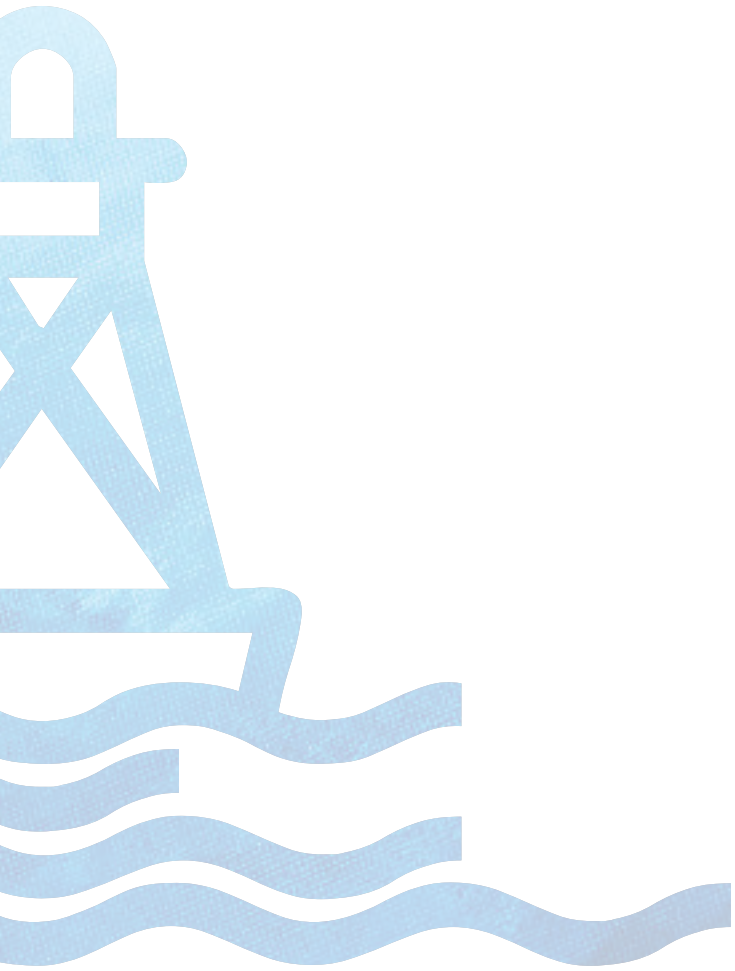
Indian Council of World Affairs

MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

TEN YEARS OF SAGAR VISION AND ITS REALISATION

A NEW PERSPECTIVE BASED ON UNDERWATER DOMAIN AWARENESS

INDIAN COUNCIL OF WORLD AFFAIRS
SAPRU HOUSE, NEW DELHI
2025



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FOREWORD

As we mark a decade since the articulation of the SAGAR (Security and Growth for All in the Region) vision by the Prime Minister of India Shri Narendra Modi, this milestone invites a meaningful reflection on India's maritime journey and its expanding influence across the Indian Ocean Region (IOR). This subject assumes profound importance when the maritime domain is becoming increasingly pivotal economically, strategically, and ecologically. The growing complexity of ocean governance, driven by climate change, geopolitical shifts, and technological advancement, demands innovative frameworks that can address the multidimensional nature of maritime challenges and opportunities.

This Special Publication, "Ten Years of the SAGAR Vision and its Realisation – A New Perspective based on Underwater Domain Awareness", is a timely and significant contribution to that discourse. Conceived as a joint publication between the Maritime Research Centre, Pune, and the Indian Council of World Affairs, this publication brings together diverse voices to integrate into the SAGAR doctrine on Underwater Domain Awareness (UDA) framework, which is an inclusive, multi-disciplinary approach that brings to light the often-neglected sub-surface dimensions of maritime governance. In fact, UDA framework needs to be comprehensively integrated into MDA frameworks, which are in focus in multilateral forums such as Quad and are being advocated for forums such as IORA and ADMM+ as well as nationally. The enunciation of the MAHASAGAR vision building upon the earlier SAGAR outlook presents such an opportunity. UDA offers solutions for a range of activities across maritime security, ecology, environment, resource management, navigation, etc. At the national level, UDA needs an enabling policy framework to fully utilize the opportunities it presents.

The eleven chapters in this compendium address a range of interconnected themes that define the future of India's maritime engagement. The publication begins with an introduction to the UDA Frameworks and its alignment with the SAGAR vision, establishing the foundational link between strategic intent and operational awareness. It demonstrates how sub-surface data and acoustic capabilities as

also actionable data analytics can enhance Underwater Domain Awareness and technological self-reliance and foster comprehensive Maritime Domain Awareness.

Next, the geopolitical dimension explores India's strategic positioning in the Indo-Pacific, emphasising the importance of multilateral cooperation and regional diplomacy in safeguarding shared interests related to traditional and non-traditional maritime security. This is followed by a chapter on maritime power dynamics, which explores the broader concept of maritime power beyond naval strength, highlighting India's need to integrate Blue Economy goals with UDA for sustainable growth, strategic capability, and maritime sovereignty.

The chapter on the Sustainable Blue Economy addresses the need to harness oceanic resources in an ecologically sound and economically inclusive manner. It connects SAGAR's developmental goals with global sustainability targets, including the UN Sustainable Development Goals (SDGs).

Climate resilience is central to maritime strategy, and the chapter on navigating climate change highlights the urgent need for adaptive policies, especially in coastal infrastructure, fisheries, and disaster management. Complementing this, the marine spatial planning (MSP) section emphasises the role of data-driven, cross-sectoral planning in optimising marine resource use and minimising conflicts. Coastal management and sediment management chapters focus on physical and ecological challenges faced by coastal zones, underlining the need for integrated coastal zone management and sustainable dredging practices, especially for ports and navigation.

On the technology front, the chapter on acoustic fingerprinting presents emerging innovations in underwater acoustics and surveillance, demonstrating their relevance for both national security and marine biodiversity monitoring. Adding a cultural and historical perspective, the chapter on maritime history and indigenous practices traces longstanding maritime traditions and local knowledge systems, reinforcing the importance of heritage in shaping maritime policy.

Together, these chapters weave a narrative that blends strategic foresight with scientific understanding and heritage with innovation. The compendium does not merely look back at the achievements of the past decade, but actively charts the course for the future.

Lastly, the '100 Warriors' Initiative, launched by the Maritime Research Centre Pune, is a grassroots program that empowers coastal, riverine, and water-dependent communities by promoting sustainable livelihoods, ecological conservation, and climate resilience. The initiative trains youth and local stakeholders in water management, disaster preparedness, and sustainable practices, while integrating modern technologies through the Underwater Domain Awareness framework.

This Special Publication will be a critical resource for policymakers, academics, strategic thinkers, maritime professionals, and technology innovators. It reflects on a decade of maritime policy evolution and a roadmap toward a secure, sustainable, and self-reliant maritime future for India and the region. As the nation continues to assert its identity as a trusted and responsible maritime partner, this volume underscores the depth of its vision and the strength of its resolve. While senior Indian experts have also contributed to this Special Publication, it would be appropriate to view it more as a platform for young voices where views of our young technical professionals from premier institutes of India have been aired.

The preparation of this ICWA Special Publication brought out in collaboration with Maritime Research Centre, Pune was coordinated by Shri Keshav Verma, Research Associate, ICWA.

Ms. Nutan Kapoor Mahawar

Acting Director General & Additional Secretary

Indian Council of World Affairs
Sapru House
New Delhi
August 2025

Effective Realization of the SAGAR Vision

A New Perspective based on the UDA Framework

Dr. (Cdr.) Arnab Das

BACKGROUND

The Security and Growth for All in the Region (SAGAR) vision, announced by the Honourable Prime Minister in 2015, has been an ambitious declaration involving multiple dimensions. It was a bold attempt to alter the sea blindness that we as a nation have been accused of since independence. India, with its 11,098 km long coastline, including the mainland, islands, bays, estuaries, and inlets, presents massive challenges and opportunities at multiple levels. We must also include the freshwater systems in this discussion to get a holistic picture. The first level is the safe, secure, and sustainable growth aspects that merit attention. The safety from natural disasters, internal and external security vulnerability, sustainability & climate change risk concerns, and most importantly, the huge growth opportunity that needs to be tapped. The second level is domain awareness, which will drive the first level in terms of managing challenges and opportunities. The Maritime Domain Awareness (MDA) has been propagated as the critical driver, however, the conventional approach to MDA falls short of addressing the underwater domain. Experts will argue that over 90% of the maritime challenges and opportunities reside in the underwater domain, and it require specialized acoustic capabilities. The conventional sonars developed during the Cold War period for the temperate/polar waters and aggressively marketed by the West to the tropical Indian Ocean Region (IOR), suffer 60% degradation of performance. Tropical waters also bring underwater resources for unimaginable economic gains; however, the geopolitical and geostrategic realities ensure manipulation by the extra-regional powers. The socio-economic, socio-political, and socio-cultural realities of the region further ensure fragmentation among the stakeholders. Thus, Underwater Domain Awareness (UDA) for the IOR demands a nuanced and indigenous approach. The digital

The Maritime Domain Awareness (MDA) has been propagated as the critical driver, however, the conventional approach to MDA falls short of addressing the underwater domain.

Underwater Domain Awareness (UDA) for the IOR demands a nuanced and indigenous approach. The digital transformation manifested as Marine Special Planning (MSP) will be a game changer for good governance. The acoustic capacity & capability building can be extended in the entire Indo-Pacific strategic space as a diplomatic tool.

transformation manifested as Marine Special Planning (MSP) will be a game changer for good governance, both for the marine and freshwater systems. However, the conventional approach towards digital transformation is highly resource-intensive, so it is a non-starter for the developing nations in the IOR. The UDA framework must ensure the pooling of resources and synergizing of efforts across the four stakeholders, namely strategic security, blue economy, sustainability & climate change, and science & technology. It must provide policy and technology intervention, along with acoustic capacity & capability building to effectively and efficiently realize the SAGAR vision. The acoustic capacity & capability building can be extended in the entire Indo-Pacific strategic space as a diplomatic tool, bolstering our leadership claim in the region. The unique tropical characteristics in the Indo-Pacific strategic space have escaped the attention of the strategic community at the risk of marginalizing all attempts at situational awareness. The Global South can ill afford the expensive Western UDA solutions with minimal guarantee of performance; thus, India has a chance to be the preferred partner for both the West and the Global South in the tropical waters of the Indo-Pacific strategic space. The demographic advantage

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can be appropriately channelized towards implementing the MSP for the tropical waters. This paper attempts to provide a clear roadmap for realizing the SAGAR vision, driven by the UDA framework.

INTRODUCTION

The SAGAR vision, as enumerated by the Honourable Prime Minister in his keynote address at the IISS Shangri-la Dialogue 2018, at Singapore, has four tenets as mentioned below[1]:

- We acknowledge the security challenges that exist in the region due to the political volatility and geopolitical fragmentation.
- We recognize the economic potential that awaits us given the rich biodiversity, connectivity possibilities, and mineral resources.
- We are conscious of the civilizational legacy and rich maritime heritage that we possess.
- India wants to play a leadership role in the region, given our geostrategic location and emerging geopolitical status[2].

The security challenges are serious given the state and non-state actors operating in unison across the region. The disruptive capabilities available with the non-state actors and their seamless connection with some of the nation states in the region make it a complex challenge to handle using conventional means. The vast coastline, along with the transboundary rivers, makes the vulnerability grow manyfold. The underwater threat is real, given the availability of acoustic mines and underwater drone technology, not just with our adversaries, but also with non-state actors. Conventional surveillance mechanisms are not able to cover the massive underwater domain, exposing our vulnerability. Submarine proliferation in the region

Disaster management mechanisms are yet to include the Underwater Domain Awareness (UDA) as an integral part of their strategic formulation.

1 Das, Arnab. "Underwater radiated noise: A new perspective in the Indian Ocean region." Maritime Affairs: Journal of the National Maritime Foundation of India 15, no. 1 (2019): 65–77.

2 Padmaja, G. "Revisiting SAGAR: India's Template for Cooperation in the Indian Ocean Region." National Maritime Foundation, 2018.

The absence of an institutional mechanism to revive the traditional knowledge to deal with the unique site-specific tropical conditions and the associated socio-economic, socio-political and socio-cultural realities, has been a serious concern.

is another serious concern, both from a safety and security perspective[3].

The natural disasters originating from the ocean space are only rising, and the massive infrastructure push in the maritime space makes us more vulnerable. Disaster management mechanisms are yet to include the Underwater Domain Awareness (UDA) as an integral part of their strategic formulation. The massive infrastructure push to bolster the SAGAR vision stands exposed to vulnerabilities in the absence of comprehensive UDA-driven early warning systems[4].

The rich biodiversity and the massive mineral resources available underwater can be harnessed for huge economic gains, however in the absence of a cohesive approach we still get manipulated by the west for want of technology and knowhow. The connectivity in the coastal waters and the vast network of rivers, can bring efficient transportation of goods and people. However, navigability in the tropical waters is a significant challenge. We seem to be going to the Nordic countries, ignoring their lack of appreciation of the tropical characteristics. Dredging, has become the de facto tool for ensuring navigability, making it unsustainable, both economically and ecologically. At present the maritime domain, only contributes 4% to the GDP, so there is huge potential for the GDP to grow backed by blue economic growth[5].

The traditional or indigenous knowledge, given the over 10,000 years of civilization legacy has somehow been completely ignored under corporate and geopolitical pressures. The absence of an institutional mechanism to revive the traditional knowledge to deal with the unique

3 Mukherjee, Anit. "India as a Net Security Provider: Concept and Impediments." RSIS Policy Brief (August 2014).

4 Michel, David. "Tempest Tossed: Meeting Environmental Challenges in the Indian Ocean." Stimson Center Report (2012).

5 Ninawe, A., and S. T. Indulkar. "Blue Economy Mission: India's Focus." Journal of Aquaculture & Fisheries (2019).

site-specific tropical conditions and the associated socio-economic, socio-political and socio-cultural realities, has been a serious concern. Indigenous communities have to be mainstreamed in the development process, to ensure peace and harmony[6].

The Small Island Developing Nations (SIDN) in the IOR are eagerly looking towards India to provide capacity & capability building support to manage the local site-specific challenges and opportunities of the tropical waters. Capacity & capability building will be the most effective diplomatic tool to wean them away from the extra-regional powers and truly establish our leadership role in the region. A blend of modern science & technology, mapped to traditional knowledge & practices to solve local problems, is the key to success[7].

The Indo-Pacific strategic space has become the de facto arena for global power play. Every global power has been maintaining its strategic assets in the region to ensure its geostrategic dominance. However, the Indo-Pacific by definition is the tropical waters of the Indian and the Pacific Oceans. Thus, tropical characteristics have to be prioritized in any strategic discourse. The Indo part of the Indo-Pacific is important for us, and our strategic dominance in the IOR will ensure our place at the high table of global strategic interaction. The demographic realities ensure that the West will require our support for their strategic presence in the Indo-Pacific, however, we need to be ready for this role. Unlike China, India still has a neutral geopolitical stance toward the West, is a preferred partner in the Indo-Pacific.

The Government of India, on its part, has been sensitive to the geopolitical and geostrategic developments and has timely announced the SAGAR vision to match the global trend. The SAGAR declaration has been

The SAGAR declaration has been backed by the announcement of mega projects like Sagarmala, Inland Water Transport, Deep Sea Mission, Gati Shakti, Jal Jeevan Mission, and more. These mega projects complement the SAGAR declaration.

6 International & Executive Programs, UC Berkeley. "Voices of the Lagoon: Traditional Ecological Knowledge in Mauritius and Rodrigues." Report (2022).

7 Padmaja, G. "Revisiting SAGAR: India's Template for Cooperation in the Indian Ocean Region." National Maritime Foundation, 2018.

The MSP will be an important tool for realizing the SAGAR vision; however, the MSP implementation can only be achieved with an effective UDA framework.

backed by the announcement of mega projects like Sagarmala, Inland Water Transport, Deep Sea Mission, Gati Shakti, Jal Jeevan Mission, and more. These mega projects complement the SAGAR declaration; however, they also demand massive capacity & capability initiatives to ensure a nuanced way forward on the ground.

The Government of India has also announced the Digital India initiative to ensure good governance. The digital transformation in the marine or freshwater systems is referred to as Marine Spatial Planning (MSP). However, the tropical challenges in the Indo-Pacific strategic space will require acoustic capacity & capability building at a different level. The multi-sectoral and multi-disciplinary dimensions need to be addressed in a coordinated manner. The MSP will be an important tool for realizing the SAGAR vision; however, the MSP implementation can only be achieved with an effective UDA framework, particularly in the tropical waters of the Indo-Pacific strategic space[8].

MSP in its conventional form is resource-intensive, and the global south can ill afford to participate in such an initiative. The fragmentation among the stakeholders within and also among the nations in the region is a major bottleneck for the success of MSP. This allows sub-optimal utilization of resources and easy access for the extra-regional powers to meddle in our domestic politics. The UDA framework will be a nuanced way forward.

CHALLENGES

The tropical waters present unique challenges, and thus, we need to first identify them, connect them to the opportunities, and then discuss the way forward. In this section, we will elaborate on the challenges due to the tropical waters in the Indo-Pacific strategic space.

8 Mukherjee, Anit. "India as a Net Security Provider: Concept and Impediments." RSIS Policy Brief (August 2014).

Demographic Challenge

The conducive climatic conditions and easy availability of resources have ensured significant population density in the region. The young aspirational population demands meaningful career opportunities with reasonable returns. The demographic bulge, if not channelized properly, could become an internal security nightmare. Pressures on food, minerals, connectivity, and more are massive to sustain such huge populations in this region. These demographic challenges give rise to binaries like security vs development, development vs sustainability, sustainability vs security, and more, making it a complex political dilemma. The young educated population is being labelled as unemployable by the corporates. The skilling and academic curricula have to be far more aligned to solve real-world problems that recognize the local site-specific characteristics[9].

Diversity of Indigenous Communities

The civilizational legacy with diverse communities having unique traditional knowledge and practices becomes a challenge for scaling up in a globalized world of today. Institutionalizing the indigenous knowledge and mapping them using modern science & technology for scaling up in the new global order requires lots of research and sustained political will. The indigenous knowledge and practices have evolved locally over millennia, so these are extremely aligned with the site-specific ecosystem. This makes these practices sustainable, and they ensure minimal climate change risk. Matured societies have encouraged the local communities to scale up their traditional businesses to bring socio-economic prosperity, which in turn brought socio-political stability. Socio-cultural wellbeing is a sign of peace and harmony among the communities and the region as a whole. The coastal and riverine communities are extremely critical for a maritime nation like ours, with over 11,098 km of coastline and over 20,000 km of inland waterways[10].

