Position Paper

UDA for Sediment Classification in the Indian Ocean Region

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1. Introduction:

Recreational, economic, and military oceanic applications need qualities of the seabed close to the surface. For locating stable environments and ensuring the proper operation of structures, pipelines, and other installations on the surface of and buried within marine sediments, construction projects on ocean seafloors frequently require extensive knowledge of strength, deformability, and hydraulic, thermal, acoustic, and seismic properties.

A detailed study of the surface sediment topography and composition is thus necessary for an enhanced understanding of the immense potential of marine resources. These are based on the sediment classification idea. The effective use of sediment classification systems lies in estimating the bathymetry, strength, and stability of sediment layers necessary for offshore construction and exploration operations. The Acoustic Seafloor Classification thus has many crucial applications. The Indian Ocean Region has vast quantities of petroleum, natural gas, and essential minerals such as iron, manganese, nickel, and gold[1]. To anticipate geotechnical and acoustic qualities in the upper few metres of the seabed, civilian and military communities must establish seafloor and sub-bottom structures[2]. The types of sediment present on the ocean floor are of immense importance in today's ever-evolving world. This demands a comprehensive view of the sediment topography and composition at the surface and in deeper layers of the chosen location. The conventional methods for sediment classification involve taking physical samples from the desired site. But, conventional direct or in-situ seabed sampling is inefficient and costly, making it hard to perform a large-scale, rapid study.

Owing to the fast development of sonar devices and signal-processing technology, acoustic approaches for imaging seabed ecosystems have shown considerable promise. The Acoustic Seabed Classification System (ASCS) is a system for predicting acoustic impedance, sediment type, and various specified geotechnical parameters of the seafloor in near real-time. Classification of sediments using acoustic remote sensing techniques is advantageous due to their excellent coverage capabilities and low cost compared to the physical sampling of the bottom. For this, acoustic systems involving active sonars like Side Scan Sonars (SSSs), Single Beam Echo-Sounders (SBESs), Multi-Beam Echo-Sounders (MBESs), and Sub-Bottom Profilers (SBPs) are used. [3] [4] Optical remote sensing is another alternative to map seabed sediments. Depending on the depth, environmental circumstances, area of interest, and available resources, these devices may be hull-mounted, towed, or hung. Autonomous Underwater

[1] 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-norms/

[2] Lambert, Douglas N, Walter, Donald J, and Griffin, Sean R, Benjamin, Kim C, "Acoustic sediment classification developments," Sea Technology, Sep 1999

[3] 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

[4] Wan J, Qin Z, Cui X, Yang F, Yasir M, Ma B, Liu X. MBES Seabed Sediment Classification Based on a Decision Fusion Method Using Deep Learning Model. Remote Sensing. 2022; 14(15):3708. https://doi.org/10.3390/rs14153708

Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) have enabled seamless surveys in remote places.

Such new technologies offer opportunities for exploring, exploiting, conserving, and managing diverse marine resources. Sediment texture impacts biotic and abiotic components, with significance in various disciplines. Potential aspects of such systems include

- Offshore infrastructure, like drilling rigs, tanks, and refineries, is supported by seabed foundations.
- Benthic Ecosystem Management, for establishing the value of marine organisms, mapping, monitoring and conserving these resources and ocean biodiversity.
- Marine Litter - Trash deposits in aquatic environments destroy marine ecosystems and pose a long-term economic and environmental threat.
- Underwater Cable routes. Communication cables carrying voice and data transmissions constitute the majority of ocean cable installations.
- Offshore oil and gas activities. This includes developing presently unleased areas of the outer continental shelf (OCS) where mature technology offers the assurance of operationally safe, environmentally sound, and economically secure development.

In this paper, we'll look deeper into the opportunities in the marine domain about the three broad aspects - Sediment Bearing Pressure Analysis, Benthic Ecosystem Management and Abiotic Element Assessment. We will then present the Under Domain Awareness (UDA) framework, highlighting how it can prove to be a game-changer in harnessing the socio-economic potential of the Indian Ocean Region.

2. Applications of the sediment classification systems in the marine domain:

2.1. Sediment Bearing Pressure Analysis:

Sediment Bearing Pressure (SBP) refers to the force per unit area exerted by sediment 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. Overall, understanding sediment-bearing stress is essential for ensuring the safety and stability of structures built on or in contact with sediment and for preventing costly and potentially dangerous failures. Such structures are vital considering economic growth and strategic importance. For example, the bearing pressure may be critical in shallow-water warfare, like the deployment of tanks, temporary bridges or amphibious vehicles in shallow waters.

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[5]. 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[6]. This necessitated the collection of bathymetric data from ships. Despite being made public, the data collected during the flight search of MH370 only covers about 1% of the ocean floor in the Indian Ocean[7].

With the introduction of acoustic-sounding technology, it is now possible to gather the bathymetry, topography, measure 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[8]. This information is collected using specialised vehicles equipped with sensors to capture and store the necessary data. Standardly, specialised drilling vessels are outfitted with basic soil testing equipment. This facilitates testing and characterisation of samples, subsampling specimens for immediate testing, and resealing the remaining sample in a watertight container[9].

Moreover, such systems form crucial aspects in determining the safety and settlement of bridges. Every year after flood erosion around piers, the settlement must be moored. If necessary, protection measures must be taken to prevent sudden failures[10]. The Chadoora Bridge is situated in the tehsil of Chadoora in Budgam, Kashmir, India. During the floods on September 2014, scouring around the foundation removed particles from the sand, gravel, and boulder matrix. Similarly, In August 2007, the Jahu bridge, situated 30 kilometres from District Hamirpur, collapsed twice for the same reason: foundation erosion. Local erosion around the bridge's abutment is one of the leading causes of bridge failure. A routine inspection schedule is essential for maintaining any bridge structure[11].

In India and worldwide, acoustic systems are widely used during port construction. They are essential for the characterisation of the seafloor, the evaluation of sediment properties, and the monitoring of sedimentation, erosion, and environmental impacts. The cases of Vizhinjam

[5] Smith, W. H. F., and Sandwell, D. T. (1997). Global seafloor topography from satellite altimetry and ship depth soundings. Science 277, 1957–1962.

[6] Picard, K., Brooke, B. P., Harris, P. T., Siwabessy, P. J. W., Coffin, M. F., Tran, M., et al. (2018). Malaysia Airlines flight MH370 search data reveal geomorphology and seafloor processes in the remote southeast Indian Ocean. Mar. Geol. 395, 301–319. doi: 10.1016/j.margeo.2017.10.014.

[7] 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.

[8] National Research Council. 1989. Our Seabed Frontier: Challenges and Choices. Washington, DC: The National Academies Press. https://doi.org/10.17226/1413.

[9] GUIDANCE NOTES ON GEOTECHNICAL INVESTIGATIONS FOR SUBSEA STRUCTURES FULL DRAFT FOR DISCUSSION REVISION 02 : 31st August 2000, Prepared by the Subsea Working Group of the Offshore Soil Investigation Forum .

[10] Jain, J. K.; Bhargava, Rajesh; and Saxena, A. K., "Foundations Failures of Bridges and Geotechnical Investigations" (1993). International Conference on Case Histories in Geotechnical Engineering. 34. https://scholarsmine.mst.edu/icchge/3icchge/3icchge-session01/34

[11] Rajendran, Raghavendra. "Bridge failures case studies in India (2016-2019)." (2019).

