, resource exploration, marine engineering, and coastal zone management. They provide insights into benthic ecology, potential mineral and fuel resources, and the influence of sediment processes on coastal ecosystems.

Advancements in acoustic technology have revolutionised our understanding of the ocean basins. Acoustic systems like sonar transmit sound waves into the

water, capturing returning echoes to understand the ocean floor topography. Initially employed in World War I to detect submarines, this technology has become a crucial tool for oceanic studies. In the study, we attempt to present a sediment classification framework built upon acoustics and the Underwater Domain Awareness (UDA) framework within the Indian Ocean Region.

3. Aspects of the Sediment Classification Systems

The sediment classification systems provide their applications in various domains ranging from offshore construction to navigation, marine ecosystem management and marine disaster management. We will focus on three crucial applications - Sediment-bearing Pressure, Benthic Ecosystem Assessment and Abiotic Element Detection. Following this, we'll present the sediment classification framework.

3.1. Sediment Bearing Pressure Analysis

Sediment Bearing Pressure (SBP) refers to the force per unit area exerted by deposition on the surface it is in contact with. This pressure is generated when sediment, such as soil or rock, is placed on or against a surface, and it can be influenced by several factors, including the weight, density, and moisture content of the sediment, as well as the shape and roughness of the surface. Sediment-bearing pressure is essential in many engineering and geotechnical applications, including foundation design, retaining wall design, and soil stabilisation. It is necessary to understand sediment-bearing pressure to ensure structures are built safely and securely and to prevent damage or failure due to excessive force or settlement.

In the wake of the recent missing of Malaysia Airlines Flight MH370, it has become clear that large swaths of the world's seas lack adequate bathymetric data[1]. Deploying deep-water equipment for a thorough bottom analysis during the fuselage search was impossible due to a lack of single and multibeam data coverage in the Region[2]. Understanding sediment-bearing pressure is essential for ensuring the safety and stability of structures built on or in contact with sediment and preventing costly and potentially dangerous failures. Such systems are vital considering economic growth and strategic importance. For example, the bearing

[1] Smith, W. H. F., and Sandwell, D. T. (1997). Global seafloor topography from satellite altimetry and ship depth soundings. Science 277, 1957–1962.
[2] Wölfl A-C, Snaith H, Amirebrahimi S, Devey CW, Dorschel B, Ferrini V, Huvenne VAI, Jakobsson M, Jencks J, Johnston G, Lamarche G, Mayer L, Millar D, Pedersen TH, Picard K, Reitz A, Schmitt T, Visbeck M, Weatherall P and Wigley R (2019) Seafloor Mapping – The Challenge of a Truly Global Ocean Bathymetry. Front. Mar. Sci. 6:283. doi: 10.3389/fmars.2019.00283.

pressure may be critical in shallow-water warfare, like the deployment of tanks, temporary bridges or amphibious vehicles in shallow waters.

3.2. Benthic Ecosystem Assessment

The benthic ecosystems consist of organisms, such as sponges and corals, that live at the bottom of a body of water, such as an ocean, lake, or river. In aquatic environments, benthic ecosystems are essential for energy transfer and nutrient cycling. Benthic ecosystems provide vital goods and services, such as fishery products and support, regulation, and cultural services[3]. They are regarded as indicators of environmental health, deciphering changes in the structure and diversity of benthic communities caused by pollution or other human interventions.[4]

Once the sediment particles have been introduced into marine habitats, the hydrodynamics, meteorology, climate, and bottom morphology play a significant role in their dispersion. The size of sediment particles substantially affects the diversity and composition of benthic communities[5], organic carbon[6] and contaminant dispersion[7]. Therefore, sediment texture must be evaluated for topographical study, biological characterisation of benthic environments, and environmental assessment of human-affected marine coastal areas[8].

India is recognised as one of the 12 mega-biodiversity countries in the world and is endowed with abundant biological resources. The benthic assessment has implications for fisheries management and aquaculture. Many fish species rely on benthic environments as homes and food sources. They provide habitat, breeding grounds, and feeding grounds for various fish species, particularly those that exploit the benthic environment as part of their life cycle. Fishing operations, on the other hand, may have a considerable influence on benthic ecosystems. Bottom trawling may harm benthic ecosystems and change the structure and functioning of benthic populations. Appropriate management and conservation

[3] Sala, Antonello, et al. "Adriaan D. Rijnsdorp, Ole R. Eigaard, Andrew Kenny, Jan Geert Hiddink, Katell Hamon, Gerjan Piet, Antonello Sala, J. Rasmus Nielsen, Hans Pole, Pascal Laffargue, Mustafa Zengin, Olavur Gregerson"
[4] Benthic Indicators. Retrieved from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-benthic-macroinvertebrates
[5] Sediment Classification and the Characterization, Identification, and Mapping of Geologic Substrates for the Glaciated Gulf of Maine Seabed and Other Terrains, Providing a Physical Framework for Ecological Research and Seabed Management by Page C. Valentine, U.S. Geological Survey, Reston, Virginia: 2019.
[6] Douglas N. Lambert, John C. Cranford and Donaid J. Walter, Development of a High-Resolution Acoustic Seafloor Classification Survey System, Proceedings of the Institute of Acoustics, 1993.
[7] Sediment Classification using Model-based Techniques with Field Validation, Maritime Research Centre, Pune.
[8] The Territorial Waters, Continental Shelf, Exclusive Economic Zone And Other Maritime Zones Act, 1976.

methods are needed to guarantee the sustainable use of fishing resources and the protection of benthic ecosystems.

The assessment of the quality of benthic communities directly relates to the Environmental Impact Assessment of a proposed project. The benthic indicators can estimate the future distribution of the benthic assemblages due to environmental fluctuations. Different species have different habitat preferences and are better suited to distinct benthic habitats. Scientists can estimate which species are likely to be present in these places based on their known habitat preferences by mapping the breadth and features of these ecosystems. Mapping the distribution of indicator species may assist in identifying areas of concern or conservation priority by providing insights into the spatial variation of ecological conditions. Researchers may increase the accuracy and precision of species distribution models by including benthic ecosystem information in these mapping efforts. Changes in ocean temperature and acidity are among the effects of climate change that significantly impact global marine ecosystems.