Sediment Transport Pattern

The concentration of annual rainfall into a few months ensures significantly high siltation, causing massive disruptions in navigability, water

9 Chauhan, Pradeep. "India as a Net Security-Provider in the Indian Ocean and Beyond." Center for International Maritime Security (April 29, 2016).

10 International & Executive Programs, UC Berkeley. "Voices of the Lagoon: Traditional Ecological Knowledge in Mauritius and Rodrigues." Report (2022).

Environment Impact Assessment has to be a holistic approach, addressing the unique underwater issues.

resource management, ecological sustainability, and more. Flooding, erosion, freshwater scarcity, and more are some of the serious concerns we face today as a result of poor sediment management. The unique sediment transport pattern of the tropical water bodies needs to be studied, and all attempts at managing these water bodies for economic and ecological growth need to be made accordingly. Dredging as a de facto tool for sediment management is a flawed argument. It is only an attempt by the West to push their heavy engineering products into our markets with minimal impact on the ground[11].

Sustainability

The unregulated, unplanned, and indiscriminate activities in the water bodies is a serious sustainability concern. The rapid urbanization, unplanned industrialization, rapid coastal development, and more are causing unimaginable degradation to the underwater ecology. Issues like Acoustic Habitat Degradation are not even recognized, whereas it is one of the major concerns given the importance of acoustics in the underwater space. The marine and freshwater species depend on sound for biologically critical functions, so acoustic habitat degradation is a serious concern. Water quality is a critical concern and we are yet to build a real-time monitoring mechanism for water quality management. Environment Impact Assessment has to be a holistic approach, addressing the unique underwater issues. Overemphasis on plastic is marginalizing the other serious concerns[12].

Climate Change Risk

Climate change is a real threat now, with increasing extreme weather events taking a toll on offshore and coastal infrastructure. Given that 75% of the earth is water and within that, more than 90% is below the surface of the water, the UDA will

11 Helmholtz Association of German Research Centres. "Erosion, Landslides and Monsoon Across the Himalayas." Press release, April 29, 2015.

12 Das, Arnab. "Acoustic Habitat Degradation and Its Containment." Maritime Foundation UK (November 6, 2020).

play a crucial role in climate change management. Climate change management has to be a three-step framework with a local site-specific approach. Modelling and Simulations (M&S) to predict the climate change phenomenon with a spatiotemporal scale of statistical significance. The multi-dimensional effort must include the varied underwater parameters. M&S must then be translated to the impact assessment to allow nuanced risk management. The M&S will also allow optimum resilience planning over a long-time horizon and spatial scale. The unique tropical region is far more vulnerable to the climate change impact ecologically, economically, and politically[13].

Sub-optimal Sonar Performance

The underwater domain demands acoustic means for any kind of awareness efforts. Acoustic survey across the audible spectrum can provide varied inputs regarding the multiple applications in the underwater domain. The acoustic survey inputs can be further processed for impact assessment on ecology, economy, communities, and more. Modelling & Simulations (M&S) using Artificial Intelligence (AI), can provide predictive inputs for long-term planning and management. Sonar is the device that processes acoustic signals to provide inputs across applications. However, the sonar performance in the tropical waters deteriorates by more than 60% compared to the temperate waters, where they were designed and developed during the Cold War era. Such degradation in sonar performance is a serious concern for all stakeholders across applications. Thus, acoustic fingerprinting needs to be prioritized and worked upon[14].

OPPORTUNITIES

The local site-specific challenges have to be addressed in our efforts to build the future. The mega projects to complement the SAGAR vision can only be driven if these challenges are addressed. We will discuss a few recent mega projects to illustrate this argument[15].

13 Michel, David. "Tempest Tossed: Meeting Environmental Challenges in the Indian Ocean." Stimson Center Report (2012).

14 Chitre, Mandar, S. Kuselan, and V. Pallayil. "Ambient Noise Imaging in Warm Shallow Waters: Robust Statistical Algorithms and Range Estimation." Journal of the Acoustical Society of America 132, no. 2 (2012): 838–847. https://doi.org/10.1121/1.4733553.

15 Das, Arnab. "Underwater radiated noise: A new perspective in the Indian Ocean region." Maritime Affairs: Journal of the National Maritime Foundation of India 15, no. 1 (2019): 65–77.

Sagarmala

The Sagarmala is a massive initiative by the Government of India to ensure port-led growth across the entire coastline of the country and the hinterland. A huge infrastructure push is being encouraged across the maritime sector to allow transportation of goods and people. This will significantly impact not just the logistics cost but also in enhancing efficiency and sustainability. However, the overdependence on external agencies, not just in technology and know-how, but also in determining the entire framework, has made it unsustainable both economically and ecologically. They are not able to generate jobs for our own people and are not able to achieve their full potential. Dredging is being promoted as the de facto tool for sediment management, because the western partners want to make it their market for heavy engineering products like dredgers. The coastal communities are getting displaced as a result of such mega projects with no equivalent compensation. Project Affected People (PAP) has become a significant political challenge. So-called development needs to be inclusive to ensure that the local indigenous communities are not marginalized. Sagarmala if managed well, will be a game changer and can ensure huge efficiency in connectivity and logistics[16].

Inland Water Transport (IWT)

The massive network of rivers across the country with perennial flow is a huge opportunity for connectivity and logistics. The ports on the coast need to be connected to the hinterland, so the Inland Water Transport will complement the Sagarmala. Conceptually, it is a great idea, however, the tropical challenges make it a complex implementation problem. National Waterway no. 1 & 2 on the Ganga and Brahmaputra, respectively, are good case studies to appreciate this problem. The siltation, marginalization of the riverine communities, lack of job opportunities for locals, sustainability, extreme weather events, and many more issues due to the unique tropical characteristics are some of the challenges the western partner can never address. The West is investing huge resources to study the Brahmaputra due to its geostrategic significance, whereas we ourselves are relying on their reports, rather

16 Ministry of Ports, Shipping and Waterways (India). "Sagarmala Programme: Port-Led Development (National Perspective Plan)." Government of India, 2016.

India has been a pioneering investor in the exploration of the deep ocean minerals, since 1987. The Ministry of Earth Sciences (MoES) has been conducting explorations across the Indian Ocean and beyond.

than investing our own efforts. Both the Ganga and the Brahmaputra have unique freshwater Dolphins as their inhabitants, and they are extremely sensitive to the underwater noise from marine vessels. These freshwater Dolphins are endangered and use sound for their biologically critical functions, like foraging, navigation, communication, finding mates for breeding, and more. Excessive movement of vessels in their habitat causes serious acoustic habitat degradation often leading to fatalities. Sustainability, both economic and ecological, needs to be addressed[17].

Deep Ocean Mission

India has been a pioneering investor in the exploration of the deep ocean minerals, since 1987. The Ministry of Earth Sciences (MoES) has been conducting explorations across the Indian Ocean and beyond. The exploitation is still being deliberated by the International Seabed Authority (ISA), due to concerns of sustainability and also the participation only by a few developed nations. The government agencies have undertaken the exploration, whereas the corporates are being encouraged to participate in the exploitation. However, the corporate is worried that the inputs generated during the exploration, may not be sufficient for commercially viable exploitation. The UDA capacity and capability will be grossly inadequate for undertaking such a huge initiative. Retrospective environmental regulations is another major concern by the corporates. The near shore mining is also a massive opportunity, however the lack of coordination among the multiple authorities, right from environmental clearances, security clearances, commercial clearances, and more, makes it a complex process for the corporates to navigate. The absence of a long-term indigenous plan makes it easy for the external agencies to get inroads into our corporate structure[18].

17 Kannangara, Pabasara. "Sagarmala: India's New Port Development Strategy and Its Implications for Sri Lanka." Lakshman Kadirgamar Institute Policy Brief (February 2019).

18 Press Information Bureau (India). "Cabinet Approves Deep Ocean Mission." Press release, June 16, 2021.

The UDA framework could be a great enabler for the Gati Shakti initiative by building the digital transformation backbone to manage all the water bodies, both in the marine and freshwater systems. The MSP will be the backbone for the Gati Shakti, cutting across varied sectors

Fisheries and Aquaculture

The tropical waters have massive biodiversity, and thus the commercial potential is unimaginable. However, the fisheries and the aquaculture in the IOR is largely in the unorganized sector, so the 90% indigenous population is engaged in traditional methods, while 10% employment goes to the corporate-led mechanized methods. The corporates earn 90% of the revenue, whereas the indigenous population earns only 10% revenue. The corporates dictate the policy, whereas the 90% indigenous population suffers the skewed policies, causing political turmoil. The lack of transparency in the underwater domain makes it easy for the unscrupulous elements to manipulate and generate ad hoc policy structures. Illegal, Unregulated and Unreported (IUU), fishing has become a serious concern, impacting the local indigenous communities, causing a serious livelihood crisis. The entire socio-economic structure has been disturbed, leading to significant socio-political and socio-cultural turmoil. Sustainability concerns and climate change risk is a consequent outcome of such turmoil[19].

Strategic Security Concerns

The political volatility and the geopolitical fragmentation in the IOR is making a complex mix of internal and external security challenges. The state and non-state actors are working in unison to create an environment of fear and lawlessness. The security establishments also face massive challenges of sub-optimal sonar performance for any surveillance efforts, and also navigability in the constrained waters. Most of our security forces are structured around the European model and have not been able to incorporate the traditional knowledge and practices into their operational deployment in the tropical waters. The Europeans have developed

19 United Nations Development Programme. "Mauritius & Rodrigues: Biodiversity for Sustainable Development." UNDP Report (2021).

The UDA framework could be a great enabler for the Gati Shakti initiative by building the digital transformation backbone to manage all the water bodies, both in the marine and freshwater systems. The MSP will be the backbone for the Gati Shakti, cutting across varied sectors.

their capabilities in the temperate and polar waters, and thus cannot adapt to the tropical conditions, given their demographic disadvantage. The western world continues to push its military hardware to the developing world, using geopolitical and geostrategic manipulations, knowing fully well the performance limitations in the tropical waters[20].

Gati Shakti

The Gati Shakti is an initiative to coordinate varied infrastructure projects and generate a framework where the overlaps across sectors are addressed optimally. The UDA framework could be a great enabler for the Gati Shakti initiative by building the digital transformation backbone to manage all the water bodies, both in the marine and freshwater systems. The MSP will be the backbone for the Gati Shakti, cutting across varied sectors[21].

Jal Jeevan Mission

Freshwater management is a serious crisis across the urban and rural landscape. The excessive siltation in the reservoirs has eroded the storage capacity, and the excessive dumping

The freshwater systems, particularly the transboundary rivers, are not defended by the Navy & the Coast Guard, but these waters are equally vulnerable and more complex to manage.

20 Chauhan, Pradeep. "India as a Net Security-Provider in the Indian Ocean and Beyond." Center for International Maritime Security (April 29, 2016).

21 Press Information Bureau (India). "PM Launches Gati Shakti National Master Plan for Multi-Modal Connectivity." Press release, October 13, 2021.

across the water bodies has ensured poor water quality standards. Serious UDA efforts are required to ensure reasonable storage capacity and also real-time water quality monitoring[22].

UNDERWATER DOMAIN AWARENESS (UDA) FRAMEWORK

The concept of Underwater Domain Awareness (UDA) in a more specific sense will translate to our eagerness to know what is happening in the underwater realm of our maritime areas and the freshwater systems. This keenness for underwater awareness from the security perspective means defending our Sea Lines of Communication (SLOC), coastal waters, and varied maritime assets against the proliferation of submarines and mine capabilities intended to limit access to the seas and littoral waters. The freshwater systems, particularly the transboundary rivers, are not defended by the Navy & the Coast Guard, but these waters are equally vulnerable and more complex to manage. However, just the military requirement may not be the only motivation to generate underwater domain awareness. The Earth's underwater geophysical activities have a lot of relevance to the well-being of humankind, and monitoring of such activities could provide vital clues to minimize the impact of devastating natural calamities. The commercial activities in the underwater realm need precise inputs on the availability of resources to be able to effectively and efficiently explore and exploit them for economic gains. Underwater resources include fisheries, aquaculture, seaweeds, pharma ingredients, minerals, and more, which have significant market value. The regulators, on the other hand, need to know the pattern of exploitation to manage a sustainable plan. The connectivity through the water bodies has been recognized as the most effective and efficient mode of transportation; however, ensuring navigability in these water bodies requires a massive amount of UDA. With so many activities, commercial as well as military, there is a significant impact on the environment. Any conservation initiative needs to precisely estimate the habitat degradation and species vulnerability caused by these activities and assess the ecosystem status and climate change risk. The scientific and research community needs to engage and

22 Ministry of Jal Shakti (India). "Deaths Due to Lack of Clean Water." Press release, March 21, 2022.

continuously update our knowledge and access of the multiple aspects of the underwater domain[23].

The UDA Framework on a comprehensive scale needs to be understood in its horizontal and vertical constructs. The horizontal construct would be the resource availability in terms of technology, infrastructure, capability, and capacity specific to the stakeholders or otherwise. The stakeholders represented by the four faces of the cube will have their specific requirements, however, the core will remain the acoustic capacity and capability. The vertical construct is the hierarchy of establishing a comprehensive UDA. The first level, or the ground level, would be the sensing of the underwater domain for threats, resources, and activities. The second level would be making sense of the data generated to plan security strategies, conservation plans, and resource utilization plans. The next level would be to formulate and monitor a regulatory framework at the local, national, and global levels. The individual cubes represent specific aspects that need to be addressed. The 'User-Academia-Industry' partnership can be seamlessly formulated based on the user requirement, academic inputs, and the industry interface represented by the specific cube. It will enable a more focused approach and a well-defined interactive framework. Given the appropriate impetus, the UDA Framework can address multiple challenges being faced by the global community today. Meaningful engagement of the young and aspirational population is probably

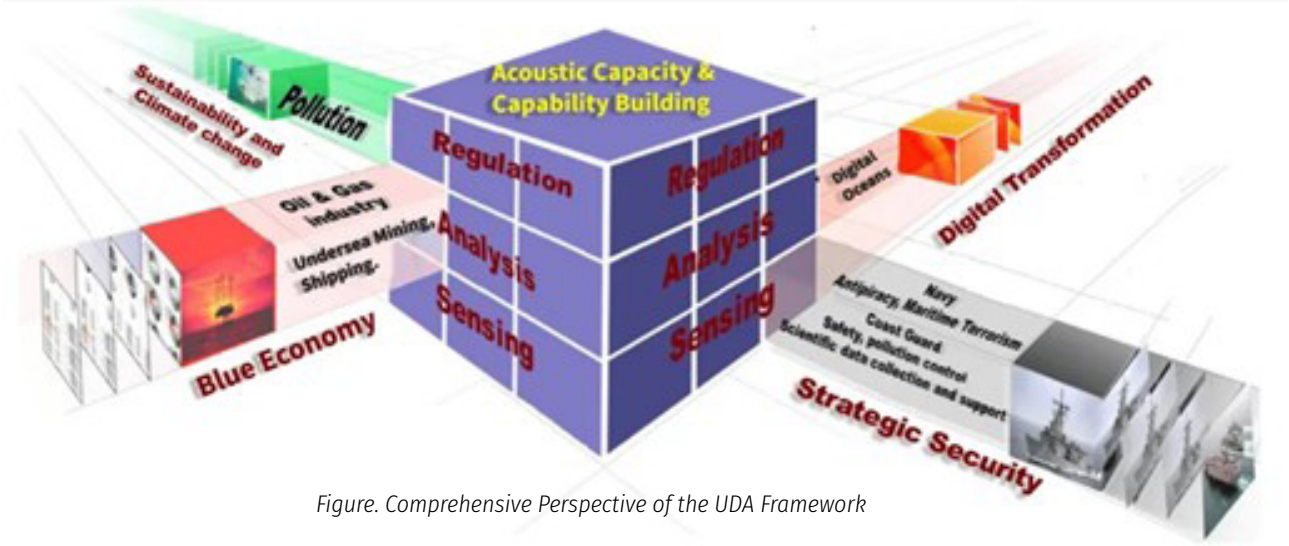

Figure. Comprehensive Perspective of the UDA Framework

23 Das, Arnab, and Kashish Parpiani. "US-India Defence Trade and India's Underwater Domain Awareness." Observer Research Foundation, Expert Speak (2020).

the most critical aspect that deserves attention. Multi-disciplinary and multi-functional entities can interact and contribute to seamlessly synergize their efforts towards a larger goal[24].

The UDA framework is a structured, comprehensive, and inclusive framework to drive the underwater domain effectively and efficiently. The structured approach will minimize the fragmentation among the stakeholders, regional players, national authorities, and local bodies. The multiple entities will have divergent interests and priorities, thus converging them into one single and focused governance mechanism will be a challenge. The governance mechanism has to be comprehensive and cannot afford to ignore any dimension of the stakeholder requirement. The dimensions include varied layers that are instrumental in building a strong governance mechanism. The first layer would be five pillars, namely research, skilling, academia, innovation, and policy. The second layer is its translation into policy & technology intervention, along with acoustic capacity & capability building. The inclusive aspects include varied socio-economic, socio-political, and socio-cultural native groups in the larger governance framework. The varied socio-economic strata of the society, particularly the coastal & riverine communities, are excluded from the conventional development models. The students are never prepared for real-world challenges and get very late before they get exposed to the nuances of real-world issues. The political spectrum is always driven by the social structure, based on left or right leanings. The governance mechanism has to address the concerns and aspirations of both sides. The cultural divide translates to the traditional practices and beliefs that drive their livelihoods and social structure. The governance mechanism has to address these divides and integrate everyone into one national, regional, or global framework[25].

The global community is also professing the triad of people, economy, and nature for enhanced governance mechanisms. The people component includes the livelihood, well-being of the native communities, social dynamics, and more. The economic component is the growth and prosperity associated with the activities. The nature component addresses sustainability and climate change risk management. This

24 Cdr (Dr) Arnab Das, "Underwater Domain Awareness (UDA) Framework", Maritime Research Centre, https://maritimeresearchcenter.com/wp-content/uploads/2024/04/Underwater-Domain-Awareness.pdf.