International Seaport[12] in Kerala, Chabahar Port[13] in Iran and Ennore Port, Tamil Nadu[14], showcase the use of acoustic systems like MBES and SBP to characterise the seafloor and evaluate sediment properties. The collected data was utilised to inform the design of the port's breakwaters, jetties, and other infrastructure.

2.2. 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[15]. 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.[16]

After 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 macrobenthic and meiobenthic communities[17] [18], as well as organic carbon[19] and contaminant dispersion[20]; and organic carbon. Therefore, sediment texture must be evaluated for topographical study, biological characterisation of benthic environments, and environmental assessment of human-affected marine coastal areas[21].

India is recognised as one of the 12 mega-biodiversity countries in the world and is endowed with abundant biological resources. The mapping of lakes and rivers necessitates technical expertise in remote sensing, GIS, and hydrology. 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 which 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 drags a net down the bottom to capture fish or other target

[12] Development of Vizhinjam International Multipurpose Seaport Through Public Private Partnership MANUAL OF SPECIFICATIONS AND STANDARDS.
[13] Mahmoudof, Seyed Masoud, Amin Eyhavand-Koohzadi, and Mohammad Bagheri. "Field study of wave reflection from permeable rubble mound breakwater of Chabahar Port." Applied Ocean Research 114 (2021): 102786.
[14] Rao, V. Ranga, et al. "Littoral sediment transport and shoreline changes along Ennore on the southeast coast of India: Field observations and numerical modeling." Geomorphology 112.1-2 (2009): 158-166.
[15] Sala, Antonello, et al. "Adriaan D. Rijnsdorp, Ole R. Eigaard, Andrew Kenny, Jan Geert Hiddink, Katell Hamon, Gerjan Piet, Antonello Sala6, J. Rasmus Nielsen, Hans Polet, Pascal Laffargue, Mustafa Zengin, Olavur Gregerson."
[16] Benthic Indicators. Retrieved from: https://www.epa.gov/national-aquatic-resource-surveys/indicators-benthic-macroinvertebrates
[17] 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.
[18] The Law of the Sea in Perspective. Downloaded from https://www.cambridge.org/core.
[19] 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.
[20] Sediment Classification using Model-based Techniques with Field Validation, Maritime Research Centre, Pune.
[21] The Territorial Waters, Continental Shelf, Exclusive Economic Zone And Other Maritime Zones Act, 1976.

species. This approach may harm benthic ecosystems and change the structure and functioning of benthic populations. Appropriate management and conservation methods 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. Research[22] highlights how complicated and varied the responses of benthic organisms to aquaculture, water flow and how fish are raised should be considered when figuring out the effects. The results could change fisheries management, site selection, and monitoring schemes. The study also stresses the importance of combining benthic measures with other tools and information to make the environmental assessment and forecasts more accurate.

Benthic ecosystems offer diverse habitats, such as coral reefs, kelp forests and seagrass meadows. 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. To build complete species distribution maps, benthic data such as seabed maps, habitat classification systems, and underwater photography may be coupled with species occurrence data such as surveys, trawl data, and remote sensing. Researchers may increase the accuracy and precision of species distribution models by including benthic ecosystem information in these mapping efforts.

Moreover, changes in ocean temperature and acidity are among the effects of climate change that significantly impact global marine ecosystems. For instance, The Gulf of Mexico, one of the world's largest dead zones, has oxygen levels too low for marine life[23]. Scientists have warned local officials and legislators for years, but they have refused to take action, causing damage to the marine ecosystem and fishery communities. Climate change, exploitation, and pollution imperil the iconic and biodiverse marine environment of Australia's Great Barrier Reef[24]. In recent years, bleaching episodes, when ocean temperatures surge above average, have devastated the reef.

[22] Assessing the suitability of a range of benthic indices in the evaluation of environmental impact of fin and shellfish aquaculture located in sites across Europe Ángel Borja, J. Germán Rodríguez, Kenny Black, Alain Bodoy, Chris Emblow, Teresa F. Fernandes, Janez Forte, Ioannis Karakassis, Iñigo Muxika, Thom D. Nickell, Nafsika Papageorgiou, Fabio Pranovi, Katerina Sevastou, Paolo Tomassetti, Dror Angel

[23] Rabalais, Nancy N., R. Eugene Turner, and William J. Wiseman Jr. "Gulf of Mexico hypoxia, aka “The dead zone”." Annual Review of ecology and Systematics 33.1 (2002): 235-263.

[24] Ainsworth, Tracy D., et al. "Climate change disables coral bleaching protection on the Great Barrier Reef." Science 352.6283 (2016): 338-342.

2.3. Abiotic Element Detection:

The discovery of abiotic elements in the Indian Ocean is a key part of understanding the makeup, movement, and geological processes of sediments in this huge marine area. Classifying and identifying abiotic elements in sediments is important for understanding ocean settings, resource exploration, and managing the environment. Abiotic element detection on the seafloor is a fundamental issue necessitating the identification and localisation of items that are not part of the natural ecosystem of the seafloor, such as lost or abandoned debris or shipwrecks. In fact, half of the top 10 nations responsible for ocean plastic pollution come from Indonesia, Thailand, Malaysia, India, and Bangladesh, and two of the biggest and most polluting rivers (the Ganges and the Indus) empty into the Indian Ocean. In addition, it is predicted that the Indian Ocean has the second-largest plastic load in the ocean behind the North Pacific Ocean[25].

The region surrounding the Indian Ocean contains petroleum, natural gas, and essential minerals such as iron, manganese, nickel, and gold[26]. Polymetallic nodules (PMN), which form another essential aspect of the abiotic component, are an exceptional type of high-tonnage mineral deposit containing cobalt, nickel, and manganese. Deep-sea polymetallic nodules are potato-sized concretions that have the potential to be economically exploited as a mineral resource, particularly for use in novel energy batteries[27]. However, these PMNs are located in environmentally protected, remote regions[28] 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[29].

To conduct deep-sea research, it is necessary to acquire scientific, bathymetric, and biological data, which can be used to develop long-term conservation programmes, exploration missions, and other benthic applications. Consequently, depending on the required data, multiple geophysical and geotechnical surveys are conducted to collect samples from the seafloor[30]. 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

[25] 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.

[26] 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/

[27] 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.

[28] Kang, Y.; Liu, S. The Development History and Latest Progress of Deep-Sea Polymetallic Nodule Mining Technology. Minerals 2021, 11, 1132.

[29] 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

[30] Best Practices for Marine Microplastic Sampling and Analysis National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences. Retrieved from: https://www.niot.res.in/niot1/uploads/edited_Ocean_Best_Practice_Marine_plastics_samping_in_Open_Ocean.pdf

now considering schemes to develop prolonged technological devices and promote responsible e-waste recycling[31].

Another aspect of the abiotic component is underwater archaeology, the study of past human societies and activities in lakes, rivers, and oceans. This field employs archaeological techniques and principles to locate, identify, and investigate submerged cultural heritage sites, such as shipwrecks, sunken civilisations, and other underwater archaeological sites.