3.3. Abiotic Element Detection

The discovery of abiotic elements in the Indian Ocean is vital to understanding the makeup, movement, and geological processes of sediments in the vast expanse of the Indian Ocean. Classification of the abiotic components within sediments is essential for comprehending oceanic environments, resource exploration, and environmental management. This is a fundamental concern involving identifying and localising objects not naturally part of the seafloor ecosystem, including marine litter, abandoned debris and shipwrecks.

Remarkably, Indonesia, Thailand, Malaysia, India, and Bangladesh are the top contributors to ocean plastic pollution. The Indian Ocean faces considerable plastic pollution, with the Ganges and Indus rivers, known for their substantial pollution, flowing into its waters. Projections also suggest that the Indian Ocean ranks second in plastic accumulation, trailing behind the North Pacific Ocean[9].

Additionally, the IOR contains petroleum, natural gas, and essential minerals such as iron, manganese, nickel, and gold[10]. Polymetallic nodules (PMN), which form another crucial aspect of the abiotic component, are an exceptional type of

[9] Eriksen, Marcus, et al. "Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea." PloS one 9.12 (2014): e111913.
[10] Lakshman Kadirgamar Institute. The Importance of the Indian Ocean: Trade, Security and Norms. Retrieved from: https://lki.lk/publication/the-importance-of-the-indian-ocean-trade-security-and-norm/

high-tonnage mineral deposit containing cobalt, nickel, and manganese. These nodules are potato-sized concretions that have the potential to be economically exploited as a mineral resource, particularly for use in novel energy batteries[11]. However, these PMNs are located in environmentally protected, remote regions[12,] requiring specialised extraction technology and apparatus. The Polymetallic Nodule project is one of India's most crucial R&D initiatives for the socioeconomic development of abiotic elements because India is among the top eight nations pursuing a long-term exploration and utilisation programme for polymetallic nodules[13].

Technological advances have permitted the investigation of the deepest parts of the ocean, revealing new species and the possibility for bottom mineral extraction. Since no commercial seabed mining has occurred, and its effects remain unknown, manufacturers are now considering schemes to develop prolonged technological devices and promote responsible e-waste recycling[14].

Underwater archaeology represents another aspect of the abiotic system, focusing on the historical human societies and actions in aquatic environments like lakes, rivers, and oceans. This discipline applies archaeological methodologies to discover, recognise, and explore submerged cultural heritage sites. These sites encompass shipwrecks, submerged civilisations, and other underwater archaeological locations. Thus, assessing the impact of such abiotic elements on the marine ecosystem is one of the significant challenges in the current scenario.

3.4. Sediment Classification Framework

Creating a comprehensive Sediment Classification (SC) system for the Indian Ocean necessitates a multidisciplinary strategy that leverages the extensive array of sediment classification applications. These applications include assessing sediment-bearing pressure and monitoring benthic ecosystems. The approach adopted for this framework draws inspiration from the UDA framework. This conceptual framework can be visualised as a cube, where each of its four faces emphasises distinct facets that establish the framework's foundation. This framework emphasises the fact that acoustics represents the most promising path

[11] Wong, Liang Jie, et al. "Acoustic assessment of polymetallic nodule abundance using sidescan sonar and altimeter." IEEE Journal of Oceanic Engineering 46.1 (2020): 132-142.
[12] Kang, Y.; Liu, S. The Development History and Latest Progress of Deep-Sea Polymetallic Nodule Mining Technology. Minerals 2021, 11, 1132.
[13] Press Information Bureau Government of India Ministry of Earth Science India's Exclusive Rights to Explore Polymetallic Nodules from Central Indian Ocean Seabed Basin Extended by Five Years. Retrieved from: https://pib.gov.in/newsite/PrintRelease.aspx?relid=170138
[14] Miller KA, Thompson KF, Johnston P and Santillo D (2018) An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts, and Knowledge Gaps. Front. Mar. Sci. 4:418. doi: 10.3389/fmars.2017.00418.

forward. It offers an efficient, cost-effective, and all-encompassing means of comprehending the marine ecosystem and its valuable assets.

The conceptual framework of sediment classification can be visualised as a cube, wherein each of its four vertical faces represents a critical aspect. These encompass the realms of sediment classification applications, the source, path, and receiver model, the integration of policy and technological interventions, and the ability to see, understand, and share concepts. This comprehensive structure encapsulates indispensable domains that require significant understanding for the efficient and holistic deployment of sediment classification systems within the IOR.

The first illustrates the fundamental concepts of sediment classification. It identifies and quantifies sediment types based on their composition, grain size, and other relevant characteristics. These are helpful for applications such as evaluating sediment-bearing pressure, assessing the health and functionality of benthic ecosystems and underwater resource exploration. The source-path-receiver concept, inherent to deploying the acoustic devices, is highlighted on the second face. The policy, technology interventions and auditory capacity come next. The policy support recommends formulating and implementing regulations that assist sustainable sediment management, stop pollution, and safeguard benthic habitats. Combining these fundamental concepts can help us get a thorough understanding of the sedimentary environment of the Indian Ocean, enabling wise decision-making and encouraging the sustainable management of its marine resources and ecosystems. It's crucial to comprehend the elements of the sediment classification framework before utilising the framework. Each aspect of the framework is now discussed in the following parts of the article, highlighting the subjects of each framework domain.