25 Cdr (Dr) Arnab Das, "Underwater Domain Awareness (UDA) Framework", Maritime Research Centre, https://maritimeresearchcenter.com/wp-content/uploads/2024/04/Underwater-Domain-Awareness.pdf.

is also measured in terms of the Environmental, Social, and Governance (ESG) formulation. The UDA Framework is consciously addressing all these varied measures of global good parameters[26].

CONCLUSION

The way forward can be categorized into three broad aspects, ranging from the technology resources, human resources, and the roll-out strategy[27]. The technology resources will include the following:

To See

The sensors and the platforms that will carry the sensors to the desired location will form part of the field data collection. This is the hardware component comprising acoustic (not limited to) sensors and platforms like surface crafts, underwater crafts, autonomous or manual crafts, manned or unmanned crafts, and more. Collaborations on hardware could be an interim measure to fast-track the process.

To Understand

Once the data is collected, the analysis comprising of pre-processing, application-specific processing, and post-processing will be critical. The Modelling & Simulation (M&S) will also be an important component of this stage. The tropical characteristics can be modelled and mitigated using these techniques. This stage should never be outsourced as the data is highly classified and should never be shared at any cost.

To Share

The actionable output from the earlier two stages needs to be shared in real time with the users. The user could vary from the top policy makers, to stakeholders, and also the ground-

The real-time computing hardware configuration and analytics algorithm design and development will require high-end data scientists and digital signal processing experts. They will build the entire digital infrastructure for the Marine Spatial Planning (MSP) realization.

26 Ninawe, A., and S. T. Indulkar. "Blue Economy Mission: India's Focus." Journal of Aquaculture & Fisheries (2019).

27 Cdr (Dr) Arnab Das, "Underwater Domain Awareness (UDA) Framework", Maritime Research Centre, https://maritimeresearchcenter.com/wp-content/uploads/2024/04/Underwater-Domain-Awareness.pdf.

level users like fishermen and field deployment specialists. Each of these users will require a unique format of data and customized inputs. Each of them will require unique displays for them to access the inputs. This stage also needs to be indigenously developed using local inputs.

The technology and know-how imported from the West come as a complete package, and thus fail to meet the ground requirements of the tropical waters. The human resource requirement will again be threefold as discussed below:

High-End Data Analysts

The real-time computing hardware configuration and analytics algorithm design and development will require high-end data scientists and digital signal processing experts. They will build the entire digital infrastructure for the Marine Spatial Planning (MSP) realization.

Domain Experts

Once the data is collected across varied dimensions, the application-specific interpretation needs to be undertaken using domain specialists from across varied disciplines. Political science to community engagement, geopolitics to domestic socio-economic factors, geostrategy to local policy framework, and many more need to be aligned prior to formalizing the framework.

Field Deployment Specialists

The field experimental validation and community engagement will require deployment of experts on the waterfront. This will require seamanship abilities to deal with the challenges of the water bodies. The coastal and riverine communities are well adapted to this task, given their traditional knowledge and practices. With minimal skilling, these indigenous communities can be integrated into this massive digital transformation initiative[28].

The acoustic capacity and capability-building effort have to include these nuanced aspects, keeping the tropical characteristics at the forefront. The roll-out strategy has to be threefold again as enumerated below:

Outreach

The lack of awareness of the UDA is a serious limitation in taking this

28 International & Executive Programs, UC Berkeley. "Voices of the Lagoon: Traditional Ecological Knowledge in Mauritius and Rodrigues." Report (2022).

initiative forward. Sensitization of the policy makers, stakeholders, communities, young professionals, students and more will be the first step. Workshops, seminars, conferences, and more have to be undertaken on a regular basis to make it happen.

Engage

The second stage will be to identify specific areas of interest and engagement. Right from policy makers to stakeholders will formalize the specific engagement model. The young professionals and students will be offered internships and fellowships to make them employable. Academic and skill-based curriculums will be formalized and introduced in academia.

Sustain

The policy and technology interventions will be formalized as projects for sustained and long-term implementation, with an evaluation mechanism to assess the efficacy. The complete transition to a digital framework will be a game changer, however, it will require a massive transition across varied dimensions and sectors.

Thus, the realization of the SAGAR vision can be achieved effectively only with Marine Spatial Planning (MSP), driven by the UDA framework. The recent accouchement of MAHASAGAR by the Honourable Prime Minister at Mauritius, emphasizes the soft power of capacity & capability building to achieve maritime prosperity in the IOR[29]. Here again, we need to recognize the UDA framework and its comprehensive, structured, and inclusive approach towards achieving safe, secure, sustainable growth for all in the tropical waters of the IOR.

29 Venter, Denis. "India and Africa: Maritime Security and India's Strategic Interests in the Western Indian Ocean." In Fluid Networks and Hegemonic Powers in the Western Indian Ocean, edited by Iain Walker, Emmanuel Graglia, and Alessandra Mezzadri. Lisbon: Centro de Estudos Internacionais, 2017.

Enhancing Regional Cooperation in the Indian Ocean

The Role of SAGAR and Underwater Domain Awareness

Anup K. Mudgal

INTRODUCTION

The Indian Ocean Region (IOR) is a crucial geopolitical arena where growing regional collaboration could determine scope for blue economy, security, and sustainability. As major trade routes pass through the IOR, effective governance mechanisms are essential for balancing national, regional, and global interests and goals.

India's Security and Growth for All in the Region (SAGAR) initiative promotes a cooperative approach to maritime governance, emphasising shared opportunities and responsibilities through regional partnerships in full conformity with international law. This collaboration is key to addressing challenges such as maritime security, sustainable resource management, and marine conservation. To implement the SAGAR vision on the ground, Underwater Domain Awareness (UDA) could play a vital role in resource mapping, optimal harnessing, and real-time monitoring of environmental impacts. Given that the Indian Ocean Region is primarily located in tropical and sub-tropical zones, specialised adaptations of conventional Western UDA practices would be necessary to address variations in biological, chemical, and physical characteristics.

Strengthening ocean governance through regional and global partnerships, data-driven decision-making, technology-driven mapping and monitoring of marine activities can mitigate conflicts and foster sustainable development and stability by facilitating a more comprehensive evidence and science based marine spatial planning. By aligning economic priorities, environmental concerns, and security considerations, the IOR

To implement the SAGAR vision on the ground, Underwater Domain Awareness (UDA) could play a vital role in resource mapping, optimal harnessing, and real-time monitoring of environmental impacts. Given that the Indian Ocean Region is primarily located in tropical and sub-tropical zones, specialised adaptations of conventional Western UDA practices would be necessary.

India's geographic location and natural access to the Indian Ocean give it a unique maritime advantage and responsibility.

can serve as a model for effective global ocean governance. Under the SAGAR spirit the UDA applications would not only support sustainable ocean resource harnessing but also generate employment opportunities through capacity building and technological advancements.

HEALTH AND SECURITY OF THE INDIAN OCEAN

With a vast coastline stretching over 11,098 kilometres, an Exclusive Economic Zone (EEZ) of 2.02 million square kilometres, more than 1,300 island territories, and nearly 14,500 kilometres of inland waterways, the Indian Ocean and its adjoining waterways have been integral to India's civilization and socioeconomic history. Coastal communities have long engaged in maritime trade, cultural exchange, and movement across the region, creating a deep-rooted Indian diaspora and cultural footprint across the Indian Ocean Region (IOR), which today encompasses nearly 33 percent of the global population across 38 littoral states.[30]

Economically, the Indian Ocean is vital: fisheries, coastal tourism, ports, transport, and hydrocarbon extraction contribute significantly to India's economy, while approximately 90% of its trade, including critical energy imports, passes through these waters. As global economic activity increasingly shifts towards this region, the Indian Ocean's importance grows, serving as a hub for markets, investments, mineral resources, and sectors like energy, transport, tourism, education, and healthcare. The stability and growth of the region also underpin the welfare of India's widespread diaspora, who contribute substantially to the nation's development.

However, the region faces threats from piracy, armed conflict, organized crime, terrorism, and trafficking, endangering maritime security and trade routes—risks highlighted by incidents like the 26/11 Mumbai attack. Environmental

30 New Scientific Calculations, India's Coastline Expanded From 7,516 Km (1970) to 11,098 Km (2023-24)

India's maritime strategy centres on securing its mainland and islands, safeguarding sea lanes of communications (SLOC) and maritime trade, and ensuring a stable Indian Ocean principally through cooperation. It emphasizes strengthening economic and security ties with neighbouring maritime states, enhancing their capacities, fostering collective regional action for peace, security, and emergency response, and advancing integrated, cooperative regional development in accordance with respective requirements.

challenges, including ocean ecosystem degradation and climate change, threaten to disrupt weather patterns, monsoons, freshwater availability, fishery yields, and coastal lands, posing serious risks to livelihoods and national development. Consequently, safety, security, and conservation of the Indian Ocean's marine environment is not optional but a strategic national imperative.[31]

India's geographic location and natural access to the Indian Ocean give it a unique maritime advantage and responsibility. Stretching from the Arabian Sea across to the Bay of Bengal and the eastern Indian Ocean, India's position has historically supported flourishing maritime trade and cultural exchanges, facilitated by favourable monsoon currents. Ancient Indian civilizations developed sophisticated maritime infrastructure and security capabilities to protect their economic interests. Yet, with the medieval shift towards land-based routes and colonial rule, India's maritime focus waned ironically coinciding with a general economic decline.

Post-independence, maritime security challenges and responsibilities reverted to India. Initially, land-based threats took precedence, limiting naval development and leaving the Indian Ocean's security largely in the hands of extra territorial powers during the Cold War. The end of the Cold War, coupled with regional conflicts, piracy, terrorism, and the rise of China and Pakistan's naval capabilities, compelled India to build robust maritime forces

31 Maritime Safety & Security | iora

with regional and global reach to protect its core interests.

India's maritime strategy centres on securing its mainland and islands, safeguarding sea lanes of communications (SLOC) and maritime trade, and ensuring a stable Indian Ocean principally through cooperation. It emphasizes strengthening economic and security ties with neighbouring maritime states, enhancing their capacities, fostering collective regional action for peace, security, and emergency response, and advancing integrated, cooperative regional development in accordance with respective requirements.

Prime Minister Modi's 2015 articulation of SAGAR—Security and Growth for All in the Region—embodies this vision, reflecting India's commitment to being a net security provider and collaborative partner in the Indian Ocean. This approach aligns national priorities with regional well-being, aspiring to a maritime order that is free, open, inclusive, and anchored in international law—fundamental for peace, prosperity, and India's future.[32]

The ocean, by its very nature, defies rigid geopolitical boundaries and sovereign jurisdictions. As a vast, interconnected, and fluid domain, it functions as a global common, governed not by territorial limits but by shared planetary functions, migratory species, transboundary currents, and interlinked economic activities. The complex and dynamic interactions within the marine ecosystems—ranging from fish stocks that migrate across Exclusive Economic Zones (EEZs), to pollution that travels via oceanic currents—demand governance models that are cooperative, adaptive, and transnational in scope.

A unilateral, inward-looking, or fragmented national approach is inherently inadequate to address the intricate and multi-dimensional challenges of ocean governance. Issues such as Illegal, Unreported and Unregulated (IUU) fishing, marine pollution, loss of biodiversity, and overexploitation of resources cannot be effectively mitigated unless nations work together across scientific, legal, economic, and strategic domains. Climate change further compounds these challenges, intensifying the need for cohesive and collective action,

32 Press Release:Press Information Bureau: INDIAN NAVY's MAIDEN INITIATIVES OF INDIAN OCEAN SHIP SAGAR (IOS SAGAR) AND AFRICA INDIA KEY MARITIME ENGAGEMENT (AIKEYME)

particularly in vulnerable regions like the Indian Ocean Region (IOR).

SAGAR (Security and Growth for All in the Region) recognizes the intrinsic international character of the ocean and places strong emphasis on regional and multilateral partnerships as a cornerstone of effective maritime governance. India actively champions institutional collaboration through regional groupings such as the Indian Ocean Rim Association (IORA), the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), and the Indo-Pacific Oceans Initiative (IPOI). These platforms provide the mechanisms necessary for aligning national interests with regional priorities and global responsibilities.

Additionally, international cooperation is vital in safeguarding freedom of navigation, managing shipping lanes that pass-through choke points like the Strait of Malacca and the Bab-el-Mandeb, and ensuring equitable access to deep-sea resources under the framework of the United Nations Convention on the Law of the Sea (UNCLOS). These efforts must prioritize peace, sustainability, and non-hegemonic engagement.

By embracing a truly internationalist and cooperative maritime ethos, SAGAR moves beyond India-centric objectives to offer a regional public good—one that nurtures a collective maritime consciousness rooted in shared prosperity, security, and stewardship. The ocean's health and productivity hinge on this shift from fragmented control to integrated governance, where science, diplomacy, and mutual trust converge to manage our shared blue future.

THE INDIAN OCEAN REGION (IOR): STRATEGIC AND ECONOMIC CENTRALITY

The Indian Ocean Region (IOR) is pivotal to 21st-century global trade and energy security. As a key maritime corridor, it facilitates over two-thirds of global oil shipments, one-third of bulk cargo, and half of all container traffic. Stretching from Africa's eastern coast to Australia's western shores, it connects major economies across the Middle East, South Asia, Southeast Asia, and East Africa, making it a dynamic and interconnected maritime space.

Since the introduction of the Blue Economy concept at the 2012 United

Nations Conference on Sustainable Development, the IOR has gained prominence in global ocean governance. Organizations such as the Indian Ocean Rim Association (IORA), African Union (AU), BIMSTEC, ASEAN, and global institutions like the World Bank and OECD have worked to align regional development with sustainable use of marine resources. For India and other littoral states, engaging in these dialogues is essential to protect economic interests and promote inclusive maritime growth.

The IOR is endowed with marine resources—including hydrocarbons, fisheries, renewable energy, seabed minerals, and rich biodiversity with biotechnological potential. When managed sustainably, these assets can drive economic growth, ensure food security, alleviate poverty, and create coastal livelihoods. Yet, the region faces challenges such as piracy, pollution, illegal fishing, smuggling, and climate change impacts like sea-level rise and ocean acidification. These issues are compounded by technological disparities, weak governance, and uneven infrastructure across nearly 40 littoral states.[33]

In 2018 Sustainable Blue Economy Conference in Nairobi marked a turning point, with regional leaders emphasizing ecological balance, inclusive governance, and international cooperation. The Nairobi Statement of Intent called for investment, partnerships, and a science-based, community-driven approach.[34]

Going forward, the region must enhance cooperation through platforms like IORA, BIMSTEC, and the broader Indo-Pacific construct

Prioritizing marine research, data collection, and modelling will enable evidence-based policy and adaptive management. The IOR must aspire to become a model of cooperative, science-led ocean governance. The prosperity of the region depends not on competition, but on how effectively its nations collaborate to protect ecosystems and ensure equitable benefits from the Blue Economy.

33 Environmental drivers of maritime insecurity: governance, enforcement and resilience in the western Indian Ocean

34 SBEC-FINAL-REPORT-8-DECEMBER-2018-rev-2-1-2-PDF2-3-compressed.pdf

to harmonize policies and ensure fair resource sharing. Bridging capability gaps through training, technology transfer, and financing is vital, particularly for smaller and developing states.

Integrated governance frameworks that transcend silos—across fisheries, energy, conservation, tourism, and maritime security—are essential for coordinated and resilient management. Strengthening maritime security and adherence to international law will help prevent unchecked geopolitical tensions.

Finally, prioritizing marine research, data collection, and modelling will enable evidence-based policy and adaptive management. The IOR must aspire to become a model of cooperative, science-led ocean governance. The prosperity of the region depends not on competition, but on how effectively its nations collaborate to protect ecosystems and ensure equitable benefits from the Blue Economy.

SAGAR: INDIA'S VISION FOR REGIONAL MARITIME COOPERATION

India's "Security and Growth for All in the Region" (SAGAR) initiative promotes a cooperative, inclusive, and rules-based maritime governance model focused on shared security and prosperity through regional collaboration. It positions India as a responsible maritime actor and net security provider committed to fostering stability and sustainable development in the Indian Ocean Region (IOR).

SAGAR is built on five foundational pillars: enhancing maritime security, improving connectivity and infrastructure, promoting the blue economy, advancing disaster risk reduction and climate resilience, and championing environmental protection. These pillars collectively offer a comprehensive strategy to address regional challenges and unlock maritime opportunities.

India advances SAGAR through a mix of bilateral and multilateral partnerships. Engagement with platforms like the Indian Ocean Rim Association (IORA) and the Indian Ocean Naval Symposium (IONS) supports policy alignment and capacity building. Initiatives such as Integrated Coastal Surveillance Networks and white shipping agreements with IOR countries have enhanced maritime domain awareness and operational transparency.

Conceived as an open, inclusive, and non-treaty-based initiative, IPOI reflects India's strategic intent to foster practical maritime cooperation across the Indo-Pacific, while offering an alternative to narrow geopolitical contestation.

Aligned with India's broader Indo-Pacific strategy, SAGAR also emphasizes port-led development and regional logistics. Projects like Sagarmala aim to strengthen maritime infrastructure and trade corridors, enhancing connectivity while promoting sustainable resource use.[35]

SAGAR places strong emphasis on a sustainable and inclusive blue economy. Areas such as fisheries, offshore renewable energy, aquaculture, and marine biotechnology are prioritized—particularly to benefit smaller island and coastal nations. The initiative supports global objectives like UN Sustainable Development Goal 14 (Life Below Water), promoting ocean-based livelihoods while conserving ecosystems.

Given the region's exposure to natural disasters, SAGAR fosters coordination in disaster preparedness and coastal resilience. India's role in humanitarian aid and leadership in the Coalition for Disaster Resilient Infrastructure (CDRI) underscore its commitment to shared security.[36]

Environmental protection remains a critical component, with India supporting regional cooperation on marine pollution, coral reef conservation, coastal erosion, and clean technology adoption—advancing sustainability through joint research and connectivity efforts such as the India-Myanmar Trilateral Highway, IMEC, and INSTC.

INDIA'S INDO-PACIFIC OCEANS INITIATIVE (IPOI): SAGAR PLUS

India's maritime outreach in the Indian Ocean Region (IOR) and wider Indo-Pacific took a major leap forward with the launch of the Indo-Pacific Oceans Initiative (IPOI) in 2019 at the East Asia Summit (EAS) in Bangkok. Conceived

35 SAGAR, Sagarmala and seaports: How 'Triple S' growth triangle promises to rewrite India's maritime history - Centre for Public Policy Research (CPPR)

36 Disaster Risk Reduction, Climate Change Adaptation and Their Linkages with Sustainable Development over the Past 30 Years: A Review | International Journal of Disaster Risk Science

as an open, inclusive, and non-treaty-based initiative, IPOI reflects India's strategic intent to foster practical maritime cooperation across the Indo-Pacific, while offering an alternative to narrow geopolitical contestation.