Assessing the impact of such abiotic elements on the marine ecosystem is one of the major challenges in the current scenario. Accurately predicting and monitoring techniques lead to proper management of the ecological assets. There is now a pressing need to incorporate marine geophysical equipment, including side scan sonar, echosounder, etc., which have become indispensable for locating submerged and concealed objects like shipwrecks and anchors. Such systems also aid during the initial reviews of port installation remnants and other subsea structures. These techniques can quickly explore a relatively large area without endangering living organisms[32].

3. Critical gaps in the current operations:

The Indian Ocean lies on a strategic axis being the vital route for trade, commerce and travel among the various nation-states. It has been an important trade path for centuries, linking Africa, the Middle East, India, Southeast Asia, and East Asia. Ancient trade routes like the Silk Road and the Spice Routes relied on the Indian Ocean to move goods like spices, cloth, precious metals, etc. Even though it has so much potential, the Indian Ocean doesn't get as much attention as the North Pacific or the Atlantic. Developing a holistic plan for a sustainable socio-economic development of the region requires understanding the gaps in the current systems and then building models by looking at how other systems work worldwide.

But before we dig into understanding the various knowledge and policy gaps, we must understand where the gaps actually lie. The Oceans and their resources are shared resources. Thus, any initiative for deep sea exploration, research and exploitation of such assets requires strong global and regional backing. The global legal frameworks and the national enforcement capabilities must be precise to reduce the strain on the assets. But in reality, there are flaws in the international systems, which have also crippled across the regional and national landscapes. The combination of the gaps at all the levels of governance hampers the sustainable use of marine resources.

[31] 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.

[32] 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.

3.1. Capacity and supporting infrastructure

Our knowledge of the Indian Ocean's potential is seeing varied growth across the nations because some countries don't have the right human, institutional, or technological resources. Many of the countries in the region lack the skills and resources they need to handle and protect their marine zones and to contribute to the security of the whole area[33].

- Inadequate infrastructure poses a significant challenge in the realm of acoustic system development and deployment. Establishing these systems necessitates specialised resources such as research vessels, acoustic sensors, and advanced processing equipment. Unfortunately, the accessibility of such essential infrastructure remains restricted within India, thereby impeding the seamless integration of advanced sediment classification systems.

- Due to financial and resource constraints, maintaining and enhancing data infrastructure becomes challenging, potentially resulting in outdated or insufficient information. The process of developing, implementing, and maintaining acoustic devices incurs significant costs. The expansiveness and effectiveness of sediment classification systems are curtailed by financial considerations, particularly in regions with limited resources. India's prominent role in the Indian Ocean Region (IOR) has been undermined due to insufficient financial allocation by the national government towards marine initiatives, coupled with a lack of awareness about their significance. The governmental funding for nationwide environmental monitoring projects has been inadequate. For India to sustain its leadership position, it must substantially increase research, innovation, and technology investments.[34]

- Collaboration among marine science, acoustics, data analysis, and technology experts are imperative for creating and sustaining acoustic sediment classification systems. However, it's important to note that there might not be an extensive pool of highly skilled professionals available in these domains.

- The development of acoustic sensors capable of detecting specific local conditions necessitates a substantial research capacity. Fields such as sound surveys, underwater biotechnology, and underwater artificial intelligence and robotics hold paramount importance in marine studies and skill enhancement. Regrettably, no university in the country offers these courses at any academic level. Having such a capability would have facilitated the training of our young population, fortified heavy industries and their associated enterprises, and generated numerous employment opportunities.[35]

- To effectively share sediment classification data like bathymetry or benthic species distribution, a robust infrastructure is necessary to facilitate data storage, organisation, and distribution. This entails the need for comprehensive expertise across various domains, including data management and analysis, cloud computing,

[33] Krishnappa Venkatshamy (2013) The Indian Ocean Region in India's strategic futures: looking out to 2030, Journal of the Indian Ocean Region, 9:1, 17-41, DOI: 10.1080/19480881.2013.793911

[34] https://timesofindia.indiatimes.com/blogs/voices/how-funding-for-rd-research-and-development-will-promote-innovation-in-the-online-gaming-industry/

[35]

and underwater acoustics. Unfortunately, a deficit of skilled professionals in specific fields has led to a depletion of qualified workforce, thereby diminishing the efficiency of existing systems.

3.2. Scientific data and knowledge gaps

The Indian Ocean remains the most under researched of all the world's oceans. In the past, political differences have made it hard for scientists to study the ocean. If we knew more about the oceanography of the Indian Ocean, we could develop early warning systems for say cyclones. This would allow us to make better plans ahead of time to lessen the effects of these terrible natural disasters. Improving marine scientific research in the area is mostly a group effort, and many things can be done there. [36]

- India, a megadiverse nation, has bountiful biological resources, but the existing databases are insufficiently exhaustive. Due to a lack of data on benthic communities, for instance, it is challenging to assess the effects of climate change on these habitats and to develop effective adaptation strategies to safeguard them[37].The conservation processes have been further strained by a lack of attention to acting on such problems and a delay in funding to resolve these issues. In addition, there is insufficient understanding of fisheries resources and their value[38].

- Accurate classification of sediments requires training data for acoustic classification systems. Obtaining high-quality training data in India can be difficult due to limited resources, logistical challenges, and the immensity of the littoral and marine regions. Accurate calibration and validation of acoustic systems are indispensable for producing trustworthy results. Establishing ground truth data for sediment characteristics in Indian waters can be difficult and time-consuming, which can affect the classification system's precision.

- To fully comprehend the marine environment, acoustic data collected from multiple sources, such as sonar systems, underwater gliders, and autonomous underwater vehicles, must be integrated and fused. This necessitated an in-depth comprehension of diverse data management and marine technology domains, which is scarce in India.

- Numerous methods and technologies are used to acquire sea data, resulting in varying data quality and formats. The accumulation of data from various sources into a common national/regional database is hampered by the absence of standardised guidelines outlining the tolerance of equipment to be used, data storage and processing techniques conforming to international standards.

[36] Integrated ocean management for a sustainable ocean economy Jan-Gunnar Winther
[37] Agardy, M. Tundi. "Advances in marine conservation: the role of marine protected areas." Trends in ecology & evolution 9.7 (1994): 267-270.
[38] Nine nations, one ocean: A benchmark appraisal of the South Western Indian Ocean Fisheries Project (2008–2012) Rudy P. van der Elst , Johan C. Groeneveld, Ana Paula Baloi, Francis Marsac, Kaitira I. Katonda, Renison K. Ruwa, William L. Lane

3.3. The monopoly of Western organisations

Across the globe, various expeditions and scientific data collection projects are underway. But most of such interventions are focussed on the North Atlantic and Mediterranean seas, backed by North America's and Europe's developed economies. Many of the early advances in marine data gathering and study came from Western nations, which had the financial means, technical skills, and scientific competence to engage in maritime exploration.

- Western corporations have established themselves as leaders in marine data due to their historical advantage. Historically, Western governments have made substantial investments in research infrastructure, including maritime research vessels, oceanographic apparatus, and data collection networks. These expenditures have enabled Western companies to accumulate substantial maritime data, contributing to their dominance.

- They have substantial relationships with academic institutions, government agencies, and international organisations, which facilitate sharing of knowledge, data exchange, and joint research initiatives. These networks have strengthened their position in maritime data collection and processing.