3.5. Acoustic systems

Underwater sediment modelling is traditionally accomplished using in-situ sampling; this approach, however, is limited in scale, time-consuming, and expensive [8]. With the introduction of acoustic-sounding technology, it is now possible to gather the bathymetry, topography, sediment-bearing pressure and other geotechnical parameters of sediment particles without collecting samples. Diverse subsurface remote-sensing systems employ a variety of sensors to monitor seafloor properties, such as changes in backscatter, acoustic reflectance,

and gravitational and magnetic properties[15]. This information is collected using specialised vehicles equipped with acoustic sensors, like Multi-Beam Echosounders (MBESs), Single-Beam Echosounders (SBESs), Side Scan Sonars (SSSs), and Sub-Bottom Profilers (SBPs), to capture and store the necessary data. Such systems also aid during the initial reviews of port installation remnants and other subsea structures. These Modern technologies reduce the capital and time constraints of conventional methods[16]. In this case, the active sonars[17] are of focus. The active sonars are high-tech acoustic devices that transmit sound waves into the sea and then receive and process the good echoes that bounce back.

4. The Source-Path-Receiver Model

Developing monitoring and conservation strategies requires the acoustic capacity capability development for the sediment classification systems. Since sonars are the principal instrument for acoustic surveys, any effort to construct sediment classification systems would need them. As mentioned, acoustics is the only signal propagating effectively and efficiently underwater. Understanding the sonar pulse propagation and its characteristics underwater is crucial to building acoustic capacity. This might be accomplished by creating prediction maps utilising internet data from several open-source datasets. The application-specific source prediction will include examples of Underwater Radiated Noise (URN) or from the marine ecosystem. Each application will have a unique input-output matrix that must be carefully considered. The source-path-receiver model needs to be correctly created and implemented for each application.[18]

4.1. Source

[15] National Research Council. 1989. Our Seabed Frontier: Challenges and Choices. Washington, DC: The National Academies Press. https://doi.org/10.17226/1413.
[16] Tripati, S. & Gaur, A.s & , Sundaresh & Bandodkar, S.N.. (2002). Marine Archaeological Explorations off Goa, India. International Journal of Maritime History. 14. 10.1177/084387140201400210.
[17] https://oceanservice.noaa.gov/facts/sonar.html#:~:text=Active%20sonar%20transducers%20emit%20an,the%20strength%20of%20the%20signal.
[18] https://mrc.foundationforuda.in/marine-spatial-planning-a-new-perspective-based-on-the-underwater-domain-awareness-uda-framework/

The source describes the original signal underwater that needs to be analysed. This contains source signals relevant to specific applications, such as marine platform URNs, species distribution, and source signals specific to particular activities. The sonar waves that must be transmitted depend on the obtained data parameters. It is necessary to individually determine the signal pulse characteristics based on the propagation medium. The most important factors when discussing underwater communication are frequency, amplitude, attenuation, and beam pattern.

Due to the peculiar characteristics of sound transmission underwater, sonar frequency is critical in underwater applications, particularly in the ocean environment. The sonar pulse's interaction with the surroundings is governed by its frequency. The frequency is determined by the particular application and desired trade-offs. Low-frequency sonar sounds may travel farther and reach deeper depths in water. They are, therefore, suited for mapping the seafloor, deep-sea environment exploration, and long-range detection and communication. They may cover more extensive regions but have a poorer resolution. They help map the ocean floor and find bigger submerged objects, such as ships and submarines. Such Low-Frequency Active Sonar is capable of long-range detection and communication and works from a few hundred Hz to several kHz. Short-range applications requiring high-resolution imaging work better with high-frequency sonar sounds. Better resolution is provided by higher-frequency sonar sounds, enabling comprehensive imaging of underwater objects, structures, and wrecks. Applications like underwater archaeology, research, and specific military operations can all benefit significantly from this. High-Frequency Active Sonar (HFAS) is utilised for close-range, high-resolution imaging and detection, and it operates in the frequency range of 200 kHz to several MHz.

The beam pattern of the sonar outlines the spatial distribution of the sound wave's energy. Depending on the sonar transducer's frequency, angle, and construction, the beam pattern might take on different shapes. The sonars can be categorised as single-beam echosounders (SBES), Multi-Beam Echosounders (MBES), Side Scan Sonars, or Bottom Profilers. Each has unique uses due to differences in the acoustic pulse emission pattern, operating frequencies, and depth ranges. For instance, SBES can produce a single downward-pointing acoustic pulse and track how long it takes to reach the seabed before returning. Its frequency range can vary, although it commonly lies between 12 and 200 kHz. The intended depth

range and resolution have an impact on the frequency chosen. At the same time, MBES emits several sonic pulses concurrently in a fan-like pattern using an array of transducers. This allows them to gather bathymetric data over a larger area, leading to quicker mapping and better resolution. Multibeam echo sounders generally operate in the frequency range of 30 kHz to 500 kHz.

Side scan sonar systems emit high-frequency acoustic pulses to the sides of the sonar device. The comprehensive pictures of the seabed and other underwater objects created by the reflected signals provide essential details about their forms and textures. Side scan sonars typically function between 100 kHz and 500 kHz, which is a more extensive frequency range. Sub-bottom profilers are used to investigate the layers beneath the seafloor by emitting low-frequency sound pulses that penetrate the sediments. Returning echoes detail the geological formations, sediment composition, and possibly buried things. Generally, sub-bottom profilers work between 1 kHz and 20 kHz at relatively low frequencies. The required penetration depth and sediment properties will determine the frequency.

As sound waves propagate through water, they gradually lose energy due to scattering, absorption, and other interactions with the medium. This is referred to as attenuation of the signal. The acoustic signal's high-frequency components may be absorbed more quickly than its lower-frequency components due to attenuation. This might cause the received signal to lose clarity and resolution, making it difficult to discern between various frequencies or to detect minute details. The behaviour of sonar pulses can be influenced by environmental conditions such as water temperature, salinity, and water layers. Sonar signals may be refracted, reflected, or interfered with due to sound velocity profiles brought on by changes in water characteristics with depth. These can result in phase shifts and changes in the signal’s waveform, causing signal distortion. The effective range of sonar systems may be restricted by attenuation, making it more difficult for sonars to detect things at great distances.

4.2. Path: Indian Ocean Characteristics

The source signal will likely experience distortion throughout its travel in the undersea medium. Therefore, having a high-resolution underwater channel model

with accurate mapping of the medium conditions is crucial. The secret to accurately forecasting the received signal is to combine the source signal and the path modification. This is accomplished by creating unique corrective factors that consider medium losses. Our focus is the Indian Ocean; we shall now discuss the path distortions and their causes experienced by the acoustic signals in the waters of the IO.