Rooted in India's SAGAR (Security and Growth for All in the Region) vision announced in 2015, IPOI—often referred to as "SAGAR Plus"—embodies the next step in promoting rules-based, cooperative, and community-driven maritime governance. Its central goal is to build a sense of regional community through voluntary, interest-based collaboration among like-minded countries.

IPOI is structured around seven thematic pillars, with one or two countries voluntarily leading each pillar, and others contributing based on their capacities and interests. Unlike rigid institutional mechanisms, IPOI leans on existing regional architecture—such as EAS, IORA, BIMSTEC, and others—for execution and synergy.

The Seven Pillars of IPOI and Lead Countries:

- Maritime Security – *Led by India and the United Kingdom*
- Focuses on cooperative frameworks to counter threats such as piracy, terrorism, trafficking, and illegal fishing. Builds on India's existing white shipping agreements, Humanitarian Assistance and Disaster Relief (HADR) operations, and participation in IONS and Quad dialogues.
- Maritime Ecology – *Led by Australia and Thailand*
- Aims to promote sustainable marine practices, tackle pollution and coral reef degradation, and conserve coastal ecosystems. India's blue economy initiatives and regional environmental programs align with this objective.
- Maritime Resources – *Led by France and Indonesia*
- Seeks equitable and sustainable use of fisheries, marine renewables, and seabed minerals. Emphasizes capacity-sharing and technology transfer for smaller and developing littoral states.
- Capacity Building and Resource Sharing – *Led by Germany*
- Enhances regional skills, institutions, and infrastructure through training programs, technology partnerships, and centres of excellence. Scales India's hydrography, coastal surveillance, and maritime skilling initiatives.

- Disaster Risk Reduction and Management – *Led by India and Bangladesh*
- Addresses vulnerabilities to cyclones, tsunamis, and sea-level rise through early warning systems, climate resilience planning, and HADR coordination. Supported by India's role in the Coalition for Disaster Resilient Infrastructure (CDRI).
- Science, Technology and Academic Cooperation – *Led by Italy and Singapore*
- Promotes collaborative research, knowledge exchange, and marine innovation. India's bilateral and multilateral academic programs contribute to expanding oceanographic understanding.
- Trade, Connectivity and Maritime Transport – *Led by Japan and the United States*

Strengthens Sea lines of communication (SLOC), port infrastructure, and multimodal maritime logistics. India's Sagarmala project and strategic port partnerships in Chabahar, Duqm, and Sittwe are key to operationalizing this pillar.

The Indo-Pacific Oceans Initiative (IPOI) holds significant strategic and policy relevance as it provides a cooperative alternative to the intensifying geopolitical competition in the Indo-Pacific region. By emphasizing openness, inclusivity, and a rules-based maritime order, IPOI promotes collaborative engagement among like-minded nations. It aligns with India's long-term maritime objectives, notably the Maritime India Vision 2030 and the Maritime Amrit Kaal Vision 2047, supporting national priorities in sustainable development, maritime security, and regional integration. Furthermore, IPOI demonstrates strong convergence with other regional frameworks, enhancing policy coherence and multilateral synergy. These include the Australia-India Indo-Pacific Oceans Initiative Partnership (AIIPOIP)[37], which bolsters bilateral cooperation; the ASEAN Outlook on the Indo-Pacific (AOIP), which promotes ASEAN-led principles of maritime dialogue and sustainability; and the Indo-Pacific Economic Framework (IPEF), which focuses on regional economic integration and resilience. Through such alignments, IPOI strengthens India's role as a responsible stakeholder in the Indo-

37 Australia-India Indo-Pacific Oceans Initiative Partnership: Grant Round 1

Pacific and reinforces efforts toward a secure and prosperous maritime future.

FOUNDATIONS OF SAGAR

The SAGAR (Security and Growth for All in the Region) doctrine outlines a comprehensive vision for the Indian Ocean Region (IOR), built on three interlinked pillars: Economy, Security, and Sustainability. This strategic framework aims to optimize natural and human-driven ocean processes to enhance productivity and reduce inefficiencies and conflicts. Together, these components form the basis for inclusive, responsible, and cooperative maritime governance.

Economy(OceanHarnessing)

SAGAR positions the ocean as a shared economic space with immense potential for sustainable development. It advocates the responsible harnessing of resources such as offshore renewable energy, fisheries, aquaculture, marine biotechnology, coastal tourism, and seabed minerals. Acknowledging the capacity gaps among IOR nations, India promotes equitable regional cooperation through joint exploration, cross-border maritime clusters, and integrated ocean-based value chains, particularly benefiting island and developing coastal states.

Infrastructure development through initiatives like Sagarmala and the adoption of Marine Spatial Planning (MSP) demonstrate India's commitment to balancing economic activity with ecological concerns. Focus is placed on empowering small-scale fishers and coastal communities while fostering employment, poverty reduction, and inclusive blue growth through bilateral and multilateral engagements.

Security (Enabler)

Maritime security is viewed as a key enabler of economic prosperity. SAGAR emphasizes cooperative approaches to both traditional threats and non-traditional challenges such as piracy, trafficking, and natural disasters. India has enhanced its maritime partnerships through Coordinated Patrols (CORPATs), joint naval exercises like MILAN and DOSTI, and capacity-building efforts with IOR navies.

The Information Fusion Centre – Indian Ocean Region (IFC-IOR) in Gurugram plays a vital role in fostering

The ocean is a multi-dimensional space, and many of its most critical processes and threats lie beneath the surface. While MDA provides robust visibility above water, it offers limited insight into the complex and dynamic subsurface environment. Activities such as illegal dumping, submarine intrusions, underwater infrastructure sabotage, and acoustic pollution often escape detection by conventional systems focused on surface tracking. Moreover, surface-originated actions—like dense shipping traffic or offshore drilling—have cascading subsurface impacts, including coral degradation, seabed erosion, and elevated noise levels that affect marine life behaviour and biodiversity, thus making a case for UDA frameworks.

maritime domain awareness (MDA) through real-time information sharing and regional collaboration. Additionally, India's swift and effective Humanitarian Assistance and Disaster Relief (HADR) operations underscore its commitment to regional stability and solidarity.

Sustainability (Ecological Foundation)

Sustainability anchors SAGAR's vision, emphasizing that ocean health is fundamental to long-term security and prosperity. India supports a conservation-oriented model aligned with SDG 14 and global environmental frameworks. Efforts include expanding Marine Protected Areas (MPAs), promoting climate-resilient fisheries, curbing marine pollution, and adopting green shipping technologies.

Scientific research is also prioritized to monitor ocean health, assess environmental impacts, and respond to climate trends affecting the Indian Ocean. Collaborative conservation with IOR partners seeks to protect biodiversity and restore vital ecosystems such as coral reefs, mangroves, and seagrasses.

Together, these pillars create a synergistic and future-ready framework. By integrating economic ambition with security assurance and ecological stewardship, SAGAR

presents a blueprint for sustainable and cooperative governance of the Indian Ocean Region, rooted in regional ownership, mutual respect, and long-term resilience.

SURFACE CHALLENGES AND UNDERWATER REALITIES: INTEGRATING MDA WITH UDA

Maritime governance has traditionally emphasized surface-level monitoring through Maritime Domain Awareness (MDA). MDA plays a vital role in ensuring maritime security and efficiency, encompassing vessel tracking, port operations, shipping route management, and counter-piracy efforts. These functions remain essential for safeguarding maritime trade, supporting naval operations, and maintaining coastal vigilance.

However, the ocean is a multi-dimensional space, and many of its most critical processes and threats lie beneath the surface. While MDA provides robust visibility above water, it offers limited insight into the complex and dynamic subsurface environment. Activities such as illegal dumping, submarine intrusions, underwater infrastructure sabotage, and acoustic pollution often escape detection by conventional systems focused on surface tracking. Moreover, surface-originated actions—like dense shipping traffic or offshore drilling—have cascading subsurface impacts, including coral degradation, seabed erosion, and elevated noise levels that affect marine life behaviour and biodiversity, thus making a case for UDA frameworks.

To complement and extend the capabilities of MDA, India's maritime strategy under SAGAR (Security and Growth for All in the Region) must adopt Underwater Domain Awareness (UDA) as an essential pillar. UDA represents an evolution in maritime governance, encompassing real-time sensing, modelling, and analysis of underwater physical, chemical, biological, and acoustic parameters. It draws on interdisciplinary inputs from oceanography, acoustics, ecology, and data science to provide a three-dimensional, data-driven understanding of the ocean space.[38]

By integrating UDA, SAGAR's objectives are significantly enhanced in multiple domains:

38 udafoundation.in/wp-content/uploads/2024/12/Underwater-Domain-Awareness-UDA-Framework.pdf

- **Subsurface Surveillance:** Detecting underwater intrusions, illegal deep-sea trawling, and safeguarding critical infrastructure such as undersea cables and pipelines.
- **Environmental Monitoring:** Supporting conservation of marine habitats like coral reefs and seagrass beds that are vital to biodiversity and coastal livelihoods.
- **Disaster Preparedness:** Improving early warning systems for seismic and geophysical events such as tsunamis and underwater earthquakes.
- **Infrastructure Planning:** Informing siting and construction of ports, offshore wind farms, and energy infrastructure by analysing subsurface conditions and sediment dynamics.
- **Acoustic and Pollution Mapping:** Monitoring ambient noise, pollutant dispersion, and sensitive marine zones to support sustainable shipping and ecosystem management.
- **Marine Spatial Planning (MSP):** Enabling more effective spatial allocation of ocean uses based on comprehensive underwater data.

The tropical and sub-tropical waters of the Indian Ocean Region (IOR) present unique challenges for UDA, including intense biological activity, thermal stratification, and high salinity gradients. These factors, along with prevalent bio-fouling and elevated ambient noise, demand region-specific technologies and methodologies. Tailored UDA frameworks, built on indigenous innovation, localized modelling tools, and regional capacity building, are essential to address these complexities.

India's leadership in acoustic capacity development—facilitated through institutions like the Information Fusion Centre – Indian Ocean Region (IFC-IOR) and the Maritime Research Center (MRC)—positions UDA as a transformative tool. By incorporating the subsurface dimension into strategic and policy-level planning, UDA complements MDA to create a more secure, sustainable, and informed maritime governance framework.

INITIATIVES FOR SUSTAINABLE OCEAN HARNESSING

India has undertaken a series of forward-looking initiatives to promote sustainable, inclusive, and technologically driven ocean development, aligning with its

Fragmented institutional responsibilities, lack of inter-ministerial coordination, and limited convergence between science, policy, and community development hinder integrated ocean management. One critical area of concern is the absence of a clear regulatory or governance framework for submarine cables.

SAGAR (Security and Growth for All in the Region) vision and Sustainable Development Goal 14 (Life Below Water). These initiatives span scientific exploration, policy formulation, environmental monitoring, and regional cooperation to harness ocean potential without compromising ecological integrity.

A key pillar of this effort is the Deep Ocean Mission (DOM), launched by the Ministry of Earth Sciences. This multi-disciplinary initiative focuses on deep-sea exploration, seabed mapping, biodiversity documentation, and the development of indigenous technologies for underwater mining and research. DOM aims to unlock resources such as polymetallic nodules and hydrothermal sulphides while enhancing India's capabilities in underwater robotics, manned submersibles, and ocean data acquisition—laying the foundation for long-term sustainable utilization of ocean wealth.

Complementing DOM is the Blue Economy Policy Framework, which outlines a strategic roadmap for sustainable ocean resource use to drive economic growth, improve livelihoods, and safeguard ecosystems. It emphasizes Marine Spatial Planning (MSP), community empowerment, climate resilience, and innovation to ensure that maritime sectors operate within both national and global sustainability parameters.

India's regional leadership is reinforced through the Information Fusion Centre – Indian Ocean Region (IFC-IOR), operated by the Indian Navy. IFC-IOR enhances maritime domain awareness by facilitating real-time data sharing and coordinated responses across the IOR. While primarily addressing security, it also supports sustainability by deterring activities like illegal fishing, pollution, and marine trafficking.

Human capacity development is central to India's approach. Institutions like

Internationally, India contributes to global ocean stewardship through active participation in the UN Decade of Ocean Science for Sustainable Development (2021–2030) and as a lead pilot state for the IMO's GloNoise Partnership , which addresses underwater radiated noise and its ecological impacts.

the Maritime Research Center (MRC) offer e-learning and skilling programs on Underwater Domain Awareness (UDA), acoustic sensing, marine data analytics, and environmental impact assessments. These initiatives empower youth, researchers, and coastal communities to actively engage in the Blue Economy.

Despite this momentum, India faces significant governance and technological gaps. Fragmented institutional responsibilities, lack of inter-ministerial coordination, and limited convergence between science, policy, and community development hinder integrated ocean management. One critical area of concern is the absence of a clear regulatory or governance framework for submarine cables—which serve as the digital backbone of the global economy and are increasingly vulnerable to accidental damage, sabotage, and environmental degradation. With growing strategic and economic dependence on subsea infrastructure, India must urgently establish a governance architecture that addresses cable route planning, monitoring, protection, and repair coordination, while aligning with international best practices and environmental safeguards.

Additionally, India's acoustic and underwater sensing capacity remains underdeveloped relative to the complexities of the Indian Ocean Region. There is a pressing need for indigenous sensor development, tropicalized technologies, and improved data-sharing systems across government, academia, and industry. Coastal communities—key stakeholders in maritime sustainability—also require greater inclusion in planning processes through localized skilling and awareness campaigns.

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To truly embody its SAGAR vision (Security and Growth for All in the Region), India must deepen its development cooperation in the Indian Ocean Region (IOR) through a people-centric, collaborative, and knowledge-driven approach. This effort should begin by prioritizing education and scholarships as tools for long-term ocean stewardship.

Development (2021–2030) and as a lead pilot state for the IMO's GloNoise Partnership[39], which addresses underwater radiated noise and its ecological impacts. As a signatory to the Nairobi Convention, India reaffirms its commitment to protecting the marine and coastal environment in the Western Indian Ocean.

Domestically, the Blue Economy National Framework—a joint initiative of key ministries—drives an integrated approach to sustainable maritime development. The MRC supports this through its MSP position paper, skilling modules, and collaboration with industry bodies such as FICCI. Additionally, India advances maritime connectivity through regional corridors like the India-Middle East-Europe Corridor (IMEC) and the North-South Transport Corridor, complemented by soft power initiatives such as Bali Yatra, celebrating ancient maritime heritage.

Together, these efforts reflect India's integrated ocean governance model, balancing ecological stewardship, economic opportunity, regional cooperation, and innovation. However, addressing critical governance voids such as submarine cable protection and policy fragmentation is essential for India to realize its vision of regional leadership and ocean sustainability.

INDIA ASSUMES SECRETARY-GENERALSHIP OF IORA

India's election to the Secretary-General position of the Indian Ocean Rim Association (IORA) marks a significant diplomatic milestone and reinforces its enduring leadership in the Indian Ocean Region. This is not India's first tenure in the role; rather, it represents a continuation of its legacy, previously exemplified by the leadership of Ambassador Bhagirathi, and reaffirms India's long-standing commitment to regional cooperation. With a well-established blueprint already in place, India is now positioned to transform IORA into a more action-oriented and responsive platform, advancing concrete initiatives across maritime security, sustainable development, and economic connectivity. This renewed leadership comes at a crucial time, offering India the opportunity to shape a collective regional agenda that balances strategic interests with inclusive growth,

39 GloNoise Partnership

Offering specialized training in Underwater Domain Awareness (UDA), hydro-acoustics, and ocean monitoring—particularly for Small Island Developing States (SIDS) and Least Developed Countries (LDCs)—can enhance regional capacity.

environmental stewardship, and multilateral collaboration.

The appointment of Shri Sanjiv Ranjan[40], a seasoned Indian Foreign Service officer, as the next Secretary-General of IORA was officially announced by the Ministry of External Affairs (MEA) on December 30, 2024. His leadership is expected to bring renewed vigour to IORA's mission of fostering regional collaboration and sustainable growth.[41]

As Secretary-General, India is poised to play a pivotal role in advancing the vision of SAGAR (Security and Growth for All in the Region), a doctrine that underscores India's commitment to regional peace, prosperity, and inclusive development. Through this leadership role, India aims to deepen institutional cooperation among IORA member states and foster a more integrated and resilient Indian Ocean community.

The External Affairs Minister Dr. S. Jaishankar during his keynote address at the 8th Indian Ocean Conference in February 2025, also emphasized India's proactive role in regional institution-building and its commitment to multilateralism.[42]

India's resumption of leadership within the Indian Ocean Rim Association (IORA) is expected to bring renewed momentum to multilateral cooperation in the region. It reaffirms India's role as an equal partner and enabler, committed to fostering inclusive and rules-based regional development. This opportunity, which comes to India once again, offers a timely platform to translate strategic vision into coordinated action. It also provides a significant impetus to indigenous innovations, encouraging region-specific solutions and technologies that can strengthen the collective capabilities of Indian Ocean littoral states.

INDIA'S DEVELOPMENT PARTNERSHIP MODEL: AN INVITATION FOR SHARED GROWTH

India extends an open invitation to its neighbours and partners in the Indian Ocean Region (IOR) to join a collective journey of growth and

40 Secretary-General | iora

41 Shri Sanjiv Ranjan appointed as the next Secretary General of the Indian Ocean Rim Association

42 Keynote Address by EAM Dr. S. Jaishankar at Indian Ocean Conference 2025 : Voyage to New Horizons of Maritime Partnership (February 16, 2025)

prosperity. Anchored in the vision of *SAGAR* (Security and Growth for All in the Region), India's development partnership model champions sovereign equality, mutual respect, and regional solidarity. Moving away from extractive or conditional aid models, India offers a collaborative, demand-driven approach that responds directly to the priorities and aspirations of partner nations. This inclusive model is not just assistance—it is an offer to co-create sustainable, people-centric maritime development that benefits all stakeholders in the region.

To truly embody its SAGAR vision (Security and Growth for All in the Region), India must deepen its development cooperation in the Indian Ocean Region (IOR) through a people-centric, collaborative, and knowledge-driven approach. This effort should begin by prioritizing education and scholarships as tools for long-term ocean stewardship. Expanding initiatives like those under the Indian Council for Cultural Relations (ICCR) can help foster regional talent, while academic partnerships with IOR countries should support joint degrees, faculty exchanges, and research in marine science, biodiversity, and underwater technologies. Indian universities must also adapt their curricula to better serve regional maritime needs.