- The Indian Ocean region currently lacks substantial technological proficiency and established scientific foundations. As a result, it is imperative to exert renewed endeavours towards incorporating new technologies and conducting comprehensive explorations within this region. Due to insufficient financial resources and limited government support, numerous nations rely on more developed countries to provide data from their own immediate surroundings.

- Few Indigenous private players in the Indian Ocean having expertise in such acoustic sensors, sonars etc, again aggravate the reliance on Western firms, which pose dangers of strategic data being transferred to non-state actors.

3.4. Unique Indian Ocean Characteristics

Compared to the Atlantic and the North Pacific, the Indian Ocean has received relatively little research attention. The Indian Ocean region has its own political, social, oceanic, and other features.

- **Climate:** Due to elevated surface temperatures, it is susceptible to weather changes like monsoons, tsunamis, cyclones, and high winds. There are strong border currents in the IO, just as in the Atlantic and Pacific, but significant differences exist between them. The Indian Ocean Region (IOR) encompasses a range of environmental circumstances comprising varying water depths, fluctuations in temperature, and underwater currents. Acoustic systems need to adjust to these dynamic conditions to ensure precise and dependable data acquisition.

- **Acoustic:** Sonars utilised for underwater surveillance in the warm coastal waters of the Indian Ocean Region are not as effective as they could be. This applies to both

military and non-military endeavours. The warm coastal waters of the IOR are acoustically shallow, making it difficult for any type of sonar to function effectively. The efficacy declines by 60 to 70%. Due to both manmade (such as shipping) and natural (such as marine life, and geological processes) sources, the IOR may be a noisy environment.

- **Diversity:** Additionally, IOR's coastal seas are among the most diversified, which delays the signal and increases transmission losses. Due to this complexity of the distribution model, proper adjustments are required to retrieve relevant data.[39] [40]

- As stated in the preceding subsection, the monopoly of Western companies over modern technologies exacerbates the existing knowledge disparities. Most international systems are inappropriate for local conditions, and their high costs make them a poor investment. New systems exploiting the demographic dividend's potential must be developed in the IOR.

3.5. Inefficiencies in Governmental Institutions

In many cases, the local authorities have frequently been sluggish in regulating and enforcing environmental laws, resulting in significant damage to the marine environment and local economies despite the hazards associated with industrial activities.

- The authorities lay a blind eye to the development potential of the seafloor as it would require extensive funding and swift technological interventions.

- The situation is further exacerbated due to a lack of awareness and expertise. The government workers might not have the basic information and skills to monitor water bodies well. This means knowing how to monitor things, collect data, and figure out what the data means.

- They often use conventional, old-fashioned methods that take a lot of time and money; have limited resources, such as limited budgets and a lack of tools and lab space to track water bodies.

- The deployment of modern systems requires extensive training of the staff by specialised instructors, which might include complex procedures, apart from the being time and capital-intensive. Such ignorance by the authorities leads to inefficient operations.

[39]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)

[40]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

3.6. National Maritime Law

Maritime rules help monitor and control private, international, and local marine issues worldwide. Most of the time, these kinds of rules are hard to follow and cover a small area. So, there needs to be a national marine law that is a full system of public and private, substantive and process laws that rule all parts of the maritime regime, including maritime security, study, environmental protection, rescue, and recovery.[41]

- India has no single central authority exclusively for marine studies. Also, there isn't enough standardisation and harmonisation of research study methods, making it hard to compare different studies[42] [43].

- The absence of a central authority overseeing marine policy has led to a phenomenon known as "sea blindness." This term characterises a deficiency in comprehending issues related to the ocean, with terrestrial solutions often taking the place of maritime considerations[44].

- There are many expeditions going on in the IOR for a variety of purposes. Lack of regulating authority hampers the monitoring of the quality of data, damage to the environment, data collection process and documentation.

4. The UDA Framework and its Role in Assisting the Deployment of Modern Systems:

The increasing pressure on limited land resources has prompted the recognition of the potential of marine resources to meet human requirements. This pursuit of understanding the world's oceans, which remain less explored than Mars, demands the cultivation of specialised knowledge, advanced technologies, and a proficient workforce. These factors can contribute to socio-economic progress while adhering to sustainable objectives for an improved future. In this regard, the Underwater Domain Awareness (UDA) framework introduced by the Maritime Research Centre (MRC) will significantly contribute to creating comprehensive policy frameworks and skill enhancement in countries worldwide.

4.1. UDA Framework

The concept of Underwater Domain Awareness (UDA) originates from the aspiration to comprehend the occurrences within the submerged domains of our marine regions. The subsurface geophysical phenomena of the Earth hold significant relevance for human welfare, and monitoring these activities could offer essential insights to mitigate the impact of

[41] https://www.legalserviceindia.com/legal/article-10806-legal-guide-to-maritime-law.html#:~:text=The%20purpose%20of%20maritime%20law,claim%20damages%20and%20certain%20benefits.
[42] https://government.economictimes.indiatimes.com/blog/water-governance-reforms-are-key-to-sustainable-water-management-in-india/95736850
[43] Haegerbaeumer A, Mueller M-T, Fueser H and Traunspurger W (2019) Impacts of Micro- and Nano-Sized Plastic Particles on Benthic Invertebrates: A Literature Review and Gap Analysis. Front. Environ. Sci. 7:17.
[44] https://www.orfonline.org/wp-content/uploads/2012/12/Maritime_Capacity_of_India.pdf

catastrophic natural calamities. For assessing the state of ecosystems, it is imperative that every conservation initiative accurately gauges the deterioration of habitats and the susceptibility of species induced by these actions.