Diversity: A wide variety of marine life, including whales, dolphins, and different fish species, can be found in the coastal seas of IOR. Marine animals use sound for communication, navigation, and hunting. This biological noise can interfere with the echoes from possible targets or result in false positives regarding sonar signals. The IO's varied underwater habitat may produce complex acoustic clutter and sound wave reflections. The echoes from possible targets may be obscured by this clutter, making it challenging to differentiate between the clutter and actual objects. Along with complicating the distribution model by slowing down the signal and increasing transmission losses, this interference necessitates adjustments to retrieve valuable data.[19] [20]

Climatic Fluctuations: The IO is vast and diverse, covering various water depths, temperatures, and salinity levels. These different water conditions can considerably impact the propagation of sound waves. Other types of water conduct sound differently, and these variances can distort and weaken sonar signals, making it challenging to identify and analyse echoes from underwater objects precisely. Due to greater surface temperatures, the IO is vulnerable to weather variations such as monsoons, tsunamis, hurricanes, and strong winds. Like the Atlantic and Pacific, the IO also has strong border currents. However, these currents vary significantly from one another[21]. Variations in sedimentation rates brought on by seasonal monsoon winds considerably impact sediment transport and deposition patterns. The input characteristics of the sonar pulse are altered due to these fluctuations.

Topographic Characteristics: The undersea landscape of the Indian Ocean is diverse and includes seamounts, trenches, and ridges. Active and dormant

[19]Rishabh Patra, Shridhar Prabhuraman, Arnab Das AI & ML based Implementation of the Underwater Channel Model in the Tropical Littoral Waters of the Indian Ocean Region (IOR)
[20]Arnab Das, Acoustic Habitat Degradation Due to Shipping in the Indian Ocean Region, Changing Ecosystems and Their Services, DOI:10.5772/intechopen.90108DOI:10.5772/intechopen.90108, March 2020
[21] Hood, Raleigh & Wiggert, Jerry & Naqvi, S.W.A.. (2009). Indian Ocean research: Opportunities and challenges. Geophysical Monograph Series. 185. 10.1029/2008GM000714.

underwater volcanoes are present in IO, which influences the distribution and variety of sediment. The Ganges-Brahmaputra delta, the Red Sea, and the Arabian Sea are just a few places it gets material from, creating a complex sedimentary ecosystem. It may be challenging to differentiate between echoes from the seabed and those from real objects due to the acoustic interactions caused by these geographic features' ability to reflect, refract, and scatter sound waves.

Acoustic Challenges: The IOR's tropical littoral waters provide significant difficulties for underwater sound surveillance. Due to their subpar performance, the sonars used for any effort at underwater survey are severely constrained. The SOFAR channel, which controls how tough travels between the surface and the bottom, is more significant in depth in tropical waters. Acoustically, the littoral waters are determined by interactions with the surface and bottom borders; as a result, the undersea domain exhibits characteristics of shallow waters in tropical seas. Additionally, tropical weather guarantees more surface and bottom variations, increasing acoustic signal distortions due to multipath propagation. In the warm coastal waters of the IOR, sonars used for underwater monitoring don't perform as effectively as they could. Any sonar has difficulty operating effectively in the warm coastal waters of the IOR due to its short acoustic depth, with the performance being reduced by 60% to 70%. [22] [22][23]

The IO is a significant centre of numerous human activities, including shipping, fishing, offshore drilling, and transcontinental trade. These operations produce anthropogenic noise, such as engine noise, propeller cavitation, and seismic surveys, which can obstruct necessary sonar signals and interact with other noise sources. The IO is also a hub for underwater cables that transmit enormous volumes of data internationally. The added sonic interference produced by these undersea cables might hinder the region's sonar systems' ability to operate effectively. As a result, the IOR's tropical littoral limits will apply to any effort at acoustic habitat assessment to determine acoustic habitat damage. [22].[24]

4.3. Receiver

The receiver describes the received characteristics. The receiver characteristic becomes crucial to evaluate the source signal distortion's effects. As a result, the

22https://www.orfonline.org/expert-speak/us-india-defence-trade-and-indias-underwater-domain-awareness-61571/
23 https://www.intechopen.com/chapters/70229
[24] https://www.intechopen.com/chapters/70229

source-path-receiver model will be closely associated with the overall successful administration of the application.
The sonar receiver's properties in marine settings are essential for precise detection of the transmitted acoustic waves. These characteristics are influenced by the properties of water, underwater conditions, and the design of the receiver system.

The receiver must conform to specific requirements for adequately hearing the propagated signal. The first is sensitivity. It refers to the receiver's capacity to pick up faint acoustic signals. A sensitive receiver is necessary for identifying echoes from far-off or tiny objects in the frequently loud underwater environment. The receiver's electronics, the transducer quality and the methods used for signal processing all affect sensitivity. Second, the receiver's frequency response. It reveals whether it can accurately reproduce signals across a variety of frequencies. To correctly collect both low- and high-frequency signals, which can convey various information, the receiver should have a smooth frequency response—third, noise rejection. Due to elements like ship traffic, marine life, and geological activity, underwater settings may be loud. Effective noise-reduction techniques, incorporating filtering, signal averaging, and other processing techniques, are required to differentiate between actual echoes and background noise. A greater sampling rate also makes it possible to capture quick changes in the signal more effectively, guaranteeing the correct representation of the received echoes.

The amplitude and signal intensity differences between the transmitted and received pulses can reveal how the signal was amplified or attenuated throughout its journey through the water. The effects of distance, scattering, absorption, and target reflectivity all affect attenuation. A weaker received pulse can suggest a greater distance travelled or an environment with more scattering. The frequency of the received echo may also change due to the Doppler effect when the source pulse strikes a moving object. Determining the velocity of the objects in the sonar system is made possible by analysing these frequency changes. Due to reflections from the bottom, objects, and water layers, sound waves in underwater environments might travel through several different courses before being heard by the receiver. These reflections, which can occasionally result in signal distortion or false echoes, can be detected by the existence of several echoes in the received signal. Changes in the properties of the received pulse can reveal the

presence of submerged structures or modifications in the make-up of the bottom. Identifying changes in the undersea environment can be aided by attenuation patterns and reflections of various levels. Due to adjacent ship activity, marine life, or geological activity, variations in background noise levels or unanticipated interference in the received signal can be used to detect changes in the undersea environment.