A strengthened focus on skill development through the Indian Technical and Economic Cooperation (ITEC) program can address critical gaps in maritime governance, port operations, and coastal infrastructure. Offering specialized training in Underwater Domain Awareness (UDA), hydro-acoustics, and ocean monitoring—particularly for Small Island Developing States (SIDS) and Least Developed Countries (LDCs)—can enhance regional capacity for climate resilience and sustainable ocean use. These programs should increasingly adopt hybrid and digital formats to ensure inclusivity.

India's economic engagement in the region should aim to enable Blue Economy growth through equitable trade partnerships, technology transfer, and sustainable infrastructure development. Collaboration on renewable energy, sustainable fisheries, and coastal tourism can support diversified, green economic pathways across the IOR.

Above all, India should uphold a sovereignty-respecting, non-conditional approach that empowers partner nations to define their own priorities. Co-creating solutions

tailored to local ecological and social contexts—especially using affordable, frugal innovations—will reinforce trust and shared ownership. By doing so, India can lead a new model of maritime cooperation rooted not in aid, but in mutual progress, regional solidarity, and long-term ocean sustainability.

RECOMMENDATIONS FOR FUTURE COOPERATION: SAGAR TO MAHASAGAR

To realize the SAGAR (Security and Growth for All in the Region) vision in a regionally inclusive and future-ready manner, cooperation among Indian Ocean Region (IOR) countries must be deepened through the structured integration of Underwater Domain Awareness (UDA) into policy, technology, and community frameworks. UDA offers the strategic foundation for understanding subsurface dynamics vital to sustainable ocean governance. The following six domains outline a roadmap for multi-tiered regional collaboration:

Capacity Building

IOR nations must jointly invest in indigenous scientific research, technical infrastructure, and academic programs. This includes establishing UDA labs, acoustic research hubs, and test-bed facilities within existing maritime institutions. Strengthening oceanographic institutes with modern tools for data collection and modelling, while offering scholarships and fellowships, will help nurture a skilled workforce. Given the acoustic complexity of tropical waters, region-specific studies are essential to develop predictive models and tailor underwater technologies.

Capacity Expansion

As ocean governance broadens, regional capacities must scale accordingly. This requires increased investment in multi-institutional research networks, regional innovation clusters, and advanced data-processing systems. Expanding deployment-ready technologies—like AUVs, passive acoustic monitors, and smart buoys—should be paired with workforce development from vocational skilling to postgraduate research. Policy alignment across sectors like fisheries, energy, and tourism will be essential for synchronized UDA capabilities.

Capacity Sharing

Equitable access to knowledge, infrastructure, and data is critical. India should promote shared regional infrastructure, technology

UDA strategies must be context-specific. Tools should be designed for tropical environments—accounting for high turbidity, salinity shifts, and biofouling—and must be rugged, modular, and low-cost. Local stakeholders—fishers, youth, and conservationists—should be engaged through citizen science programs, mobile UDA apps, and community monitoring initiatives to build grassroots ownership and data democratization.

MAHASAGAR can combine surface and sub-surface governance through indigenous technology, capacity-building, and regional partnerships.

transfer, and collaborative projects within the IORA. Joint development of affordable UDA systems and multilingual, open-access data platforms would enhance collective stewardship and transparency.

Capacity Adaptation

UDA strategies must be context-specific. Tools should be designed for tropical environments—accounting for high turbidity, salinity shifts, and biofouling—and must be rugged, modular, and low-cost. Local stakeholders—fishers, youth, and conservationists—should be engaged through citizen science programs, mobile UDA apps, and community monitoring initiatives to build grassroots ownership and data democratization.

Technology Development

Innovation must be anchored in the region's needs. Collaborative R&D can accelerate development of tropical-ready systems like rugged AUVs, sonobuoys, and acoustic sensors. Technologies should be designed with simple, multilingual interfaces, requiring minimal training. AI-enabled predictive tools can support early warnings for marine noise, species movement, and extreme events such as tsunamis or oil spills.

Marine Spatial Planning (MSP): Integrating UDA into Governance

MSP is essential to translate UDA insights into actionable maritime governance. Integrating subsurface datasets—such as noise levels, ecological hotspots, and seabed maps—will enhance zoning and resource allocation. IORA countries should adopt harmonized, ecosystem-based MSP frameworks that prioritize inclusivity, regional cooperation, and environmental sensitivity. Marginalized coastal communities must be included in decision-making to ensure equitable and sustainable outcomes.

CONCLUSION

The Indian Ocean Region (IOR) faces a convergence of economic ambition, environmental stress, and strategic

competition. India's SAGAR (Security and Growth for All in the Region) vision provides an inclusive framework for regional cooperation and sustainable development. However, to address the full complexity of ocean dynamics, especially beneath the surface, SAGAR must evolve.

Integrating Underwater Domain Awareness (UDA) brings critical insights into sub-surface processes—ranging from acoustic ecology to deep-sea intrusions—that directly impact security, ecology, and livelihoods. UDA enhances SAGAR's objectives by offering a science-based, real-time understanding of the underwater environment.

This marks the transition to MAHASAGAR—a deeper, more comprehensive maritime vision. MAHASAGAR can combine surface and sub-surface governance through indigenous technology, capacity-building, and regional partnerships. It charts a path for the IOR to become a global model of peace, sustainability, and maritime leadership, with India at the helm of this transformation.

Building India's Maritime Power

The UDA Imperative

P.V. Rao

As India is prioritising the ocean into the nation's development framework over the last quarter century, there is growing realisation that the country is resolved to build is maritime power. Indian maritime literature generally equated national power with maritime power. There is no denying that *maritime power and naval power* are closely interrelated terms. Yet, there is a qualitative distinction between one and the other. Naval power is a very familiar term whose content and application are relevant to the power of navies and their deterrent capabilities. On the other hand, maritime power is a holistic concept whose elements embrace the multitude of ocean resources and a coastal state's capabilities to leverage such resources for national progress. In this context, naval power is comparably a narrower concept vis-a -vis the concept of maritime power. Such distinction is lucidly explained by maritime scholar Ian Speller. Speller's book *Understanding Naval Warfare* offers a detailed analysis of the concept of maritime power and its difference with naval power. Speller explains that maritime power "is an inherently broad concept embracing all uses of the sea, including both civil and military. In its widest sense, it can be defined as military, political and economic power, or influence exerted through an ability to use the sea". Notwithstanding its military component, maritime power according to him "also includes civilian capabilities such as, coast guard, shipping infrastructure, merchant shipping, fishing or shipbuilding."[43] Indian scholarship on maritime affairs generally ignored this distinction and mostly equated maritime power with naval power. Traditional maritime scholars like K.M. Panikkar, K. R. Singh and others of that genre did not make much effort to draw the distinction between the two concepts.

However, the more recent native maritime scholarship is leaning in favour of treating maritime power as conceptually distinct from naval power. Such an effort is to be found in the writings of the former Indian naval chief Adm. Arun Prakash. In his well known book, *From the Crow's Nest (*2007) Arun Prakash explains: "the concept of maritime power encompasses far more than most people seem to imagine, and certainly goes much beyond the military aspects." In defence of this thesis he

43 Ian Speller, Understanding Naval Warfare, Routledge, 2023, p.1

quotes approvingly the distinguished Russian Admiral Sergi Gorshakov who used sea power and maritime power synonymously. According to Gorshakov: "In the definition of sea power we include as the main components, ocean research and exploitation, the status of merchant and fishing fleets, and their ability to meet the needs of the state, and also the presence of a navy to safeguard the interests of the state." Furthermore, the Russian admiral who supported a strong navy for India says: "Sea power (meaning maritime power) emerged as one of the important factors of strengthening the economy, accelerating technical development and consolidating economic, political and cultural links with friendly people and countries."[44] A more explicit articulation of maritime power concept is to be found in a recently published work on the subject by India's reputed maritime scholars Kamalesh Agnihotri and Gurpreet Khurana. The two authors explain in detail the concept in their *Maritime Power Building, New Mantra for China's Rise.* Focussing on China's planned effort to leverage the ocean resources to build its comprehensive national power (CNP) they state that "the strength of the naval forces alone does not and cannot ensure the rise of a nation to a great power status." To attain this ambitious goal, "the sea has to be comprehensively understood, and then explored, as a medium of immense economic, scientific, political, social and military potential, so as to be a contributory factor in the building of a Comprehensive National Power (CNP)."[45] Though no explicit reference is made to India, it is possible to draw the inference that the book conveys India too should leverage its marine resources to build the country's national power.

Recent national maritime policy moves do strongly indicate that the national leadership and the policy community do realise the imperative of leveraging ocean wealth to raise the country's heft as a global economic power. This is unmistakably evident in the national maritime visions published by Indian government. For example the most recent official document, Maritime Amrit Kaal Vision 2047 states: "Through concerted efforts in infrastructure development, policy

44 Arun Prakash, From the Crow's Nest, 2007, p.74

45 Kamalesh K Agnihotri and Gurpreet S Khurana , ed, Maritime Power Building, New Mantra for China's Rise, Pentagon Press, 2016, xi

The most recent official document, Maritime Amrit Kaal Vision 2047 states: "Through concerted efforts in infrastructure development, policy reforms, and technological innovation, India's maritime sector is on the cusp of a transformational journey towards prosperity and progress."

reforms, and technological innovation, India's maritime sector is on the cusp of a transformational journey towards prosperity and progress."[46] The government and its ministry of ports, shipping and waterways have already launched major programmes aimed at realisation of the above vision. Sagarmala, Inland Waterways Development, Green Tug Transition Program (GTTP), PM Matsya Sampada Yojana, Deep Ocean Mission are the key constituents of India's blue economy philosophy.

Blue economy conceptualises oceans as "Development Spaces" where spatial planning integrates conservation, sustainable use, oil and mineral wealth extraction, bioprospecting, sustainable energy production and marine transport. This concept hardly figured in India's previous development plans has assumed, post reforms, a prominent place in the country's economic priorities. Major ocean-specific sectors inclusive to this model are hydrocarbons, maritime infrastructure, trade and logistics, deep sea mining, marine biotechnology, coastal tourism, hospitality and high sea cruise operations. Policy report prepared by the central government's Ministry of Earth Sciences (MOES) on blue economy states that "India should strive for efficient and sustainable utilization of ocean resources and to integrate and boost ocean related capabilities, capacities and skills, with a view to accelerate employment and gross value addition....The objective of this (blue economy) policy framework will be to enhance the country's GDP by promoting sustainable and inclusive economic growth in this new domain while aligning India's development agenda with national security goals."[47] This official pronouncement broadly complements the government's

46 Ministry of Ports, Shipping and Waterways, MARITIME AMRIT KAAL VISION 2047, https://www.pib.gov.in/PressRelease. Visited June 6, 2025

47 https://www.moes.gov.in/sites/default/files/PIB1845257_0.pdf. Visited on June 2, 2025

another major maritime project, *Sagar* (Security and Growth for All in the Region). The Sagar project launched by the Indian prime minister in 2015 at Mauritius blends economic growth and security into a single policy framework. Yet, both these major initiatives differ in their scope. Blue economy is nationalistic in its scope and framework. Sagar on the other hand is international in its appeal and coverage. This is a multilateral concept which envisages common regional appeal to the countries of the Indian Ocean. Apart from the economic and security components, strategic considerations too are embedded in Sagar. Rather, the last factor inspired India to launch and campaign for Sagar's subscription by the regional littorals.

Recalling that India was among the first to establish a separate Department of Ocean Development in the world three decades ago, Ministry of Earth Sciences (MoES) claims that ever since the country steered ahead in launching major maritime programmes like Deep Ocean Mission, oceanography from space, launching of the data buoys along the Indian coastline. As part of such ocean exploratory missions, MoES signed contracts with the International Seabed Authority (ISBA) for deep ocean exploration of minerals (Polymetallic Nodules and Hydrothermal Sulphide) in the Indian Ocean.[48] Further, such mining pursuits bring into focus the need for Underwater Domain Awareness (UDA). This essay is a fledgeling attempt to factor UDA into India's maritime power building programmes. UDA is an extended version of the Maritime Domain Awareness (MDA) which is all about knowing the different spaces and depths of the sea. The MDA concept, common to any maritime pursuit

Recalling that India was among the first to establish a separate Department of Ocean Development in the world three decades ago, Ministry of Earth Sciences (MoES) claims that ever since the country steered ahead in launching major maritime programmes like Deep Ocean Mission, oceanography from space, launching of the data buoys along the Indian coastline.

48 https://www.moes.gov.in/sites/default/files/2021-07/Blue Economy Policy_English.pdf. visited May 6 , 2025

As defined by the Indian Navy's Integrated Maritime Surveillance System (IMSS) MDA is about "being cognizant of the position and intentions of all actors, whether own, hostile or neutral and in all dimensions - on, over and under the sea.

the world over, embodies two broad postulates: governance and knowledge. The first is about the coastal state's efforts to extend its control over the sovereign spaces of the sea. Maritime governance is an integrated administrative system whose agencies extend to concerned sectors of the sea: sovereign jurisdiction (territorial sea, EEZ, continental shelf)), coastal industries and commerce, fishing, marine ecology and environment, ports, shipping, sports, tourism. All assets, and elements of marine geography. But governance requires knowledge of sea. Know the sea before you venture into it. Or, to invoke the old adage, look before you leap. Sea always had been the object of exploration for man through the ages. A symbiotic relationship evolved through the annals between man and the sea around him. Curiosity, acquisition and also adventurism drove coastal man to know more about the unknown domains of the ocean. As modern man's thrust to reap more of the ocean wealth is ever growing, he is compelled to learn more of the unknown realms of sea. Such a logic is equally extendable to the state, the sovereign authority over its legitimate maritime areas.

THE MDA IMPERATIVE

Browsing through the Indian Navy (IN) publications one easily finds that MDA is the commonly used concept to learn about the varied geophysical dimensions of the sea. As defined by the Indian Navy's Integrated Maritime Surveillance System (IMSS) MDA is about "being cognizant of the position and intentions of all actors, whether own, hostile or neutral and in all dimensions - on, over and under the sea." This of course is a broad sketch of the concept of MDA which can be subjected to different interpretations. A fairly recent publication by MOD compiling contributory articles by naval personnel titled, analyses the importance and role of MDA in Indian naval strategic pursuits. Recognising the MDA imperative for

naval operations this edited volume informs that Indian Navy (IN) will be "generating adequate maritime domain awareness" in order to "maintain effective deterrence and warfighting capabilities."[49] Going by the above descriptions of MDA drawn from the Indian naval literature, it is easily noticeable that this concept is loaded with strategic content, understandably of course. But 'maritime' is a holistic concept which embraces the many other elements of the sea (archaeology, climate, communities, infrastructure, tourism, trade, transport etc). Maritime security and its agencies like navy and coast guard are part of the composite element's integral to the maritime holistic framework. In this sense, MDA connotes a narrower application. Nevertheless, this concept is gradually finding its application to the civilian maritime exercises. The series of maritime development programmes and visions launched by India in recent times viz; Blue economy, Sagarmala, SAGAR, IFC-IOR, Deep Ocean Mission, Matsya Sampada Yojana and other such projects are calling for greater understanding of the MDA scope and acquisition of skills and technologies to execute such projects.

MDA-UDA LINKAGE

MDA as noted above is a comprehensive concept which embraces *every* dimension of the ocean: human and animal or living and non-living; surface and subsurface waters; coastal and high sea; trade and transport channels (SLOCs), research and surveys, security (military, non-state, human), disasters (natural and human), climate change and sea warming. And, a gamut of several seaborne factors. Yet, recent maritime accounts find MDA is an inadequate guide to comprehend and explore the

Dominant maritime powers have adopted UDA to their naval strategic programmes. UDA combat enablers, to cite a few, include ASW (Anti-Submarine Warfare) capability, submarine transits and patrols, acoustics, sensors and ocean bottom mapping. Acoustic testing infrastructure is rated as an essential input to regulate and monitor the submarine sounds.

49 Indian Navy in the 21st Century , Ministry of Defence, 2014, p. 230

seas today. A new concept termed as Underwater Domain awareness (UDA) is being advocated. UDA is a fairly recent maritime concept. It is a focussed branch of marine knowledge concerned with certain specific aspects of MDA. Particular focus of UDA is, as the term indicates, on the underwater space. To delve deep into the undersea bottoms, and devise requisite apparatus for the purpose. It is a technology driven concept and hence demands strong underwater technologies to build submarine warfare capabilities. Dominant maritime powers have adopted UDA to their naval strategic programmes. UDA combat enablers, to cite a few, include ASW (Anti-Submarine Warfare) capability, submarine transits and patrols, acoustics, sensors and ocean bottom mapping. Acoustic testing infrastructure is rated as an essential input to regulate and monitor the submarine sounds. Thus these are the key undersea knowledge systems helpful to boost submarine deterrence capability, or warfare of an expanding naval power. This point is strongly underlined by Adm. Sardesai who cautions that the next two decades would watch undersea warfare greatly driven by "giant technological leaps in underwater surveillance and domain awareness."[50]

Pointing out that "advances in data processing of information from underwater sensors will pose a challenge to submarine operations", the senior Indian naval officer calls for increased UDA inputs. This message is elaborated in greater details by Vijay Sakhuja, a naval veteran and India's reputed naval strategic analyst. According to Sakhuja efforts are underway to develop, what he calls the Fourth Industrial Revolution (4IR) technologies, and integrate the same with the Indian Navy (IN) to advance its strategic planning and operations at sea. The 4IR technologies include artificial intelligence (AI), big data, cloud computing, machine learning, internet of things (IoT), and other such. These advanced technologies which are driving the world into a new technology-driven era, assist several underwater operations which, as categorised by Sakhuja are the following:

- Combat operations including ASW (anti-submarine war fare); mine countermeasures (MCM); underwater domain awareness.
- Delivery of public goods (marine services) such as SAR (search and

50 Indian Navy's Vision - 2047, P.48

From strictly MDA point of view, AI component of Industrial Revolution 4.0 (4IR) can potentially translate "MDA into actionable information and offer unprecedented potential to counter crimes at sea" like IUU, vessel tracking, SAR operations, monitoring remotely operated autonomous vehicles. In short, 4IR "helps to minimize the information gap, thus limiting the number of vessels that require investigation.

rescue), HADR (humanitarian assistance and disaster relief), and

- Management and scientific endeavours that include ocean development, marine environment protection and ecology restoration.