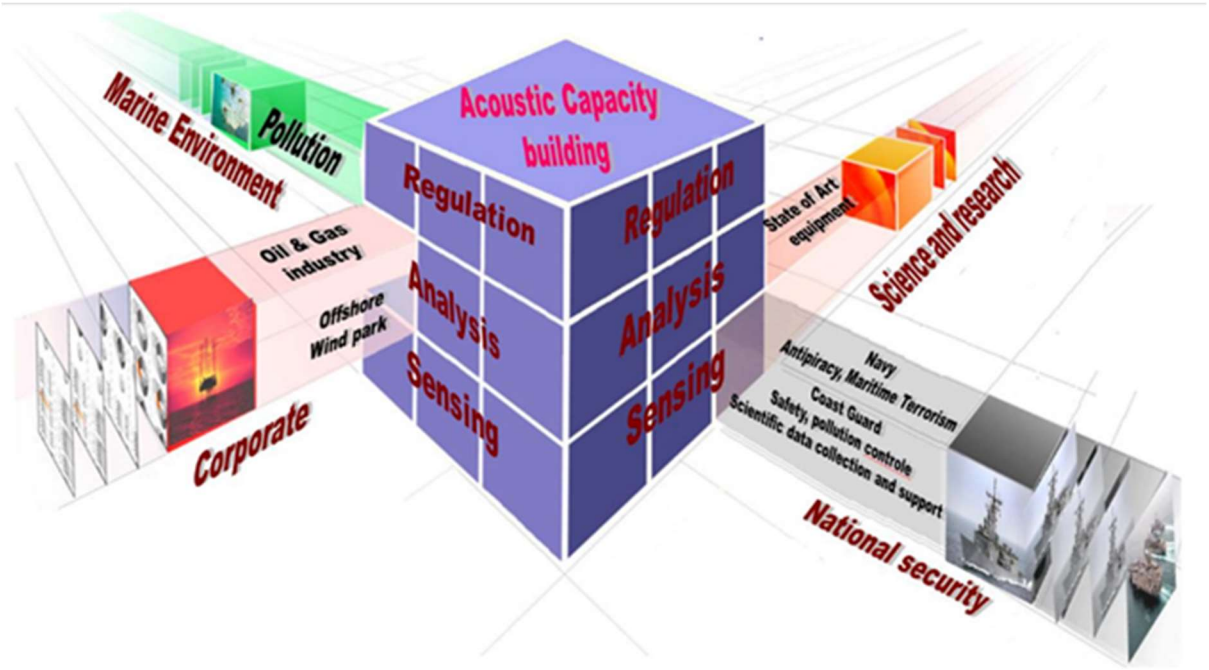


Figure 1: Underwater Domain Awareness Framework

The Underwater Domain Awareness (UDA) framework is structured in a multidimensional manner, as depicted in the given figure. On the horizontal axis, resource availability is considered, encompassing technology, infrastructure, and specific capabilities and capacities tailored to stakeholder needs. These stakeholders are symbolised by the cube's four faces, each with unique requirements, while the structure's core embodies the acoustic capacity and capability.

On the vertical axis, the framework illustrates the hierarchy for achieving a complete understanding of the UDA. At the foundational level, various undersea elements are detected, including potential threats, resources, and activities. Proceeding to the next tier involves the interpretation of the collected data to develop plans concerning security strategies, conservation measures, and resource allocation. The final stage entails creating and supervising regulatory frameworks on local, national, and international scales. This hierarchical approach ensures a comprehensive methodology for undersea domain management, reflecting an integrated strategy for security, conservation, and resource optimisation.

4.2. How can the UDA Framework lead to a holistic solution in the IOR

India needs to step up as a legitimate marine power in the IOR and help all the countries in the area handle the challenges and possibilities that are special to the IOR by creating a UDA structure based on science and technology. We can work on deploying the sediment classification techniques in the Indian Ocean region by utilising the structure of the UDA framework.

- **Stakeholders:** One of the major aspects of the UDA framework is to understand the stakeholders and their effective management. UDA encompasses activities related to monitoring, understanding, and managing underwater activities and resources. The sediment classification systems involve a variety of stakeholders. The broad domains which can be considered include

    - Sediment Bearing Pressure
        - Inland Waterways
        - Navigation
        - River dredging
        - Port Construction
        - Strategic asset deployment
        - Shipping industry
    - Benthic Ecosystem Assessment
        - Marine research
        - Environmental monitoring and conservation
        - Fisheries and aquaculture
        - Environmental Impact Assessment
    - Abiotic Element Detection
        - Oil and gas industry
        - Underwater mining
        - Underwater archaeology
        - Optic cables
        - Marine litter and pollution
        - Shipwrecks

- Collaboration systems might focus on outreach, people involvement, and long-term sustainability. The outreach will include informing politicians, partners, and practitioners in the region about the UDA framework and why it is crucial. As highlighted by Arnab Das, the demographic advantage in the region can be leveraged with a real implementation of the UDA framework for achieving the objective of “Towards a Resilient Region, Prosperous Economies, Healthy People”.

- **Skilling:** As India capitalises on its demographic advantage until 2055, it is imperative for the younger generation to be an integral component of the nation's transformation. The Indian authorities should focus on enhancing the expertise of

their workforce in domains like marine technology, underwater communications, acoustics, and cloud computing. This preparation will allow them to oversee, operate, and maintain contemporary sediment classification technologies. Furthermore, efforts should be directed towards uncovering the inherent traits of data and utilising them to devise innovative solutions tailored to the Indian Ocean Region (IOR). These endeavours can be seamlessly integrated into the Skill India Initiative undertaken by the Government of India.

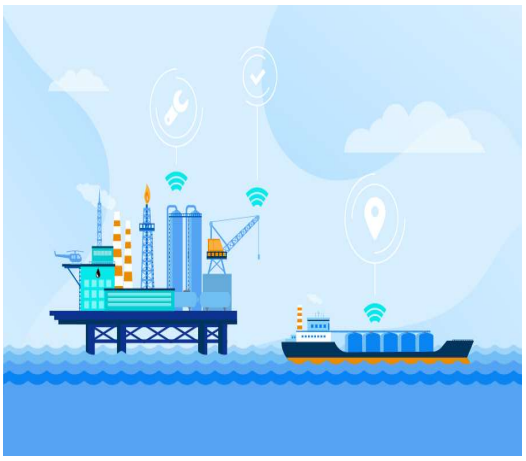
- **Innovation:** As mentioned earlier the IOR poses unique challenges to the acoustic systems rendering the foreign-developed systems ineffective and irrelevant in the local conditions. There is a pressing need to develop systems catered to the local conditions, taking leverage of the manpower and knowledge of the tropical waters.

- **Policy Gaps:** The technological capacity building is definitely one of the crucial aspects of UDA, but these would not be sufficient for developing India's capacity. The regulations bound with the deployment of such systems, the monitoring of data quality, ownership and their future use must be studied properly too. This involves highlighting the existing policy gaps and complexities within the institutional framework and working on specific interventions for the ease of deployment. This could involve formulating a common marine monitoring agency and a national maritime law.

- **Academics-Research-Industry:** The collaboration between Users, Academia, and Industry can be smoothly established by aligning user needs, academic insights, and industry involvement. Proficiency in the underwater domain is crucial for sediment classification systems, which can be catered to through specialised courses offered by domestic universities. Leveraging the advantages of the New Education Policy, these courses can be combined with practical industrial training to offer students a comprehensive perspective, fostering inventive and cost-effective solutions for the local context. The creation of multidisciplinary and multifunctional entities would allow academic institutions, industries, and stakeholders to seamlessly harmonise their endeavours towards a broader objective.

Inland Waterways[45]

Ports[46]



Fisheries[47]

Oil and Gas[48]

4.3. UDA and the Blue Economy

The UDA rests on science and technology to foster growth in the maritime domain. This can be achieved by focusing our requirements on the acoustic capacity development. Such capacity development requires interventions on all levels of governance incorporating the region's specific needs. In this regard, the blue economy can be effectively utilised to understand the urgency of developing such capacity in the region.

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 very important. [49]

- **Collaboration between the different national and international groups** would assist individuals in comprehending how the world operates and what needs to be done in India. Companies in the private sector frequently collaborate with academic

[45] https://geographyandyou.com/inland-waterways
[46] https://www.dnv.com/Publications/ports-green-gateways-to-europe-179372
[47] https://www.greenbiz.com/article/ocean-warming-has-fisheries-move-helping-some-hurting-more
[48] https://www.scnsoft.com/blog/iot-in-oil-and-gas

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

institutions and research organisations on R&D projects. Collaboration between India's top academic institutions, government institutions with private entities would pave the way for enhanced research and technological progress. Between 2019 and 2025, the National Infrastructure Pipeline in India estimates $1.4 trillion in Public Private Partnership investments across multiple industries. Infrastructure development requires significant private sector participation for PPPs.