It is also possible to minimise the effect of the source on the receiver or vice versa by using a more excellent knowledge of the source-path-receiver model. The developing world should understand the severe underwater medium distortions found in tropical environments to design and deploy acoustic equipment.

5. To See, To Understand, To Share

National security, the blue economy, disaster management, and science technology are the four UDA framework stakeholders that must work together to promote safe, secure, and sustainable growth for everybody. Effective marine governance requires complete management of the possibilities and challenges[25]. We should look at the to see, share, understand concepts, and understand the differences in the data requirements, interpretations, and user applications. The model draws attention to important issues, including retrieving necessary data, processing techniques, and finally, presenting it to the user. It combines the to see, to comprehend, and to share elements. From a strategic standpoint, these three actions have particular opportunities and difficulties. We build on these three processes to successfully understand the sediment classification system.[26]

5.1. To See

The to-see aspect includes the platform transporting the sensors to the spot. The acoustic sensors must be installed on surface and sub-surface-level platforms with the necessary payload, manoeuvrability, durability and other characteristics. These platforms should be ideal for the application specifications. It is essential to determine which input parameters must be gathered, which sensors must be deployed together with their specifications, and how these sensors will be

25 https://sundayguardianlive.com/news/see-understand-share-three-step-approach-uda
26https://sundayguardianlive.com/news/see-understand-share-three-step-approach-uda

attached. Before formally establishing the deployment strategy for these platforms, the sensor capabilities and sensor efficacy must be considered. Thus, the hardware requirements and specifications may vary depending on the specified scenario.

The first step is determining the acoustic sensor needed for the particular investigation. Single-beam Echosounders (SBES), multi-beam Echosounders (MBES), Side Scan Sonars, or Bottom Profilers can be deployed depending on the required usage. Each has unique uses due to differences in the acoustic pulse emission pattern, operating frequencies, and depth ranges. For instance, SBES can produce a single downward-pointing acoustic pulse and track how long it takes to reach the seabed before returning. Single beam echosounders' frequency range can vary, although it commonly lies between 12 kHz and 200 kHz. At the same time, MBES emits several sonic pulses concurrently in a fan-like pattern using an array of transducers. Side scan sonars typically function between 100 kHz and 500 kHz, which is a more extensive frequency range. Sub-bottom profilers are used to investigate the layers beneath the seafloor by emitting low-frequency sound pulses that penetrate the sediments.

Second, the vehicle used for deploying the sensors. To gather data, specialised research vessels are outfitted with various scientific tools, including acoustic sensors. Traditionally, the platforms have been surface boats, which have several limits regarding sensor range to the depths and oversize restrictions for customised missions. Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) are today emerging as the most agile and efficient means to deploy underwater sensors. The AUVs provide unequalled possibilities and efficiency, from design and development through implementation of particular deployment and mission-specific modification. Numerous iterations are necessary before finalisation for each parameter, including size, endurance, payload, and more. Remotely operated vehicles, or ROVs, are tethered to a surface control station. They are frequently employed to perform precise manipulation and manoeuvring operations, such as attaching sensors to underwater structures or placing acoustic sensors in the ocean bottom. The sluggish underwater gliders are excellent for surveys and have high endurance, making them perfect for lengthy deployments. The low cost further adds to their advantage in deploying them in large numbers for maximum area coverage[27].

[27] https://sundayguardianlive.com/news/see-understand-share-three-step-approach-uda

Third, the mode of deployment. Depending on the depth, environmental conditions, region of interest and available resources, these systems can be hull-mounted, towed or suspended. Multi-beam arrays are usually mounted on the ship's hull. Authors in [9] used receivers and hydrophones suspended from two boats to get bathymetric data, while in [5], the SBP was towed using a towing line. In some cases, they may be towed behind submarines or an AUV. Thus, their mapping abilities are improved by adding sound devices to AUVs and ROVs. This lets them scan large areas on their own or from a distance.

With the rising applications of the seabed, it is necessary to determine which input parameters must be gathered, which sensors must be deployed together with their specifications, and how these sensors are to be attached. Thus, the hardware requirements and specifications may vary depending on the specified scenario. Here, the synergy and diversity between the equipment must be studied. For various applications, the same sensor and vehicle might be utilised by minor adjustments in the data collection process. At the same time, some of the applications would require a diverse field of sensors for their objectives. This study can lead to developing hardware cultured for various needs with efficient utilisation of resources, capital, and time, thus reducing the complexity of the process.

5.2. To Understand

To understand refers to the data analysis at various levels. The data collected from the acoustic sensors cannot be directly translated into the final results. Instead, the data undergoes processing, including calculating parameters like reflection coefficients, sediment impedance, attenuation, density, etc. These can be determined by using well-established relationships. The use of different types of acoustic sensors requires other processing techniques.

Data analysis of acoustic signals requires a specialised skill set that includes understanding signal processing, acoustics, oceanography, and domain-specific knowledge, particularly in underwater environments. Understanding signal processing techniques is essential for filtering, noise reduction, and modifying raw acoustic data. Implementing processing algorithms and data analysis requires strong programming abilities and integration of artificial intelligence (AI) and Machine Learning (ML) algorithms.