Aggregated into a whole, these three categorisations nearly span almost every important maritime enterprise: combat, humanitarian, ocean survey. From strictly MDA point of view, AI component of Industrial Revolution 4.0 (4IR) can potentially translate "MDA into actionable information and offer unprecedented potential to counter crimes at sea" like IUU, vessel tracking, SAR operations, monitoring remotely operated autonomous vehicles. In short, 4IR "helps to minimize the information gap, thus limiting the number of vessels that require investigation."[51] China, busy raising the PLAN's naval combat capabilities, is reportedly planning an Underwater Great Wall.

UDA is used either coterminously with MDA or as an improvised substitute for it. Either way UDA is a preferred concept to plan and direct the undersea naval security strategies. As yet, this concept does not enjoy universal endorsement. Different terms

UDA is used either coterminously with MDA or as an improvised substitute for it. Either way UDA is a preferred concept to plan and direct the undersea naval security strategies. As yet, this concept does not enjoy universal endorsement.

51 Vijay Sakhuja, Fourth Industrial Revolution Technologies, Maritime and Naval Operations, Pentagon Press, New Delhi, 2021

Spending more on indigenous R&D, involving and sharing with multiple stakeholders engaged in undersea enterprises should be the guiding spirit of the UDA framework. In other words Das implies UDA should be factored into the current *Atmanirbhar Bharat* (Self-Reliant India) project.

are substituted for it. For example, undersea domain awareness is an alternative term, so too "water space management." The latter, water space management, coined by the US DOD connotes it with underwater domain awareness. UDA however is yet to gain currency in the Indian naval literature. But, attempts are underway. Reference to 'underwater' is found in *Transition to Guardianship* ,1991-2000, last of the trilogy on Indian Navy's official history, sumptuously documented by late Adm. Hiranandani. This volume briefly explains the Naval Underwater Ranges (NUR) established by Indian Navy (IN) in 2004. NUR guides warships and submarines, mine laying, noise measurement and noise reduction in warships.[52]

In recent years earnest effort to upstage UDA relevance to Indian maritime interests is apparent in the Indian strategic community, the naval community in particular. Indicative of this effort is the campaign to popularise UDA by the Pune based Maritime Research Centre (MRC), led by its founder Cdr. Arnab Das, a naval veteran. According to Das, MDA of India has not gone beyond the sea surface, and its application is security specific, ignoring the civilian sectors and stakeholders. To overcome these limitations, Das passionately pleads for promoting UDA and he conceptualised a framework which "encourages *pooling of resources* and *synergising of efforts* across the stakeholders, namely maritime security, blue economy, marine environment & disaster management and science & technology." UDA in a nutshell enables what is happening in the undersea realm. He cautions against confining UDA just to military needs. Because the *security bogey* has drained heavily the national economic resources by spending overly on imported military hardware. Spending more on indigenous R&D,

52 Transition to Guardianship, Integrated Headquarter, Ministry of Defence (Navy)

involving and sharing with multiple stakeholders engaged in undersea enterprises should be the guiding spirit of the UDA framework. In other words Das implies UDA should be factored into the current *Atmanirbhar Bharat* (Self-Reliant India) project. Not the less, by deepening MDA into the deeper domains of sea, India's current maritime development drive would gain draft and substance. The UDA framework designed by Das comprised two geometrical dimensions: horizontal; vertical. Horizontal construct involves assessing undersea resource prospects, whose enablers are the appropriate technology, infrastructure and capability. These assets would help stakeholders (industry, oil explorers, deep sea fishers, scientists, defence, conservationists) plan and pursue their respective underwater pursuits. The second dimension, vertical construct involves sensing the undersea domain, plans for utilisation of the data gathered, and then designing regulatory provisions for the use and conservation of resources by stakeholders.[53] These two interrelated dimensions thus constitute the comprehensive UDA framework by Arnab Das, the UDA campaigner. Messiah!

However, maritime experts, particularly the naval community, are sceptical about India's UDA deliverables. They see a gap between UDA's existing capabilities and prospects to execute the promises tucked into the series of maritime programmes introduced in recent years. Naval sources this author interacted admit that India as of now is far short of the technology needed to build robust UDA structure to execute the projects conceived under the Deep Ocean Mission (DOM). National maritime technology bodies such as the NIOT (National Institute of Ocean Technology) are, to quote a naval officer, short of meeting the UDA inputs. Hence dependence on foreign sources, it is felt, is imminent in order to take forward the deep ocean projects planned.

UDA FOR SAGAR

SAGAR is the often-repeated theme invoked to the UDA concept. Or, if it does not sound far fetching, UDA

53 Arnab Das,"Underwater Domain Awareness," India Foundation. https://indiafoundation.in/articles-and-commentaries/the-underwater-domain-awareness-framework-infinite-possibilities-in-the-new-global-era/. Visited May 27, 2025

owes its current advocacy to the SAGAR concept. Therefore, SAGAR is the constant consonant in the UDA discussion. As of now India's MDA capabilities are found to be inadequate to serve the country's growing strategic and civilian maritime agenda. In particular, in comparison with those of the advanced powers, Indian MDA capabilities are lower as maritime experts point out. This limitation is candidly stated by naval officer Yashodeep Bhole. Recognising the extensive MDA experience of the Australian, Japanese, US naval forces, Bhole calls for IN partnership with these navies for obtaining valuable information and expertise. Simultaneously IN "can also invest in new technologies such as ocean surveillance satellites and drones to enhance its MDA capabilities. These technologies can provide valuable information about ships and submarines in the IOR, and they can help fill the *gaps in the Indian Navy's current MDA capabilities.*" It is also suggested that "collaborative engagements with friendly navies could be useful to the Indian Navy in gaining better *undersea domain awareness* about the PLAN submarines."[54] It is very relevant to place in this context the US offer of six more P-81 maritime patrol aircraft to the IN during the summit meeting between Prime Minister Modi and President Trump in February 2025. These are meant to enhance the MDA role of the IN. Reportedly both agreed to deepen bilateral cooperation in undersea systems. (See, Harsh Pant and Kartik Bommakanti, "Trump 2.0 and the new matrix of U.S. -India defence ties,"[55] The addition of the six to the existing fleet of twelve P-81 is expected to fulfil the IN requirement to boost its ISR (Intelligence, surveillance, Reconnaissance) and anti-submarine warfare missions over the Indo-Pacific region. Two months later in May 2025, Indian media sources reported the US decision to supply maritime surveillance systems and Sea Vision software to India, a further indication of the deepening bilateral Indo-US maritime partnership. But this latest American gesture is also meant to meet the QUAD's Indo-Pacific Maritime Domain Awareness consensus. Sea

54 See, Indian Navy's Vision - 2047, P. 193). Similar message is conveyed by a serving Indian naval architect Capt. Amit Ray in his scholarly study, Tracing the Undersea Dragon, Chinese SSBN Programme and the Indo-Pacific, Routledge, 2022

55 The Hindu, February 28, 2025.

Vision as explained by the US official document is a web based maritime situational awareness tool. Its primary uses include gaining "broad array of maritime information to improve maritime operations, increase maritime security…." This software is designed to gain real time data on underwater activities. It processes such data for detecting, classifying and tracking underwater objects like submarines, ships but also meets the civilian needs of environmental protection and sustainable management of ocean resources. Needless to repeat last two elements are integral to the blue economy discourse.[56] It is pertinent here to recall this author's earlier observation that maritime security assumes priority in the overall Indo-US defence cooperation, indicating the bilateral strategic consensus to counter the Chinese naval assertions in the Indio-Pacific.[57] It is not surprising therefore that commentaries on the IN's MDA/UDA activities heavily highlight their relevance to the Indo-Pacific maritime security strategies. No less to the SAGAR campaign whose security plank too finds resonance in the UDA discussion.

But what is mostly missing in this debate is the salience of UDA to the growth plank of SAGAR. Like security, the growth plank of SAGAR also embodies many functional areas like hydrocarbon and polymetallic explorations. And such tasks befall on the UDA infrastructure. Pursuit of both the planks or ensuring an equitable balance between security and growth is crucial to meet India's geo-political and economic agenda in the Indo-Pacific. This theme is elaborately analysed in this author's forthcoming book, India's Maritime Power. Security and growth are not separate functional areas but bear mutually beneficial relationship between them. The vision of Amrit Kalash (The Urn of Nectar) can be realised by maximising the marine resource acquisition and securing the same from threats and challenges. Both pursuits depend on UDA. Returning to the Sagar theme in 2025 at Mauritius where the Indian Prime Minister first unveiled it ten years ago in 2015, Modi prefixed Sagar with Mahasagar (Mutual and Holistic Advancement for Security and Growth Across Regions). Explaining the new term Modi said: "We have

56 https://info.seavision.volpe.dot.gov/. visited May 26, 2025

57 See, P V Rao, India's Naval Diplomacy, Routledge, 2022

Sagarmala was formally launched by the Indian Prime Minister in Mumbai in 2016 at the first Maritime India Summit in 2016. This ambitious port development project is an important constituent of the blue economy framework.

taken the SAGAR vision forward for the stability and prosperity of this entire (IO) region." This new vision will go beyond SAGAR to be called Mahasagar.[58] The common theme of ensuring a free, open, secure and safe IO found in other regional forums like IORA, Colombo Security Conference and Indian Ocean Conference was also replayed by Modi at his latest visit to Mauritius, the island state with which India inked strategic partnership agreement recently. As part of this partnership, India promised helping the establishment of National Maritime Information Sharing Centre in this island state.

SAGAR-BLUE ECONOMY SYNERGY

Blue economy is integral to Sagar. Conceptually Sagar is premised on two basic factors: security and economic growth. Both are intimately interrelated, not mutually exclusive factors. For, civilian maritime projects purposed to contribute to national economy and export-led growth need the protection of maritime security forces. Ensuring freedom of navigation and protecting SLOCs (sea lanes of communication) are part of the Sagar agenda. In similar vein, sound national economy is the prerequisite of meeting the costs of defence infrastructure and weaponry. Naval professionals are fully aware of the cuts in defence expenditure and arms acquisitions in times of national economic crises reminiscent of the balance of payments breakdown in early nineties. Sagar therefore is a blend of security imperative and primacy of economic growth. Marine resource application to blue economy sectors is a multifaceted enterprise. Mapping resource potential (potential zones of fish, oil, gas, manganese nodules), MSP (marine spatial mapping), categorisation (type

58 Economic Times, March 13, 2025

of fish, oil grades, density, content etc.), technologies (navigational, underwater and remotely operated vehicles, sensors), value assessment, cost inputs,, exploration and extraction are the essential attributes of harvesting ocean properties Among the major blue economy programmes launched by the Indian government, *Sagarmala* definitely is a prominent one. *Sagarmala* was formally launched by the Indian Prime Minister in Mumbai in 2016 at the first Maritime India Summit in 2016. This ambitious port development project is an important constituent of the blue economy framework. *Sagarmala,* as the official policy document prepared by the Ministry of Ports and Shipping states, intends to comprehensively and holistically address the challenges and capture opportunities of port-led development. It is a port-led development model premised on four pillars viz; port modernization; port connectivity enhancement; port-linked industrialization, and; coastal community development. It is therefore an integrated, multimodal, and an inclusive project as well. This model eminently reflects the growth normative incorporated into the SAGAR. As the official report states port modernization is necessary to promote export driven growth. Developing transshipment ports and hubs are planned under *Sagarmala* to cut down operational costs for EXIM transaction. A growth -led economy like that of India promotes increased EXIM transactions which are expected to raise the country's industrial competitiveness in global market. It hardly needs to be repeated that efficient transportation is primary driver in supply chain management because it is the speedy supply of raw resources, industrial components and the end products through logistically supported multimodal strategies that help optimize time and cost both for the producer/ exporter and importer/receiver.

Multimodalism is a core component of port development model. Port-linked connectivity to roads, railways and inland waterways is envisaged by *Sagarmala*. No less also is the POL (petroleum, oil, lubricants) and LNG supplies (liquefied natural gas) through pipelines. As refinery establishments are growing in hinterland and along the ports, *Sagarmala* plans more port-pipeline connectivity because pipelines are effective channels of delivering

liquid cargo to and from ports and also less costly. An interesting fact revealed by *Sagarmala* report is that POL products contribute to 36% of total traffic handled by ports, higher than any other commodity. Several pipeline projects are developed by private corporates like the Adani, Hiranandani and RIL. Here comes into picture the role of maritime security forces, IN and the Coast Guard, sentinels of national maritime assets.

Exploring marine hydrocarbons is another important component of blue economy. Search for deep water hydrocarbons is the primary objective of India's energy security pursuits. Its execution however is conditioned by the advanced exploration and production technologies. In this context it is worth reproducing here from the annual report the DGH (Directorate General of Hydrocarbons). Recognising the potential for oil and gas in the deepwater fields, the report states: "Advances in drilling and production technology have made it possible to extract oil and gas from ever-deeper depths. High-resolution geophysical exploration technology enables scientists to detect oil and gas deposits in seabed and geological strata, to depths of up to 12 kilometres, leading to the discovery of many major new deposits in recent years. Despite the high cost of drilling in deep water, the high productivity of oil and gas fields can justify the expense...." India, the DGH report (2022-23) informs, is home to 26 sedimentary basins covering an area of 3.36 million square kilometres. These basins are distributed over the shallow and deepwater depths which stretch beyond India's EEZ. Of the total sedimentary area of the country, 39% lies in the deepwater areas. But herein lay the challenges to E&P (exploration and production) of oil and gas in offshore areas because these entail extensive use of seismic imaging and geologic analysis, rigorous engineering design, construction of highly specialized equipment - all of which necessitate substantial time and financial investment.[59] Recently, as informed by Adm. Girish Luthra, India initiated plans to auction for exploration and exploitation of around seven seabed mineral blocks in its EEZ off the Great Nicobar Island. In fact, Australia, Japan and US are pursuing technologically advanced programmes

59 https://www.dghindia.gov.in/assets/downloads/ar/2022-23. Visited April, 22, 2025

As early as in 1969, Naval Science and Technological Laboratory (NSTL) was established at the at the Eastern Naval Command, Visakhapatnam. NSTL is a premier laboratory founded with the objective of attaining self-reliance in underwater technology.

in this domain. And the senior naval officer suggests developing "a cooperation plan for ocean research, deep-sea exploration and seabed mining. This could be on a bilateral basis or under the umbrella of the Quadrilateral Security Dialogue—a grouping of Australia, India, Japan, and the US."[60] Other components of blue economy narrated in above sections do require relevant ocean equipment and technologies to harvest marine resources.

CONCLUSION

It is reasonable to conclude, going by the above maritime programmes and projects, that contemporary India is building long-term strategies for building country's maritime power. This does not mean that no such plans were envisaged in the earlier or port-reform decades. There were attempts, albeit slow and sporadic, to promote ocean sciences, infrastructure and technologies. For example, as early as in 1969, Naval Science and Technological Laboratory (NSTL) was established at the at the Eastern Naval Command, Visakhapatnam. NSTL is a premier laboratory founded with the objective of attaining self-reliance in underwater technology. Its tasks include design and development of surface and sub-surface vehicles, submarine design and other underwater technologies related to weapon control systems.[61] According to a media report, a team of NIO oceanographers was sent recently on a deep ocean mission into the Indian Ocean to locate deep sea minerals like cobalt, copper, manganese and zinc at a 3000 meter depth. This mission

60 Adm. Girish Luthra, "Deep-sea dilemmas: Countering China's seabed mining efforts through global collaboration." orfonline.org. visited My 20, 2025

61 The Eastern Shield, Eastern Naval Command, Visakhapatnam 2019

apparently is the first of a series of deep sea voyages envisaged under India's comprehensive Deep Ocean Mission (DOM).[62] Hence, the tasks of DOM are set into motion. Hence the drivers of deep ocean explorations are already set in motion. But the goals envisaged by DOM would be achievable if India commensurately develops the science and technologies required for Underwater Domain Awareness.

62 India Goes Deep Sea for Drivers of Future Tech." Times Of India, April 23, 2025

India's Blue Economy

Assessing Sustainability and Potential of the SAGAR Initiative

Jayseelan Cathrine

Rising territorial disputes, especially in vital maritime corridors, have intensified competition among major powers, creating new challenges for navigation, security, and diplomatic engagement. Simultaneously, global trade patterns are being reshaped by tariff wars, protectionist policies, and the urgent need for resilient and diversified supply chains. These changes underscore the indispensable role of the oceans—not only as arteries of global trade but as pivotal spaces where economic power and security intersect.

INTRODUCTION

India's Blue Economy plays a crucial role in national development, contributing nearly 4% of GDP. With approximately 18% of India's population residing in 72 coastal districts, which account for 12% of the mainland, sustainable marine resource management is essential. Additionally, about 250 million people live within 50 km of India's coastline, representing 3.5% of the world's population, highlighting the economic and ecological significance of India's coastal and marine sectors. India's flagship initiative, SAGAR (Security and Growth for All in the Region), has strengthened maritime cooperation, security, and sustainable resource utilization in the Indian Ocean Region (IOR), fostering economic resilience. This initiative promotes ocean stewardship, environmental accountability, and the exchange of knowledge, technology, and livelihood opportunities, all of which contribute to a sustainable Blue Economy. Complementing this, the Underwater Domain Awareness (UDA) framework enhances maritime governance and accessibility through marine spatial planning and capacity building. Given India's 2.37 million sq. km exclusive economic zone (EEZ), robust monitoring systems are crucial for sustainable marine resource utilization and minimizing ecological disruption. This paper evaluates the significance of SAGAR in shaping India's Blue Economy, analysing its impact on key ocean-based industries. It further explores how UDA strengthens maritime security, optimizes resource deployment, and drives long-term economic sustainability.