- **Regional cooperation for the development of the blue economy**: regional marine administrations will require a multifaceted strategy to develop regional solutions. This requires discussions and policy formulations at the highest level. All regional organisations, such as the Indian Ocean Rim Association (IORA) and the Bay of Bengal Effort for Multisectoral Technical and Economic Cooperation (BIMSTEC), should discuss the UDA structure. Unprecedented efforts are required to develop acoustic capacity and expertise unprecedentedly. India must take the lead in the true spirit of the SAGAR mission for acoustic capacity and promoting data-sharing methods for the region's overall socioeconomic and sustainable development.

- **Bringing private entities into the Blue Economy**: The collaboration between the private sector, educational institutions, and training centres is essential for developing skills in the Blue Economy. Collaborations between the private sector and academic institutions encourage the dissemination of knowledge and the cultivation of talent, such as incorporating information technology. Collaboration in projects such as the Indian programme on deep-sea benthos, which is part of a search for polymetallic nodules in the Central Indian Ocean Basin and development of AUVs are also excellent ways for the private sector to contribute its knowledge and experience.

- **Financing various initiatives:** Governments could receive blue funding to enhance their capabilities in underwater endeavours. This funding could encompass various facets, including establishing early warning systems, monitoring vessels, specialised equipment, laboratories, and training centres.

- **Shared development**: The IOR has a diverse set of challenges, thus, innovative ideas need to be developed. Our institutions can work with Other international players to develop regional solutions.

4.4. Integration of Marine Spatial Planning and UDA

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.[50] We shall look into the sectors where MSP can help better understand the UDA framework in the context of Sediment Classification in the IOR.

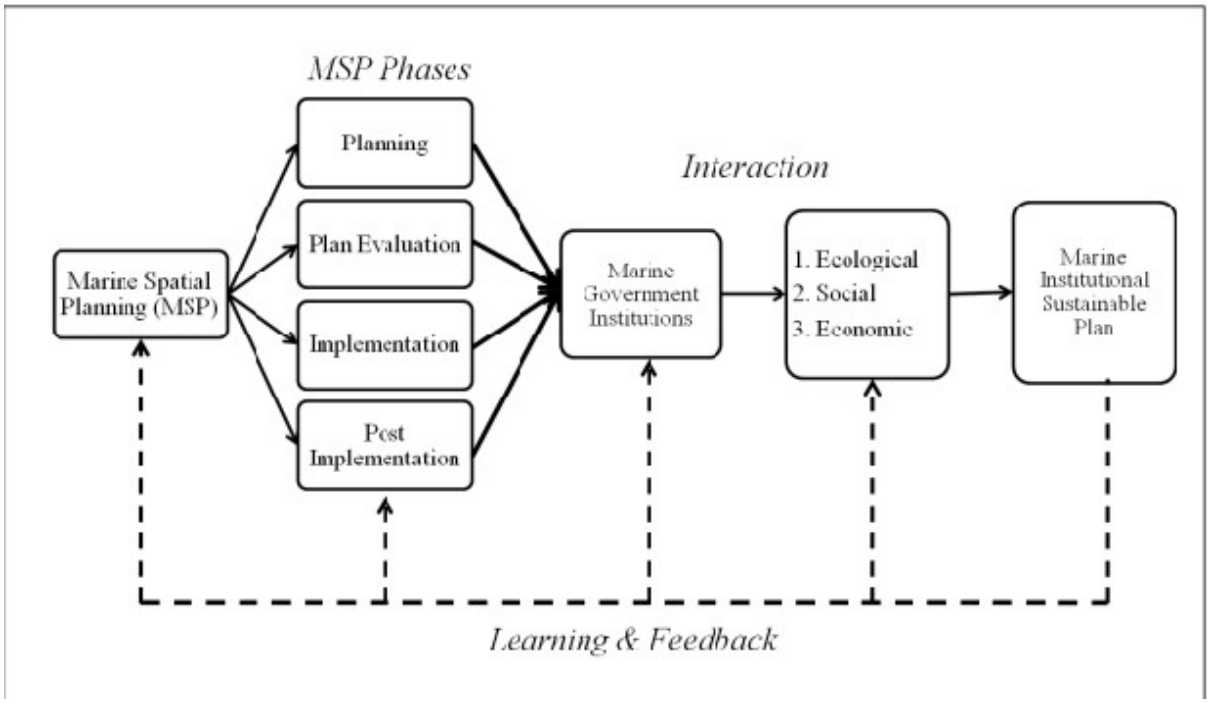


Figure 2: Marine Strategic Planning Framework[51]

- 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 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.

- **Source-Path-Receiver:** The "To see, To share, To understand" framework **[Enclosure 4]** holds significant importance in comprehending the diverse applications of acoustic systems. In the "To share" component, the emphasis lies on disseminating data to various users. Different consumers might have distinct preferences for data formats, devices, or even specific datasets. In this context, Maritime Spatial Planning (MSP) can assist in selecting appropriate options. A web-based graphical user interface (GUI) or a mobile application designed to meet distribution requirements would be developed to cater to these needs. Some users might seek bathymetric maps, while others may

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

51 Yatim, M. H. M. et al. "INSTITUTIONAL MAPPING TOWARDS DEVELOPING A FRAMEWORK FOR SUSTAINABLE MARINE SPATIAL PLANNING." ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 42 (2016): 159-166.

require data concerning sediment physical attributes. Additionally, the timeframe over which the data is presented is a pivotal consideration. For instance, policymakers would necessitate decades-long data, whereas seafarers would require real-time information.

- **Environmental Impact Assessment:** Understanding the composition and distribution of sediments is essential for estimating the potential environmental effects of human activities. For example, construction or dredging can disturb sediments and cause erosion or sedimentation in adjacent areas. Data on sediment classification can enlighten environmental impact assessments, aiding in the mitigation of negative outcomes and maintenance of ecosystem health.

- **Zoning and Allocation:** Accurate knowledge of sediment varieties can facilitate the MSP zoning procedure. Based on sediment characteristics, distinct zones can be designated, each with its own regulations and guidelines to ensure compatible and sustainable uses.

- **Stakeholder Engagement:** Integrating sediment classification data can increase stakeholder engagement by providing visual representations of sediment distribution and characteristics. This can increase the accessibility of complex technical information and facilitate stakeholder discussions.

- **Data-Driven Decision-Making**: Integrating sediment classification data into MSP improves decision-making by providing quantitative and objective information. This reduces uncertainty and enhances comprehension of the potential consequences of various management scenarios.

- **Adaptive Management:** The ability to continuously update and incorporate sediment classification data into MSP processes enables adaptive management. As additional data becomes accessible, MSP strategies can be modified to reflect the changing marine environment.

5. Future Prospects

India can only leverage its position in the IOR when it has developed functional capabilities. The following section will discuss the various aspects that will help India in developing its marine capacity in collaboration with various institutions, private entities, NGOs etc.

5.1. India's ambition to become a global maritime player and opportunities in the maritime domain

Rise in India's ambition to rise as a global player will shape its interaction in the marine domain as well. Digital seas are the only way to learn more about the conditions and changes that happen beneath. Once we understand the trends, we can do better things to reduce the uncertainty of the surroundings and the production results.

- Better and more sustainable fishing requires policy and technological improvements. India has not utilised its expansive tropical coastal waters because it has not prioritised

the digital ocean initiative. Building solid capacity and skills is once again a top priority for Digital Ocean, and if the Skill India programme is managed effectively, it could provide a significant export opportunity.