Pre-processing is the initial stage in the process of controlling data fluctuations and distortions brought on by the medium, signal processing flaws, and other factors. To improve the accuracy and value of the data, many crucial actions must be taken during this stage. Handling stochastic fluctuations in the dataset, noise filtering, and heave adjustments are essential components. To preserve the features of the signal form, noise filtering is also used. Thus, ping averages are calculated to maintain consistency. [5] These processes include bandpass and median filtering, normalisation for accurate comparisons, and deconvolution to alleviate reverberation. Frequency content may be visualised using spectral analysis, which is carried out using methods like spectrograms and short-time Fourier transform (STFT). Data segmentation, signal alignment, and feature extraction are steps in the analysis process. More trustworthy results have undergone quality control, data fusion, and interpolation to fill in missing data points. Understanding signal properties and the undersea environment is crucial for selecting the appropriate preprocessing procedures. We can specify the application-specific data analytics after removing any potential inaccuracies from the incoming signal.

Data postprocessing for acoustic waves from the seas includes improving the pre-processed data to provide insightful findings. This stage consists of various methods designed to enhance the usability of the data. Machine learning algorithms may classify events or recognise patterns by extracting pertinent information like frequencies and energy levels. More excellent knowledge of the acoustic environment can be gained by locating and identifying specific occurrences of interest, such as underwater activities or the distribution of marine species. Data patterns and correlations can be discovered through temporal and geographical analysis. In addition to exposing hidden patterns and connections, postprocessing also converts unprocessed acoustic data into insights that may be used in various disciplines, including marine biology, environmental monitoring, and undersea research. For instance, the SBES echo shape characteristics, including time spread, total energy, skewness, and flatness, may be used in Principal Component Analysis (PCA). The -means clustering method, PCA, and decorrelation create lower-dimensional features. The K-means clustering method distinguished acoustical classes for the first three principal components. [16]

The data processing results can be converted into essential discoveries but must be presented clearly to link them to the right sediment type. To have compelling

proof of the presence of sediment layers, the numerous relations between the sediment characteristics and their dependency on the suitable parameters must be portrayed accurately. Various software bathymetry maps in 2D and 3D may be created using acoustic systems like SBES and MBES data to offer a depth profile across the surveyed area [9]. It is possible to compare the fluctuation of various acoustic characteristics with depth or pressure to existing literature and data. The experimental graphs created using raw data from laboratory examination of in situ samples are compared to find the best match[15].

Various mathematical models may also be applied when processing data. Models are built on several assumptions. The use of several models yields a range of outcomes. The most accurate model, which leads to a reasonable estimation of sediment types, is obtained by contrasting the impacts of multiple models with the observed data from in situ samples. If the simulated data closely resembles any existing charts and patterns, each sediment type can be classified correctly since each has a unique way of parameter change.

5.3. To Share

The third category of to share entails networking hardware, protocols, and algorithms for sharing data with various users. Once the data has been analysed and valuable information is accessible, it should be sent to all interested parties and ground teams for prompt action. The communication network and display mechanism must be well-structured to provide a smooth flow of information and proper security. 26 The analysis efforts in the to understand category will also feed helpful information to enhance the networking capabilities. [28]

The to share concept necessitates providing consumers at various levels with actionable feedback in real time. The visualisation technique must be chosen when the goal parameters have been determined. Customers may want data in multiple formats, on various devices, or in alternative forms altogether. While practitioners wish to provide information in a short and simple style for immediate action, policymakers need inputs with solid analytical characteristics. Specific inputs in the preferred forms must be supplied to other affiliated parties. For this, either a mobile app adapted to distribution needs or a web-based GUI might be developed. While some users would need information on bathymetric

[28] Indian Strategic Studies: Acoustic Capacity Building in the Indian Ocean Region (strategicstudyindia.com)

maps, others would need details on the sediments' physical characteristics. Static displays and mobile applications may be used to create a seamless interface for users to receive input that may be taken action upon.

Another critical aspect of the topic is the time frame for the data to be visualised. Acoustic data is an essential resource for various users, such as policymakers, researchers, and the military, who each have specific demands over a range of periods. Long-term data spanning years or decades are needed by policymakers for quick reactions to calamities like tsunamis or shipwrecks, as well as for monitoring environmental phenomena that call for immediate action. However, to investigate the behaviour of marine life, the dynamics of ecosystems, and the consequences of climate change, researchers need acoustic data collected across short, medium, and long periods. While medium- to long-term data feeds strategic planning and intelligence collection for the military, real-time data is required by seafarers for marine security, tactical operations, and danger identification. Acoustic data may be used as a flexible tool for well-informed decision-making, scientific investigation, and security measures in maritime settings by catering to the various temporal demands of these users.

With the rising applications of the seabed, it has become essential to involve Marine Spatial Planning in the picture, thus providing an efficient way to visualise and interpret data and monitor the processes. Building acoustic capacity and competence requires a focused strategy and consistent efforts, particularly for tropical environments. As a result, the to see, understand, and share paradigm is crucial for assessing the success and adoption of technology.

6. Digital Transformation

The UDA framework requires a nuanced approach towards evolving the policy and technology intervention along with the acoustic capacity and capability building. These three are intertwined at multiple levels and need a clear understanding to build a comprehensive framework.

6.1. Technological interventions

Information Technology: To successfully use IT solutions for analysing sediment characteristics, marine scientists, researchers, and professionals must have the fundamental knowledge and equipment required for sediment classification. Data analytics, cloud computing, machine learning, artificial intelligence, the Internet of Things, geographic information systems (GIS), remote sensing, and data visualisation are among the topics taught in this effort. This enables them to produce sophisticated sediment distribution maps and automate classification procedures using machine learning. The ultimate goal of this capacity-building project is to improve our comprehension of sediment dynamics and environmental management in the many maritime ecosystems of the IOR via multidisciplinary cooperation, informed decision-making, and the use of cutting-edge IT technologies.