WHY THE OCEAN MATTERS MORE THAN EVER

The world today stands at a critical maritime juncture, a global moment defined by shifting geopolitical tensions, evolving trade dynamics, and profound realignments in supply chains. The ocean, which has long been a conduit for commerce, culture, and connectivity, now assumes an even greater strategic and economic significance. Rising territorial disputes, especially in vital maritime corridors, have intensified competition among major powers, creating new challenges for navigation, security, and diplomatic

Through initiatives like SAGAR (Security and Growth for All in the Region) and MAHA-SAGAR, India aims to catalyse collaboration, capacity building, and technology-driven innovation among Indian Ocean littoral states. This approach envisions a cooperative maritime order that respects sovereignty, promotes shared prosperity, and upholds environmental sustainability.

engagement. Simultaneously, global trade patterns are being reshaped by tariff wars[63], protectionist policies, and the urgent need for resilient and diversified supply chains. These changes underscore the indispensable role of the oceans—not only as arteries of global trade but as pivotal spaces where economic power and security intersect.[64] [65]

Against this backdrop, the Blue Economy emerges as the new frontier for economic resilience and sustainability. Defined broadly, the Blue Economy encompasses the sustainable use of ocean resources for economic growth, improved livelihoods, and ecosystem health. It spans a wide range of sectors, including fisheries, maritime transport, renewable energy, aquaculture, marine biotechnology, and coastal tourism. Unlike traditional economic models that often viewed the ocean primarily as a resource to be exploited, the Blue Economy promotes a balanced approach that integrates economic development with environmental stewardship and social equity. In an era marked by climate change, biodiversity loss, and increasing environmental degradation, the Blue Economy offers a pathway toward a regenerative and inclusive growth model—one that can address global challenges while unlocking vast untapped potential.

This transformation is especially critical for the Global South, home to many coastal and island nations whose economies and communities are intricately tied to the health of the oceans. These countries face acute vulnerabilities due to climate impacts such as sea-level rise, extreme weather events, and fisheries depletion, which threaten food security, livelihoods, and cultural heritage. At the same time, they possess rich marine biodiversity and strategic maritime locations that offer unique opportunities for sustainable development and regional cooperation. Harnessing the Blue Economy is thus not only an environmental imperative but also a strategic necessity for the Global South to build resilience, reduce poverty, and achieve sustainable development goals.

63 Oceans of opportunity squeezed dry by overfishing - Manila Standard, March 17 2025

64 Humanity depends on the ocean—here is what we need to prioritize for immediate ocean science research, April 14, 2025

65 Humanity depends on the ocean—here is what we need to prioritize for immediate ocean science research, April 9, 2025

The *Amrit Kaal* Vision 2047 articulates a future where India not only strengthens its port infrastructure but also adopts cutting-edge sustainable practices to safeguard marine ecosystems. The Prime Minister's inauguration of projects worth over Rs 23,000 crores, including the Tuna Tekra all-weather deep draft terminal at Deendayal Port Authority, exemplifies this dual focus. This greenfield terminal, positioned as a flagship facility within the India-Middle East-Europe Economic Corridor (IMEEC), is designed to accommodate next-generation mega vessels exceeding 18,000 TEUs, thus elevating India's capacity as an international maritime trade hub.

Amid these global dynamics, the pressing question arises: How can India turn this tide into opportunity—for itself and the Global South? India's geographical expanse, with its vast coastline, exclusive economic zone, and strategic location at the heart of the Indian Ocean, places it at the forefront of this maritime renaissance. As a rising economic power and a responsible regional stakeholder, India is uniquely positioned to lead by example, leveraging its maritime vision to foster inclusive growth and security. Through initiatives like SAGAR (Security and Growth for All in the Region) and MAHA-SAGAR, India aims to catalyse collaboration, capacity building, and technology-driven innovation among Indian Ocean littoral states. This approach envisions a cooperative maritime order that respects sovereignty, promotes shared prosperity, and upholds environmental sustainability.[66]

India's Blue Economy agenda integrates economic ambitions with ecological preservation, focusing on renewable energy, sustainable fisheries, marine biotechnology, and maritime trade facilitation. Equally important is India's emphasis on disaster resilience and climate adaptation, critical for protecting vulnerable coastal populations. By advancing science-based maritime governance

66 Development of Blue Economy for National Growth - UDA Digest

and inclusive partnerships, India not only strengthens its own strategic and economic interests but also empowers neighbouring countries and the wider Global South to harness the ocean's potential sustainably.[67]

In essence, the ocean matters more than ever because it embodies the crossroads of global security, economic opportunity, and environmental sustainability. For India and the Global South, this moment demands visionary leadership and collaborative action to turn the tides of challenge into waves of opportunity—building a future where the oceans become engines of shared prosperity and guardians of our planetary health.

INDIA'S MARITIME BLUE ECONOMY: STRATEGIC VISION, INFRASTRUCTURE DEVELOPMENT, AND GLOBAL ALIGNMENT

"We are moving towards a future where the Blue Economy will be the medium to create a Green Planet."

– Prime Minister Narendra Modi

India's maritime sector has emerged as a pivotal driver of economic growth, sustainability, and strategic influence, underpinned by an ambitious long-term blueprint—*Amrit Kaal Vision 2047*. The unveiling of this vision by Prime Minister Narendra Modi during the recent Global Maritime India Summit marks a critical milestone in institutionalizing a comprehensive approach to the blue economy, one that integrates port modernization, sustainable ocean resource management, and international collaboration. The active involvement of key leadership figures, notably the Minister for Ports, Shipping and Waterways, Shri Sarbananda Sonowal, underscores the government's unified commitment to this sector's transformative potential.

At the core of India's maritime strategy is a recognition of the ocean as a multifaceted asset essential to the nation's economic prosperity, environmental health, and geopolitical stature. The *Amrit Kaal Vision 2047* articulates a future where India not only strengthens its port infrastructure but also adopts cutting-edge sustainable practices to safeguard marine ecosystems. The Prime Minister's inauguration of projects worth over Rs 23,000 crores, including the Tuna Tekra

67 Philippine-India Defence Relations: From Good to Great - UDA Digest

all-weather deep draft terminal at Deendayal Port Authority, exemplifies this dual focus. This greenfield terminal, positioned as a flagship facility within the India-Middle East-Europe Economic Corridor (IMEEC), is designed to accommodate next-generation mega vessels exceeding 18,000 TEUs, thus elevating India's capacity as an international maritime trade hub. The strategic selection of Gujarat's Deendayal Port for this development reflects the government's intent to leverage geographic advantages and foster multimodal connectivity, reinforcing India's position in the global supply chain.[68]

Beyond infrastructure, the Prime Minister's dedication of over 300 Memorandums of Understanding (MoUs) totalling more than Rs 7 lakh crore highlights the expanding web of partnerships vital for the sector's growth. These agreements span national and international stakeholders, indicating India's emphasis on collaborative frameworks that encompass diverse domains such as shipping, fisheries, marine technology, and ocean governance. The summit's wide-ranging participation by ministers, CEOs, and investors from multiple continents further illustrates the global relevance of India's blue economy agenda and its appeal as an emerging maritime power.

India's national initiatives resonate strongly with the globally endorsed G20 High-Level Principles on Sustainable and Climate-Resilient Blue Economy. These principles, grounded in the understanding that oceans sustain billions of livelihoods and constitute a multi-trillion-dollar economy, provide a crucial framework to address the challenges posed by climate change, marine pollution, and resource depletion. India's alignment with these principles reflects a sophisticated awareness of the need for balanced development that safeguards marine biodiversity while promoting economic and social inclusion.

Notably, the G20 framework's emphasis on effective and participatory cooperation frameworks mirrors India's efforts to foster integrated governance across national and sub-national levels. The adoption of ecosystem-based marine spatial planning in India aligns with the principle of managing ocean activities within ecological limits while considering socio-economic and cultural dimensions. This holistic

68 Maritime Domain Awareness – A Call for Capacity Building - UDA Digest

approach enables the mitigation of conflicts among competing uses and ensures the sustainable provision of ecosystem services.[69]

Innovation and digital technology form another pillar of India's strategy, directly reflecting the G20's call to leverage technological solutions for minimizing environmental impact and advancing circular economy goals. India's investments in smart port technologies, real-time maritime monitoring systems, and oceanographic research underpin this objective, positioning the country at the forefront of maritime innovation in the region.

Furthermore, India's inclusive approach, which integrates gender equality and respects traditional knowledge systems, enhances the social sustainability of the blue economy. By empowering coastal communities and recognizing indigenous maritime practices, India ensures that economic development does not come at the cost of cultural erosion or social disparity.

The G20 principle advocating enhanced access to long-term finance is also mirrored in India's innovative financial frameworks, including blended finance models and public-private partnerships, [70]which underpin flagship projects such as *Sagarmala* and the Deep Ocean Mission. These mechanisms facilitate sustainable investment flows critical for scaling infrastructure and technology interventions.

In conclusion, India's *Amrit Kaal Vision 2047* and its unfolding maritime initiatives exemplify a strategic, well-coordinated, and forward-looking approach to harnessing the blue economy. Through substantial infrastructure investments, international cooperation, and alignment with global sustainability principles, India is poised to emerge as a leader in the sustainable and climate-resilient ocean economy. The concerted efforts led by the government, including the active role of ministers like Shri Sarbananda Sonowal, demonstrate a robust commitment to transforming the country's vast marine resources into enduring economic and environmental assets. As global maritime dynamics evolve, India's model offers a replicable blueprint for balancing growth,

69 The Ecological Importance of Spatial Mapping in Sustainable Aquaculture Management - UDA Digest

70 Financing Blue Economy – Outcomes of COP28 - UDA Digest

The ambitious Kerala cruise tourism policy and other tourism-driven coastal initiatives represent SAGAR's principle of sustainable and experiential regional development. By integrating cruise tourism with port infrastructure upgrades at Vizhinjam and other ports, India is leveraging SAGAR's vision to enhance connectivity, economic diversification, and community welfare along the coastline.

ecological stewardship, and inclusive development in the ocean realm.

ALIGNING BLUE ECONOMY DEVELOPMENT WITH THE SAGAR INITIATIVE

India's commitment to developing its blue economy aligns closely with the overarching vision of the SAGAR initiative—*Security and Growth for All in the Region*. Launched to ensure a secure, stable, and prosperous Indian Ocean Region (IOR), SAGAR emphasizes sustainable development, maritime security, and regional cooperation, which are critical pillars supporting India's blue economic ambitions.

One of our important priorities, the development of coastal areas and welfare of fishermen, directly complements SAGAR's focus on inclusive growth and empowerment of coastal communities. Through efforts such as improving coastal infrastructure, protecting marine ecosystems, and transforming the blue economy, India aims to foster *Aatmanirbhar Bharat*—a self-reliant nation with a resilient maritime economy.[71]

The ambitious Kerala cruise tourism policy and other tourism-driven coastal initiatives represent SAGAR's principle of sustainable and experiential regional development. By integrating cruise tourism with port infrastructure upgrades at Vizhinjam and other ports, India is leveraging SAGAR's vision to enhance connectivity, economic diversification, and community welfare along the coastline.

71 Shrimp, Pearls and All That Lies Between: Managing the Blue Economy - UDA Digest

Programs like Sagarmala[72], Integrated Coastal Zone Management, Deep Ocean Mission, and Pradhan Mantri Matsya Sampada Yojana exemplify SAGAR's comprehensive approach. These initiatives contribute not only to economic growth and employment generation but also to environmental conservation and climate resilience—key challenges highlighted within the blue economy framework.[73] [74]

Furthermore, India's commitment to maritime security, pollution control, and sustainable fisheries under the SAGAR umbrella ensures that growth in the blue economy does not come at the expense of ocean health or regional stability. Enhancing maritime domain awareness, boosting coastal surveillance, and promoting responsible resource use protect the livelihoods of millions and secure vital sea lanes, which are essential for trade and commerce.

The SAGAR initiative, by fostering multilateral cooperation with Indian Ocean littoral states, also facilitates knowledge-sharing, joint development, and capacity-building in marine technology, disaster resilience, and sustainable ocean governance. This regional partnership underpins India's vision to be a net security provider while accelerating sustainable blue growth.[75]

In essence, the blue economy's strategic development is a cornerstone of SAGAR's mission—ensuring that India's maritime domain contributes to national prosperity, ecological balance, and regional harmony. By advancing innovative technologies, modernizing port infrastructure, and engaging coastal communities, India is charting a sustainable course aligned with SAGAR's promise of *Security and Growth for All in the Region*.

INDIA'S OCEAN VISION: FROM SAGAR TO MAHA-SAGAR

India's maritime doctrine has undergone a significant and strategic evolution over the last decade, transitioning from a regionally grounded vision to a globally relevant

72 "Government plans Sagarmala 2.0 with new funding to bridge infrastructure gaps": Union Minister of Ports, Shipping and Waterways, Mr. Sarbananda Sonowal | IBEF

73 Catalysing Action for Our Ocean & Climate through Underwater Domain Awareness - UDA Digest

74 India's Samudrayan Seabed Mission Holds Promise for Clean Energy and Blue Economy - UDA Digest

75 Press Release:Press Information Bureau: DRDO's oceanographic research vessel 'INS Sagardhwani' embarks on Sagar Maitri Mission-4 to establish long-term scientific partnerships with Indian Ocean Rim countries in 'Ocean Research & Development'

framework. Introduced in 2015, SAGAR—Security and Growth for All in the Region—represented a landmark shift in India's ocean diplomacy. It marked India's intent to play a proactive role in shaping a cooperative, inclusive, and rules-based maritime order in the Indian Ocean Region (IOR). Rooted in principles of mutual respect and shared prosperity, SAGAR underscored India's commitment to regional stability, maritime security, economic development, and environmental stewardship. The doctrine reflected India's recognition that its own security and prosperity are intrinsically linked to those of its maritime neighbours, and that collaborative action is essential to protect the common maritime domain.

Over the years, as the global geopolitical and environmental landscape has grown more complex, India's maritime thinking has expanded to meet the broader demands of the Global South. This has led to the conceptual and operational evolution of SAGAR into MAHA-SAGAR—Mutual and Holistic Advancement for Security and Growth Across Regions—set to shape India's ocean vision from 2025 onwards. MAHA-SAGAR builds on the foundational tenets of SAGAR but widens the scope to foster deeper partnerships across not only the Indian Ocean but also other key regions of the Global South, including Southeast Asia, Africa's eastern coast, and the South Pacific.

This evolution does not signify a departure from the original vision but rather an ambitious scaling up. The core pillars of India's maritime approach—Security, Economy, and Ecology—remain intact, but they are now being adapted and extended to address wider global concerns. The security pillar continues to prioritize maritime domain awareness, naval cooperation, and capacity-building to counter transnational threats such as piracy, trafficking, and illegal fishing. However, under MAHA-SAGAR, this is being pursued through enhanced joint exercises, technology sharing, and integrated maritime surveillance mechanisms tailored for partner nations in the Global South.

The economic pillar has also matured beyond traditional port development and trade facilitation to embrace the full spectrum of the Blue Economy, including sustainable fisheries, marine biotechnology, renewable energy, and coastal tourism. India is positioning

itself as a partner of choice by offering frugal, scalable, and environmentally sound solutions—particularly suited to the needs of emerging maritime economies. Through its Development Partnership and Lines of Credit, India is enabling infrastructure and innovation that are both economically and socially inclusive.[76]

On the ecological front, MAHA-SAGAR significantly amplifies India's commitment to marine conservation and climate adaptation. With rising sea levels, ocean acidification, and biodiversity loss threatening the survival of many coastal and island communities, India's emphasis on environmentally sustainable practices—ranging from coral reef restoration to ocean plastic mitigation—is a cornerstone of its regional engagement strategy. Tools and frameworks like Underwater Domain Awareness (UDA) are now being deployed to generate knowledge and solutions specific to tropical marine ecosystems, where the Global South is often most vulnerable.

Together, SAGAR and MAHA-SAGAR represent a seamless continuum of India's ocean vision—one that is rooted in regional solidarity but expansive in ambition. This continuity ensures not only stability and trust but also reaffirms India's emerging role as a maritime leader, collaborator, and conscience-keeper for the Global South.

The Promise of the Blue Economy: Unlocking Value Beneath the Surface

India's maritime domain is vast, strategic, and teeming with untapped potential. With a coastline stretching over 7,500 kilometres, 12 major ports, 200+ minor ports, and access to critical sea lanes of communication, India is uniquely positioned to harness the transformative potential of the Blue Economy. At its core, the Blue Economy in India's context refers to sustainable, inclusive, and climate-resilient ocean-based growth—an integrated development model that balances economic opportunity with ecological stewardship and social empowerment.

The Blue Economy offers a multidimensional avenue for India's growth story, cutting across traditional and emerging sectors. Fisheries and aquaculture, for instance, continue to be vital sources of livelihood and nutrition for millions of Indians, particularly in coastal and island communities. The sector also contributes significantly to export

76 Japan's Deep Dive: Embracing the Underwater Frontier with Partners and Allies - UDA Digest

MAHA-SAGAR builds on the foundational tenets of SAGAR but widens the scope to foster deeper partnerships across not only the Indian Ocean but also other key regions of the Global South, including Southeast Asia, Africa's eastern coast, and the South Pacific. This evolution does not signify a departure from the original vision but rather an ambitious scaling up. The core pillars of India's maritime approach—Security, Economy, and Ecology—remain intact, but they are now being adapted and extended to address wider global concerns.

earnings. Similarly, marine and coastal tourism has immense scope for job creation, cultural promotion, and community-led economic models, especially in ecologically sensitive areas like the Andaman and Nicobar Islands, Lakshadweep, and the Konkan and Coromandel coasts.

Port-led development and shipping infrastructure under the Sagarmala programme are facilitating deeper logistics integration and industrial corridor growth, enhancing India's global trade competitiveness. Meanwhile, the country is exploring newer frontiers in offshore renewable energy—especially offshore wind and tidal energy—which are critical to India's clean energy transition. Seabed mining, although still in nascent stages, holds promise in securing critical minerals like cobalt and rare earth elements, essential for green technologies and digital infrastructure.[77]

However, the true promise of the Blue Economy lies not merely in exploiting marine resources but in responsibly managing and regenerating ocean capital. This requires placing Environmental, Social, and Governance (ESG) principles at the heart of every maritime initiative. Sustainable fisheries management, pollution control, coral reef protection, and marine spatial planning must be integrated into both policy and practice. Equally, the Sustainable Development Goals (SDGs)—especially SDG 14 ("Life Below Water")—must guide the ethical, long-term outlook India adopts as it unlocks value from the ocean.

Recognizing that ocean health directly translates into national prosperity, India is now aligning its Blue Economy vision with global frameworks and regional partnerships. This means not only leveraging advanced technologies such as Underwater Domain Awareness (UDA), satellite-based monitoring, and digital twin platforms but also investing in community empowerment, traditional knowledge systems, and climate adaptation practices.

In this vision, the Blue Economy is not just an economic strategy—it is a civilizational imperative. It reflects India's historical ties to the ocean, its aspirations for regional leadership, and its commitment to a just and sustainable future for all. But a vision is only as good as the foundation it stands on.

77 Blue Economy – Ocean Energy - UDA Digest

GAPS IN THE FOUNDATION: DATA, GOVERNANCE & ACCOUNTING GAPS: WHAT'S MISSING BENEATH THE WAVES?