- As outlined in the report by the Ministry of Ports, Shipping, and Waterways, the "Maritime India Vision 2030" initiative entails a financial commitment exceeding Rs 3 lakh crore, projecting the creation of over 20 lakh jobs and unlocking annual revenue potential of more than Rs 20,000 crore for major ports. The paper outlines intentions to invest Rs 1-1.25 lakh crore in enhancing the infrastructure of pivotal ports, ultimately leading to the generation of 7-10 lakh employment opportunities. With foreign investments growing over the decade, it's the right opportunity for the private players and the government to collaborate in scripting the way for a new India.

- The Indian government aims to increase terminal capacity to more than 3,500 million metric tonnes by 2025. It is anticipated that the private sector will contribute significantly to this investment. India intends to increase its proportion of global shipbuilding to 5% by 2025, which will require approximately $10 billion in expenditures.

- The "Make in India" policy, which prioritises local production, provides opportunities for private companies to engage in shipbuilding and repair, including the development of specialised research vehicles, recovery boats, and other vehicles such as Autonomous Underwater Vehicles (UAVs) and Remotely Operated Vehicles (ROVs).

- In addition, India's marine education and training industry has grown substantially. The government has allocated approximately $23 million to develop marine skills. This could be an opportunity for private institutions to construct training centres and academies to satisfy the rising demand for trained marine personnel. This will facilitate the research and development of novel marine systems, which India's large manufacturing sector can utilise for cost-effective mass production and deployment.

5.2. Collaboration amongst various institutions

- 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 for the sediment classification applications 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 making some minor adjustments in the data collection process. While some of the applications would require a diverse field of sensors for their objectives. This study can lead to developing region-specific hardware cultured for various needs with efficient utilisation of resources, capital, and time thus reducing the complexity of the process.

- The increasing use of acoustic techniques in the marine domain enables private organisations to develop innovative and effective solutions. For scientific ocean research, significant expenditures in engineering and technology and the deployment of human resources must be prioritised. It is necessary to develop deep ocean mining technologies such as deep ocean platforms, positioning systems, pipeline networks, power sources, launching and recovery systems, drilling rigs, navigation, and guiding.

5.3. Data collection and sharing services

Information is a key part of having good data series on how important natural factors and economic actions change over time. *Berg et al.* [52] 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.

- The private sector invests in data collection infrastructure, such as sensors, vessels, and data acquisition systems. These infrastructure configurations enable the collection of a vast array of maritime data parameters, such as the weather, water quality, and wave patterns. For oceanographic research, coastal zone management, and offshore resource development, remote sensing, satellite imaging, UAVs, and LiDAR can be used to acquire enormous quantities of maritime data.

- Private businesses can establish data-sharing platforms and services to promote the interchange of maritime data among diverse stakeholders. These platforms would aid in developing centralised repositories enabling data providers to exchange their data with authorised users such as academics, policymakers, and businesses. The private sector would provide value-added services that use maritime data to meet the demands of various industries like Weather forecasting, oceanic modelling, route optimisation, marine logistics management, and risk assessment solutions.

- Collaborative projects involving private and government organisations could be forged to enhance data quality, set data standards, and build procedures for exchanging marine data.

- Data Transmission and Communication: Monitoring and control of acoustic systems in real-time necessitate dependable data transmission and communication. Developing robust underwater communication technologies that can transmit data over extended distances and in challenging conditions is essential.

5.4. Human Resource Development

With a total predicted population of 1.42 billion as of 2023, India has huge demographic concerns as well as possibilities in the future, with around 375 million young Indians seeking acceptable employment prospects.

- Often, private-sector marine enterprises collaborate with educational institutions and training centres to design training programs aligned with industry needs. These

[52] Support to Marine Research for Sustainable Management of Marine and Coastal Resources in the Western Indian Ocean Håkan Berg, Julius Francis and Petra Souter

initiatives seek to bridge the gap between academic qualifications and industry demands, consequently enhancing graduates' job prospects.

- They can contribute to the Indian government's Skill India initiative, which aims to enhance the skill set of the Indian workforce across diverse sectors, including the maritime industry. The objective is to enhance employability by providing industry-specific training through modern approaches such as computer-assisted models, machine learning, artificial intelligence, and similar techniques.

- For India to establish long-term leadership, it must considerably expand spending on research, innovation, and technology. If India wants to achieve its declared national aim of technological self-sufficiency, it must increase public financing for R&D, particularly fundamental research.

- The seamless integration and effective utilisation require interoperability among diverse data systems and formats. Given the emergence of technologies like machine learning, artificial intelligence, cloud computing, and the Internet of Things, it's imperative to enhance the infrastructure to ensure smooth and secure data distribution.

5.5. Development of India's freshwater systems

Most of the technological systems are deployed in sea/ocean exploration. While significantly less emphasis is being laid on developing and integrating such systems into the freshwater systems like rivers and lakes. With the development of inland waterways, and rejuvenation of the rivers, especially the Ganga, Yamuna etc., this technological upskilling will surely add to the economic and ecological development of the nation.

- The Maritime India Vision 2030 intends to prioritise the construction of 23 national waterways. According to the report, it would also establish an eastern waterways connection transportation infrastructure to enhance regional connectivity. This creates an excellent opportunity for stakeholders to develop vital infrastructure and provide input during the planning and implementation phases. Multiple entities can participate in developing inland waterway infrastructure, including the construction and operation of ports, terminals, and navigation channels. The public-private partnership initiatives in constructing and managing waterways would increase connectivity and permit more efficient cargo movement. Private investors are anticipated to invest significantly in inland waterway infrastructure development.

- India is one of the largest aquaculture producers in the globe. Private actors can also engage in aquaculture and fish farming by constructing fish ponds, hatcheries, processing plants, supply chains, and processing facilities. They facilitate the connection of markets, the creation of value, and the expansion of export options for fisheries products.

- Efforts to restore ecosystems, such as revitalising rivers and lakes, also increase collaboration. For example, the Namami Gange Programme, a significant Indian government initiative to revitalise the Ganges River, incorporates public and private partnerships. The government has allocated over $3 billion for the programme, with corporate actors contributing through CSR initiatives and project execution. They engage in activities like afforestation, wetland restoration, and biodiversity enhancement to restore ecological balance and better the health of freshwater systems.

6. Conclusion:

The acoustic-based sediment-bearing pressure determination is a game changer regarding the survey regions, time and capital required. Acoustic systems are more extensive than the conventional techniques and provide a detailed representation of the sea floor. The model-based techniques allow the user to focus on the relevant parameters and save resources. The advances in the techniques used for determining sediment-bearing pressure have led to a more comprehensive and less tedious process. Even with various models and algorithms, one can't just take up a well-established model for any region. There are still many challenges concerning the marine domain development.