Region-Specific Systems: Due to their extreme specialisation in design and development, only a handful of companies worldwide provide underwater acoustic sensors. They fall within the restricted technology category as well. Therefore, imports always need an end-user certificate. The United States and the Scandinavian nations are where most of the well-known acoustic sensors are produced. Developing our capacity to manufacture these gadgets in India is unquestionably essential, but it may also need strong engineering and material science skills[29]. Private companies may provide creative and effective solutions thanks to the expanding use of acoustic methods in the maritime environment. Scientific ocean research must be prioritised, requiring significant investments in engineering and technology and the deployment of human resources. Technologies for deep ocean mining, such as drilling rigs, positioning systems, pipeline networks, power sources, launching and recovery systems, and deep ocean platforms, are to be developed.[30] Universities and research centres across India and the nations bordering the Indian Ocean should invest in developing AUVs and ROVs. They should cooperate with foreign partners to improve their capacities and advance knowledge sharing. Private businesses with a stake in developing AUVs and ROVs for economical and effective underwater operations and those engaged in offshore industries, underwater construction, and oil and gas exploration might be enlisted for joint development.

[29] Indian Strategic Studies: Acoustic Capacity Building in the Indian Ocean Region (strategicstudyindia.com)
[30] INDIA'S BLUE ECONOMY A DRAFT POLICY FRAMEWORK

Digital Oceans: Information is vital to having a good data series of the essential natural factors and economic actions that change over time. Berg et al. [31] discuss how the sea can be used to share information and ideas. Ideas and cultures have been spread both on purpose and by accident through exchanges in the marine area[32]**.** The government should fund infrastructure for data gathering, including sensors, buoys, and data collecting systems. The collection of several oceanic data parameters, including weather, water quality, and wave patterns, is made possible by these infrastructure arrangements. Large volumes of maritime data may be collected via remote sensing, satellite imaging, UAVs, and LiDAR for oceanographic research, coastal zone management, and offshore resource development. Private enterprises might set up data-sharing platforms and services to encourage the exchange of marine data among various stakeholders. These platforms would support the creation of centralised repositories, allowing data suppliers to share their information with approved users, including researchers, decision-makers, and enterprises. One of our works **[]** talks about the crucial role that private enterprises play in improving data accessibility. To improve data quality, establish data standards, and create protocols for transferring marine data, corporate and public organisations should work together on initiatives.

6.2. Acoustic Capability and Capacity

India is developing its acoustic capacity for sediment classification systems as part of a strategy plan to improve its use of acoustic technology. These endeavours include training and instructional initiatives to give scientists, researchers, and marine professionals the knowledge and abilities necessary for successful acoustic sediment analysis. Access to cutting-edge acoustic tools like sonars, robots, AUVs and detailed training on maintenance and usage is required. Participants must get practical training in data collection, processing, and sediment classification procedures to effectively interpret acoustic data and draw conclusions regarding the composition and distribution of sediment. India can lay a solid foundation for incorporating acoustic sediment classification into environmental management, policymaking, and scientific research by fostering collaboration, exchanging best practices, and supporting research initiatives. This will help to create a thorough understanding of its aquatic ecosystems and encourage sustainable practices.

[31] Support to Marine Research for Sustainable Management of Marine and Coastal Resources in the Western Indian Ocean Håkan Berg, Julius Francis and Petra Souter
[32] Integrated ocean management for a sustainable ocean economy Jan-Gunnar Winther

Upskilling: Collaboration between the different national and international groups would help people understand how things work worldwide and what needs to be done in India. Projects like the Indian program on deep-sea benthos, which is part of a search for polymetallic nodules in the Central Indian Ocean Basin, and parallel programs on the geology and geochemistry of mid-ocean ridges are also good ways to find out about the types of deep-sea benthos and where they are found[33].

Industry Training: Private sector businesses frequently contribute to collaborative R&D projects with university institutions and research bodies. Collaboration between IITs, IISC, other governmental institutions and the corporate sector would boost research and technology development. Further, cooperation between the private sector, educational institutions, and training centres is critical for skill development. Partnerships between the private sector and academic institutions promote knowledge sharing and talent development, like incorporating information technology and advanced 3D modelling.

Human Resource Development: India, expected to have a population of 1.42 billion by 2023, has significant demographic challenges and future opportunities. The government of India has to concentrate on enhancing the abilities of its personnel so that they can utilise new technology effectively and professionally. They should also learn about the data features and apply them to create fresh, practical, IOR-compatible solutions. Private maritime businesses often collaborate with educational institutions and training facilities to deliver industry-driven training courses. They may assist with the Skill India programme of the Indian government, which aims to increase the skills of the Indian workforce in various areas, including the marine sector. By giving industry-relevant training utilising cutting-edge techniques like computer-aided modelling, machine learning, artificial intelligence, etc., it attempts to increase employability. India has to significantly increase expenditure on research, innovation, and technology to create long-term leadership[34].

In addition, a complicated regulatory environment with various sovereign laws, regional agreements, and international rules adds to the difficulties. Even though

[33] IIOE-2 & Northern Indian Ocean Geosciences: some scientific questions, gap areas and challenges. (aquadocs.org)
[34]https://timesofindia.indiatimes.com/blogs/voices/how-funding-for-rd-research-and-development-will-promote-innovation-in-the-online-gaming-industry/

most countries in the Indian Ocean have their own legislation, many countries lack proper standards, guidelines, and enforcement mechanisms due to a lack of information and limited capability[35]. The subsequent section will highlight the policy interventions needed for efficient governance systems for deploying acoustic systems in the region.

7. Policy Interventions

The Indian Ocean lies on a strategic axis, being the vital trade, commerce and travel route among the various nation-states. It has been a critical trade path for hundreds of years, linking Africa, the Middle East, India, Southeast Asia, and East Asia. In today's ever-evolving world, the Indian Ocean is essential to regional and global politics[36]. To make plans for tracking, protection, and the economy, it is necessary first to understand the gaps in the current systems and then build models by looking at how other systems work worldwide.

Stakeholder Engagement: Integrating sediment classification data may promote stakeholder involvement by presenting visual representations of sediment distribution and characteristics. This may improve stakeholder engagement and boost accessibility to complicated technical knowledge. The three aspects of this are outreach, engage and sustain. The first and most important responsibility is to educate all stakeholders and decision-makers on the need for, importance of, and implementation of the sector skill council. To achieve this, hosting seminars, workshops, and round-table discussions will be necessary. Along with NITI Aayog, the Ministry of Skill and Entrepreneurship might serve as the nodal ministry for implementing this plan.[37] Then comes the engagement. Multiple layers and different organisations must be involved in the interaction. After the first outreach, the critical organisation spearheading the drive to establish the sector skill council would be urged to sign MoUs with the stakeholders and policymakers. The sustain phase ensures the policy framework, infrastructure, and continuous financial and human resources flow to guarantee the initiative's long-term sustainability.