There is an urgent need to scale up the capability and capacity of these institutions owing to the growing demand of the nation's ambitions to be a key player in the IOR. The lack of scientific and environmental data collection and sharing is a setback regarding socioeconomic progress and the blue economy. One of the biggest challenges is that different countries in the region must use of standardised procedures. Procedures and reporting will be standardised to enhance the data's utility across the region. Such gaps need to be dealt with to provide for a holistic development of the region. Since the IOR presents unique climate conditions leading to suboptimal performance of various acoustic sensors, aligning with a vast population, the current systems in other parts of the globe can be implemented directly here. The Indian Ocean Region (IOR) faces challenges due to increasing stress on resources and varying interests among countries. To deal with regional stability and the effects of climate change, a clear, complete, multi-scalar, and coordinated regional reaction is needed to ensure that marine resources are managed sustainably and to deal with the different stresses that come from climate change and environmental damage. This would require the inclusion of Underwater Domain awareness, Marine Spatial Planning, Blue Economy and modern systems to upskill the workforce. Further plans to deduce a mechanism to share data across the environmental, biological, trade and security domains need a new discussion. Increased trust amongst the regional players, a greater collaboration of the global institutes and the role of the private sector in the capacity building in IOR nations would act as a catalyst in the greater understanding of the Indian Ocean, thus providing innovative solutions for a brighter, prosperous and safe Indian Ocean.

7. Enclosures:

7.1. Enclosure 1: The journey of Maritime Research Center (MRC)

The Maritime Research Centre (MRC)[53] is a non-profit organisation situated in Pune. the Foundation for Underwater Domain Awareness. It is a comprehensive forum for advancing the Underwater Domain Awareness (UDA) Framework and brings together important players involved in Maritime Security, Blue Economy, Marine Environment & Disaster Management, and Research & Innovation. Key stakeholders have enthusiastically embraced the entire framework of UDA given by MRC for stimulating conversation and meaningful efforts.

MRC's vision is to promote the Underwater Water Domain Awareness (UDA) Framework among stakeholders and policymakers to facilitate a safe, secure, and long-term development model for the Indo-Pacific Region's tropical littoral seas and beyond. The MRC is ideally positioned to serve as a nodal agency for policy and technical initiatives, as well as acoustic capacity and capability development needs for everyone in the Indo-Pacific Strategic Space and beyond.

MRC has seen assistance from various national and international missions, as well as partners from think tanks, industry, and academia in converting ideas into focused action. MRC catalyses industry-relevant research that addresses real-world challenges, incubates tech-led ideas, and facilitates adaption within the UDA framework's domains.

7.2. Enclosure 2: How has the work done by MRC strengthened the current system?

The Maritime Research Centre (MRC) has developed a comprehensive framework for Underwater Domain Awareness (UDA), which key stakeholders have enthusiastically embraced to drive debate and positive action. The UDA structure has comprehensive Domains, with specialised areas of competence tucked inside each. MRC aims to promote communication, collaboration, and proactive action among stakeholders in Maritime Security, Blue Economy, Marine Environment, Disaster Management, and Research and Innovation.

MRC has fostered various collaborations and memorandums of Understanding (MoUs) between the various research institutes, marine corporations, foreign firms, start-ups and MNCs to create sustainable innovations in the underwater domain. This has led MRC to lead the forefront in the development of the Indian Ocean Region. MRC has hosted internships for highly qualified students from prestigious colleges like IITs, BITS Pilani, TERI, and UDA Summer School. These interns led unique initiatives and contributed substantial research articles to the UDA framework.

[53] https://mrc.foundationforuda.in/

MRC collaborates with local and worldwide platforms and boards and board-level committees from various businesses. It aids in examining and deciding governance practices and structures based on careful strategy, governance, and risk management. In fact, MRC has partnered with the Indo-Swiss Centre of Excellence (ISCE) for Skilling to solve the skilling deficit in the UDA framework. Acoustic surveys, biotechnology & bio-sciences, and Artificial Intelligence (AI) & Robotics are examples of current skill needs.

Under the UDA framework, MRC has established Centres of Underwater Excellence to develop concrete goods, tactics, regulations, and human skills to make our blue world safer, more sustainable, and better understood and explored. It has established five sub-centres under the Center of Excellence: Strategy Center, Research Center, Incubation Center, Skilling Center and Academy Center. MRC also has an extensive library of resources in the UDA Digest magazine and many articles on specialisations as a part of the knowledge centre. MRC has hosted several webinars and seminars to further this notion by bringing in diverse specialists from across the globe. This collaboration with industry experts brings information and ideas that have an even more considerable beneficial influence in the underwater domain.[54]

MRC also conducts the UDA Summer School, a six-week Summer Internship for under/postgraduate students studying science and technology focusing on a multi-disciplinary project-based programme that exposes participants to multiple technology-based real-world problem-solving issues, as guided by the UDA framework in the IOR.

7.3. Enclosure 3: Prospects of MRC in strengthening the IOR's holistic development commitments

The UDA framework sufficiently covers the policy, technological and innovation, and human resource development needs that will allow India to project itself as a significant maritime power on a global scale. With its geostrategic position and large ocean borders, India cannot afford to remain a continental country. Massive acoustic capacity development on numerous fronts is unavoidable. Integration of the blue economy and marine spatial planning has been the priority of MRC's ambition.

The current projects in the various maritime domains would aid the government in formulating comprehensive policies and plans to eliminate the knowledge gaps and facilitate sustainable development of the region. The significant specialisations include Underwater Radiated Noise (URN) Management, Sediment Management, Aquaculture and Digital Oceans. The studies call for a comprehensive policy and technological interventions to be developed into the national framework. MRC would supply the Capacity Building Commission of India (CBC) with E-learning programmes. These courses would cover the "Basics of the Underwater World." MRC has cooperated with CBC and is a knowledge partner for their Mission, Karmayogi. The team at MRC is coming up with ideas relevant to today's challenges posed by

[54] https://mrc.foundationforuda.in/centre-of-excellence/

the dangers of climate change, marine pollution and capacity. The involvement of domain experts from the top levels of the government and industry experts will lead to enhanced cross-domain expertise supplemented by the innovative solutions provided by the fellows and interns at MRC. This will aid the governments in formulating better response plans, policy frameworks and initiatives to enhance the quality of human life and conservation of the ecological assets while maintaining a level of development in the Indian Ocean Region.

7.4. Enclosure 4: Source-Path-Receiver Model

With variations in the user's data requirement, interpretation and applications, we should investigate the source-path receiver model. The model highlights vital questions like how to map the needed data, the different processing steps, and finally, how to present it to the user. It incorporates the to see, to understand, and to share aspects.

In the to-see phase, 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.

After collecting and storing the data, the following stage determines how the data should be interpreted. Several data pre- and post-processing methods are required for this. Current approaches also seek to improve statistical and computational tools' use in "big data". For instance, what kind of mathematical model is to be used for extracting parameters from incoming data or for ML models such as K-means clustering, SVM, etc.

Once the target parameters have been identified, the visualisation method must be decided. Consumers might demand data in different forms, on separate devices, or even different data. For this purpose, either a web-based GUI or a mobile app tailored to distribution requirements is created. Some users would want bathymetric maps, while others would require information on the physical features of the sediments. The time scale for which the data is to be visualised is also a crucial part of the discussion. For example, a policymaker would require data spanning for decades, while a sea-farer would need real-time data.

Hence, the source-path-receiver model is essential for determining technology's effectiveness and penetration. With the rising applications of the seabed/riverbed, it has become essential to involve Marine Spatial Planning in the picture, thus providing an efficient way to visualise & interpret data, decisions making and monitor the processes. In this regard, the synergy and diversity between the equipment must also be studied. For various applications, the same sensor and vehicle might be utilised by making some minor adjustments in the data collection process. While some of the applications would require a diverse field of sensors for their objectives. This study can lead to efficient utilisation of resources, capital, and time and reduce the complexity of the process.