7.1. Integration of Marine Spatial Planning and Blue Economy

[35] Blue Economy in the Indian Ocean: Governance Perspectives for Sustainable Development in the Region APARNA ROY
[36] Hood, Raleigh & Wiggert, Jerry & Naqvi, S.W.A.. (2009). Indian Ocean research: Opportunities and challenges. Geophysical Monograph Series. 185. 10.1029/2008GM000714.
[37] Nishtha Vishwakarma. Position Paper: Skilling for Enhanced Blue Economy

Research and technology are essential for the UDA to support marine industry growth. We may accomplish this by concentrating on the expansion of the acoustic capacity. Interventions at all levels of governance are necessary for this capacity development, considering the area's unique needs. The blue economy may be successfully used in this respect to comprehend the pressing need for building such capability in the area.

The Blue Economy (BE) is the major highlight of India's G20 presidency this year. The blue economy has greater connection and value to the global south than the global north. India's future Blue Economy strategy will govern these operations and pave the road for our UN Sustainable Development Goals objectives. It is a unique chance to prioritise the BE for the sake of development, green economy, and social fairness, given the significance of the BE on a global scale, especially for ocean-dependent populations in the global south who are vulnerable. India might do well to work with the other countries in the Indian Ocean Rim Association (IORA) to make a good plan for the Blue Economy and work with the small countries in the IOR on a positive economic goal. The role of technology and study will be vital. [38]

Additionally, Marine Spatial Planning (MSP) is becoming a practical way to create and set up a more organised way of using marine space and how its applications interact with each other to balance the need for development with the need to protect marine ecosystems and to reach social and economic goals in an open and planned way. Integrating MSP with acoustic sensors in the Indian Ocean can help develop an end-to-end model for maritime domain applications fusing acoustic sensors in the Indian Ocean by providing a framework for analysing and allocating the spatial and temporal uses of marine resources to meet ecological, economic, and social goals. This will help us find a balance between the rising pressure from human activities and the growing vulnerability of our coastal areas. We shall look into the sectors where MSP can help better understand the UDA framework in the context of Sediment Classification in the IOR. MSP is a collaborative process involving stakeholders from various sectors, such as fisheries, commerce, tourism, and conservation. MSP can assist in identifying data collection areas based on ecological, economic, and social criteria. Once the MSP plans have been developed, they must be implemented and monitored to

[38] http://www.indiandefencereview.com/spotlights/acoustic-capacity-building-in-the-indian-ocean-region/

ensure they produce the desired results. This can include a variety of activities, such as the creation of regulations and guidelines, the establishment of monitoring programmes, and the provision of compliance incentives. The surveillance data can be used to evaluate the MSP plans' efficacy and make any necessary adjustments to enhance their performance.

8. Conclusion

The Indian Ocean area is situated along the busiest trade routes in the world. Since it is strategically and economically significant, practically every global actor is interested in it. The natural resources must be used sustainably. Acoustic systems and sediment classification methods may be used to do this. The sediment classification approach is used in various operations, from ecological to economic, strategic to leisurely. Sediment-carrying pressure, benthic ecosystem management, and abiotic element detection have been our three main areas of concentration. The acoustic-based sediment-bearing pressure assessment is a game changer concerning the survey areas, time, and resources needed. Acoustic systems precisely depict the ocean bottom and are more comprehensive than traditional methods. The methods for calculating sediment-bearing pressure have improved, making the procedure more thorough and less time-consuming. One cannot just adopt a well-established model for any location despite the availability of several models and techniques. The growth of the maritime realm still faces various obstacles.

We have tried to describe the IOR's approach for classifying sediment. Its four main aspects are the source-path-receiver model, policy-technology-acoustic capability, to see, to understand, to share understanding, and the applications of sediment classification. This is based on the UDA framework and can be visualised as a multifaceted cube with four vertical faces.

The source-path-receiver model is based on a knowledge of how acoustic signals function in the underwater realm and how their features vary as they travel through the Indian Ocean's waters. We have emphasised the unique qualities of the Indian Ocean that make it difficult for imported systems to function well, necessitating the independent creation of acoustic systems for improved flexibility and financial savings. The to see, share, and understand the idea, highlighting the numerous acoustic sensors and hardware to be utilised for the various applications, is also presented in this context. The roles of data analytics,

machine learning, cloud computing, and AI are underlined in processing the signals and disseminating them to the pertinent stakeholders.

Due to the nation's expanding aspirations to participate in the IOR, increasing the institutions' competency and capacity is essential. Regarding socioeconomic development and the blue economy, more scientific and environmental data must be collected and exchanged. The need for diverse nations to employ similar processes is one of the main obstacles. The area will benefit more from the data by standardising reporting and procedure. To ensure the region's comprehensive growth, these deficiencies must be filled. The existing systems in other areas of the world can be immediately used here since the IOR has exceptional climatic circumstances that cause different acoustic sensors to work less than optimally while also being near a large population. Due to divergent national interests and growing resource constraints, the Indian Ocean Region (IOR) confronts difficulties. To guarantee that maritime resources are managed sustainably and to cope with the many stressors brought on by climate change and environmental degradation, a clear, complete, multi-scalar, and coordinated regional response is required to deal with regional stability and the consequences of climate change. Underwater domain awareness, marine spatial planning, the blue economy, and cutting-edge technologies to upskill the workforce would all need to be included. A fresh conversation about further plans to develop a framework to communicate data across the environmental, biological, commerce, and security sectors is required. A greater understanding of the Indian Ocean would lead to creative solutions for a brighter, more prosperous, and safer Indian Ocean. This understanding would be sparked by increased trust among regional players, increased collaboration between international institutes, and the role of the private sector in capacity building in IOR nations.