While the promise of the Blue Economy is immense, realizing its full potential requires a far more robust foundation than currently exists. The challenges India faces in building a sustainable and inclusive ocean-based growth model are not just technological or financial—they are deeply rooted in gaps related to data availability, governance coordination, and economic accounting. Without addressing these, the vision for a thriving Blue Economy remains aspirational rather than actionable.

One of the most critical issues is the under-reporting and under-recognition of the informal sector, which constitutes a significant share of ocean-linked livelihoods in India. Traditional fishing communities, small-scale tourism operators, and coastal artisans are often invisible in national economic planning and maritime strategy. Their contributions, though substantial, are largely missing from official statistics, leading to policy blind spots and underinvestment in capacity building. This lack of recognition not only stifles potential growth but also exacerbates socio-economic vulnerabilities in coastal areas.

Compounding this problem is the absence of comprehensive valuation of marine ecosystem services. Ecosystems such as mangroves, coral reefs, estuaries, and seagrass beds offer immense ecological and economic value through carbon sequestration, storm protection, fisheries support, and biodiversity conservation. Yet, these services are neither properly quantified nor integrated into national accounting systems like GDP or trade balances. As a result, degradation of these ecosystems continues unchecked, often justified by short-term developmental gains that ignore long-term ecological costs.

A third major gap lies in the lack of Environmental, Social, and Governance (ESG) tracking mechanisms and Marine Spatial Planning (MSP) frameworks[78]. ESG compliance in ocean industries—especially in port construction, shipping, and seabed mining—remains minimal or poorly enforced. This limits accountability

78 Developing a Comprehensive Handbook for Marine Spatial Planning in Tropical Waters - UDA Digest

Table 1: Assessing the different aspects of the blue economy

Aspect	India's Policy*	Best Practice (from other nations)	Suggested Enhancement
Marine Spatial Planning (MSP)	Mentioned, but no operational framework	EU (binding MSP directive)	Enact MSP legislation + simulation tools
Underwater Domain Awareness (UDA)	Not explicitly included	Notable gap globally	India can lead with UDA as a framework
Community & Traditional Knowledge	Limited references	Australia, Kenya, Indonesia	Institutionalize DCEF and co-management
Ocean Data Systems	Promised data platform under MoES	EMODnet, IMOS	Create an open-access Indian Ocean Data Portal
Blue Innovation & Skilling	General mention	EU, Australia	Integrate start-up support, digital skilling, e-learning
Regional Maritime Diplomacy	Focus on IORA, SAGAR	Kenya, Indonesia active regionally	Lead with tech-driven governance cooperation

* INDIA'S Blue Economy: A Draft Policy Framework, 2020

Table 2: Comparison of Blue economy policy

Country/Region	Highlights	Comparison with India's Policy Framework*
EU Blue Economy	Strong MSP mandate, Ocean Observation, Circular Economy, Digital Twins	India lacks binding MSP legislation or a marine data integration hub like EMODnet.
Australia	Integrates marine science, indigenous rights, ecosystem accounting	India can emulate its inclusion of traditional knowledge and ecosystem service valuation.
Kenya (Blue Economy Strategy)	Focuses on community empowerment, fisheries, and maritime security	India's policy is stronger on infrastructure but weaker on bottom-up community governance.
Indonesia	Strong on marine tourism, mangrove restoration, and maritime connectivity	India's policy shares tourism and logistics goals, but lacks a biodiversity-led approach like Indonesia's.
Sri Lanka (in progress)	Exploring MSP and sustainable fisheries, supported by Indian Ocean Rim collaborations	India has greater technical capacity but could do more for regional cooperation beyond economic diplomacy.

* INDIA'S Blue Economy: A Draft Policy Framework, 2020

and prevents India from aligning its maritime strategies with global sustainability benchmarks. Simultaneously, the absence of spatially-informed decision-making leads to conflicts between stakeholders, sub-optimal resource use, and cumulative ecological stress in high-value coastal zones.

Even in the domain of blue trade, a significant blind spot persists. A study by the Research and Information System for Developing Countries (RIS) highlights that blue trade contributes 15–22% of India's total trade, but this figure is vastly underestimated due to narrow definitions and poor tracking mechanisms. Services like marine tourism, coastal logistics, and maritime technology exports are often excluded, and the lack of disaggregated data limits policy interventions and investment prioritization.

These gaps in the foundation—data, governance, and accounting—are not just technical limitations. They represent a deeper systemic failure to integrate the ocean into India's mainstream development thinking. This failure risks not only slowing down progress but also deepening inequalities, environmental degradation, and geopolitical vulnerability.

To fix this, we need more than just infrastructure—we need insight. Insight that comes from listening to coastal communities, investing in data ecosystems, building transparent governance frameworks, and applying sustainability metrics rigorously. Only then can India build a Blue Economy that is resilient, inclusive, and future-ready.[79]

MAHA-SAGAR: INDIA'S RESPONSE TO A SHIFTING WORLD

In an era marked by geopolitical flux, shifting trade dynamics, and mounting environmental stress, India has taken a bold step forward with MAHA-SAGAR—Mutual and Holistic Advancement for Security and Growth Across Regions. This framework builds upon India's foundational SAGAR (Security and Growth for All in the Region) doctrine, scaling it up to respond to the expanding scope of regional and global maritime challenges. It is not just a policy articulation but a strategic blueprint

79 Buzzing Alarm to work towards Marine Sustainability - UDA Digest

MAHA-SAGAR is India's South-South answer to a fractured maritime world—a platform to build solidarity, share strength, and reshape the Blue Economy on terms that are equitable, ecological, and enduring.

for the Global South—a proactive, people-centric, and future-ready initiative designed to turn uncertainty into shared opportunity through maritime collaboration.

MAHA-SAGAR embodies India's commitment to leading through partnership rather than patronage.[80] At its core, it envisions the co-creation of a resilient, inclusive, and sustainable Blue Economy, tailored specifically for the unique needs of tropical and developing nations. It aligns development cooperation with the evolving geopolitical reality, where maritime spaces are no longer just trade routes but strategic theatres for economic resilience, environmental stewardship, and regional diplomacy.

The framework's strength will essentially lie in its multidimensional approach, spanning across four critical thrust areas:

- **Sharing Technology and Skills:** MAHA-SAGAR promotes the transfer of affordable, context-appropriate technologies and capacity-building expertise across partner nations. India's advancements in areas like ocean renewable energy, satellite-based maritime surveillance, underwater domain awareness (UDA), and digital skilling platforms are being repurposed to suit the socio-economic and ecological realities of fellow tropical countries. The goal is to build local ownership of technology while enhancing regional competence.
- **Rebuilding Resilient Supply Chains:** The COVID-19 pandemic and global trade realignments have exposed vulnerabilities in conventional supply chains. MAHA-SAGAR supports efforts to establish maritime-driven regional supply chains that are decentralized, climate-resilient, and socially inclusive. This includes reimagining coastal infrastructure,

80 INDIA'S MARITIME ECONOMY: DRIVING INDIA'S GROWTH – India Foundation

digital logistics, and blue ports that integrate small and medium enterprises (SMEs) from across the region.

- **Securing Regional Waters:** Maritime security is central to economic stability. From tackling illegal fishing and marine pollution to enhancing search-and-rescue and maritime law enforcement, MAHA-SAGAR promotes shared maritime domain awareness and coordinated action. The inclusion of climate resilience in security protocols reflects a broader vision of "comprehensive security," encompassing both hard threats and soft vulnerabilities like sea-level rise and biodiversity loss.
- **Building Tropical Solutions for Tropical Partners:** The tropical oceans face distinct environmental and operational challenges—from acoustic signal distortion to coral bleaching. India's scientific research and modelling capabilities are now being leveraged to design tropicalized innovations—tools, frameworks, and practices specifically calibrated for warm-water regions. This is a fundamental shift from importing temperate-zone models to creating knowledge systems rooted in regional realities.

MAHA-SAGAR must also embrace scenario thinking and flexible action plans, ensuring responsiveness to fast-changing variables. Whether navigating new digital trade regimes, climate-induced disruptions, or regional tensions, the initiative encourages countries to anticipate shifts, mitigate risks, and harness emerging opportunities—together.[81]

In essence, MAHA-SAGAR is India's South-South answer to a fractured maritime world—a platform to build solidarity, share strength, and reshape the Blue Economy on terms that are equitable, ecological, and enduring.

STRATEGIC ENABLER: UNDERWATER DOMAIN AWARENESS (UDA): FROM POLICY TO PRECISION: THE UDA ADVANTAGE

In the pursuit of a resilient and inclusive Blue Economy, visionary frameworks like MAHA-SAGAR require more than policy articulation—they demand precision tools for

81 US Tariffs Set to Accelerate Landmark Shifts in Global Trade Flows, January 13, 2025

implementation, measurement, and course correction. This is where Underwater Domain Awareness (UDA) emerges as a transformative strategic enabler. UDA bridges the critical gap between intent and execution, allowing policymakers, scientists, and communities to engage with the ocean not as an abstract frontier, but as a measurable, knowable, and actionable space.

At its core, UDA refers to the integration of real-time underwater sensing, data analytics, acoustic modelling, and simulation tools to gain a comprehensive and dynamic understanding of the underwater environment. It provides actionable intelligence on a range of parameters—biological, geological, acoustic, and hydrological—that are vital for maritime planning, sustainable resource use, and coastal resilience. UDA brings the submerged 70% of the ocean world into the fold of policy and planning with scientific rigor.

The application of UDA is especially critical in the tropical waters of the Indian Ocean Region (IOR), where existing global frameworks often fall short. The challenges in these waters—such as high ambient noise levels, variable salinity and temperature profiles, and region-specific biodiversity—require a customized approach to sensing and prediction. India, through the Maritime Research Center (MRC) and allied institutions, has developed and operationalized UDA tools that account for these tropical specificities, making them ideal for deployment across the Global South under the MAHA-SAGAR initiative.[82]

UDA supports MAHA-SAGAR across three fundamental dimensions:

- **Marine Spatial Planning (MSP):** UDA provides the granular data required to design multi-use ocean spaces that balance ecological protection with economic activity. By mapping underwater terrain, assessing biodiversity hotspots, and monitoring anthropogenic impacts, UDA enables evidence-based spatial zoning and sustainable resource allocation. This ensures that growth does not come at the cost of ecosystem degradation.
- **Risk Reduction:** With real-time monitoring of underwater conditions, UDA can help identify early warning signs of hazards such as underwater earthquakes, cyclones, or harmful algal blooms.

82 Blue Economy: Challenges & Opportunities - UDA Digest

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It also enhances maritime security by enabling better tracking of vessel movements, illegal activities, or transboundary threats. In short, UDA makes the ocean less opaque—and therefore, less risky.

- **Resource Optimization:** Whether it's planning the best routes for subsea cables, optimizing fishing zones, or enhancing the efficiency of offshore energy projects, UDA helps stakeholders make informed, cost-effective, and environmentally sound decisions. It enables a shift from reactive to proactive governance.

By embedding UDA into the operational fabric of MAHA-SAGAR, India offers a quantifiable and dynamic toolset to its regional partners. UDA turns abstract policy into tangible strategy. It allows for adaptive management, real-time feedback loops, and continuous improvement—all critical in an era of rapid change and heightened ocean pressures.

In essence, UDA transforms MAHA-SAGAR from a strategic vision into a science-backed action framework. It empowers the Global South with sovereign access to underwater data, locally relevant analytics, and the ability to participate fully in the Blue Economy—on their own terms, and with lasting precision.

REGIONAL DIPLOMACY IN ACTION: INDIA'S GROWING MARITIME NETWORK

India's ocean diplomacy has entered a decisive new phase—one that moves beyond symbolism and into systemic engagement across the Indo-Pacific and the Global South. Through regional platforms such as BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation), IORA (Indian Ocean Rim Association), ASEAN, the African Union, and the Indian Ocean Commission (IOC), India is actively shaping a maritime network centred on cooperation, resilience, and shared prosperity.

These forums are not merely ceremonial. They provide India with critical diplomatic and operational pathways to engage with like-minded nations on three strategic fronts:

- **Trade Facilitation:** In an era of supply chain realignments, India is leveraging regional partnerships to build smoother, faster, and more secure trade corridors through its ports and maritime routes. Whether it is through harmonizing customs procedures or modernizing port infrastructure with regional

connectivity in mind, India's trade diplomacy increasingly places the ocean at the centre of economic integration. Initiatives like the India-Middle East-Europe Economic Corridor (IMEEC) and Sagarmala exemplify this outward-looking strategy.

Innovation Partnerships: Recognizing that future maritime leadership will rest not just on size, but on technological edge, India is promoting co-innovation across marine sectors. With tropical marine challenges being distinctly different from those of the temperate West, India has emerged as a hub for frugal, scalable, and locally relevant innovations. These range from satellite-aided fisheries advisories and coastal radar systems to affordable underwater drones and acoustic mapping tools under the UDA (Underwater Domain Awareness) framework. Through MAHA-SAGAR, these innovations are being shared with and adapted for regional partners.

Skilling & Technology Localization: Diplomacy must also mean capacity building, and India's skilling diplomacy reflects this ethos. Through collaborations with IORA, BIMSTEC, and African maritime institutions, India is investing in human capital—training port operators, maritime law enforcement, blue economy entrepreneurs, and ocean scientists. These efforts not only build sovereign capability in partner countries but also create a shared knowledge base and mutual dependency that reinforces long-term regional solidarity.[83]

Yet, India's regional leadership is not about dominance—it is about enabling others. The success of India's maritime diplomacy hinges on one essential principle: building from the bottom up. Grand regional strategies, multilateral commitments, and high-level dialogues will fall short if they are not grounded in the needs, voices, and aspirations of coastal communities, local innovators, and blue economy stakeholders.

To be truly inclusive, diplomacy must meet people where they are—on the docks, in the fish markets, inside classrooms, and through digital tools tailored to their reality. India's regional maritime network, anchored in MAHA-SAGAR and supported by strategic enablers like UDA, is striving to do just that: making diplomacy tangible,

83 India-Sri Lanka relations and the BIMSTEC: A new perspective based on Underwater Domain Awareness (UDA) Framework - UDA Digest

participatory, and deeply rooted in local agency.

In this way, India is not just growing a network—it is nurturing a movement for sustainable, secure, and equitable ocean futures across the Global South.

IMPLEMENTATION TOOLKIT: WHAT WE NEED TO MAKE IT WORK: WHAT WILL IT TAKE?

To translate the MAHA-SAGAR vision into meaningful regional transformation, India and its partners must invest in more than intentions—they need a toolkit for execution that is practical, inclusive, and forward-looking. As the maritime space becomes the new theatre for both cooperation and competition, ensuring security, sustainability, and shared growth demands a strong implementation framework grounded in indigenous capacity and regional relevance.

The success of this vision rests on five essential pillars of implementation:

- **Indigenous Technology Development:**

  India must accelerate the development of homegrown, cost-effective technologies that are specifically designed for the tropical marine environment. From acoustic sensors for underwater monitoring to low-emission port operations and ocean-based renewable energy systems, indigenous innovation is the bedrock of self-reliance and scalability.[84] These solutions must be modular and adaptable to the varied socio-economic and ecological conditions across the Global South, allowing countries to customize tools without dependency on high-cost imports or proprietary systems from the Global North.

- **Open-Access Data Platforms:**

  Data is the new currency of ocean governance. However, vast amounts of marine data today remain fragmented, siloed, or inaccessible. India must lead the way in building open-access, interoperable marine data platforms that promote transparency, collaboration, and evidence-based decision-making. Whether it is ocean health metrics, shipping patterns, underwater acoustics, or disaster early warning systems, such platforms will democratize access to information and empower a diverse set of stakeholders—from

84 The Bridge Between Science and Tradition: Inclusive Policy Matters in Biosphere Reserves - UDA Digest

Through a MAHA-SAGAR with UDA, India is ready to walk with the Global South—towards a sustainable, secure, and sovereign blue future.

governments and researchers to local communities.

- **Modelling & Simulation Capacities:**

  Prediction and planning are key to both resilience and optimization. India must invest in robust modelling and simulation capabilities to enable real-time scenario analysis for marine spatial planning, climate adaptation, risk forecasting, and port logistics. These tools will help nations not only understand current ocean dynamics but also anticipate future trends—from changing monsoon patterns to shifting fish stocks—thereby enhancing preparedness and efficiency across the Blue Economy.

- **Knowledge Co-Creation:**

  Top-down solutions cannot solve complex, context-specific problems. India's approach must emphasize collaborative research and innovation that brings together scientists, policymakers, industry, and local communities. Co-creation ensures that the knowledge produced is both technically sound and socially relevant, leading to greater buy-in and more sustainable outcomes. This requires not only institutional collaboration but also fostering trust, inclusivity, and dialogue at every level of governance.

- **Skilling Tailored to the Tropics:**

  Finally, a strong workforce is the engine of any maritime vision. India must lead a tropical skilling revolution, equipping youth and professionals across the region with the knowledge and tools to thrive in the tropical maritime domain. This includes vocational training in blue economy sectors, technical upskilling in ocean data and acoustics, and digital learning platforms that are multilingual, modular, and accessible to underserved communities.

Together, these five elements constitute a readiness toolkit—designed not only to operationalize MAHA-SAGAR but also to affirm India's commitment to responsible leadership in the Global South. It is a call to act—not tomorrow,

but today—with the tools in hand and a shared future in sight.

FINAL VISION: TOWARDS A SUSTAINABLE OCEAN FUTURE: INDIA'S LEADERSHIP FOR THE GLOBAL SOUTH

As the waves of change reshape global maritime dynamics, one truth has become increasingly clear: the future of sustainable development is blue. Oceans are no longer just the backdrop for global trade or defence posturing—they are now central to climate resilience, food security, energy transitions, and geopolitical stability. And in this moment of redefinition, India stands uniquely positioned to lead the Global South into a new era of ocean stewardship, not through dominance, but through partnership, innovation, and shared purpose.

India's maritime vision—anchored in the principles of Security and Growth for All in the Region (SAGAR)—has already reoriented regional dialogue around cooperation over confrontation. Now, with the evolution of this vision into MAHA-SAGAR (Mutual and Holistic Advancement for Security and Growth Across Regions), India has expanded its horizon from regional engagement to transregional leadership. This isn't just about scaling up—it's about reimagining the very nature of maritime cooperation: one that is inclusive, tropical-contextual, and tailored to the lived realities of the Global South.

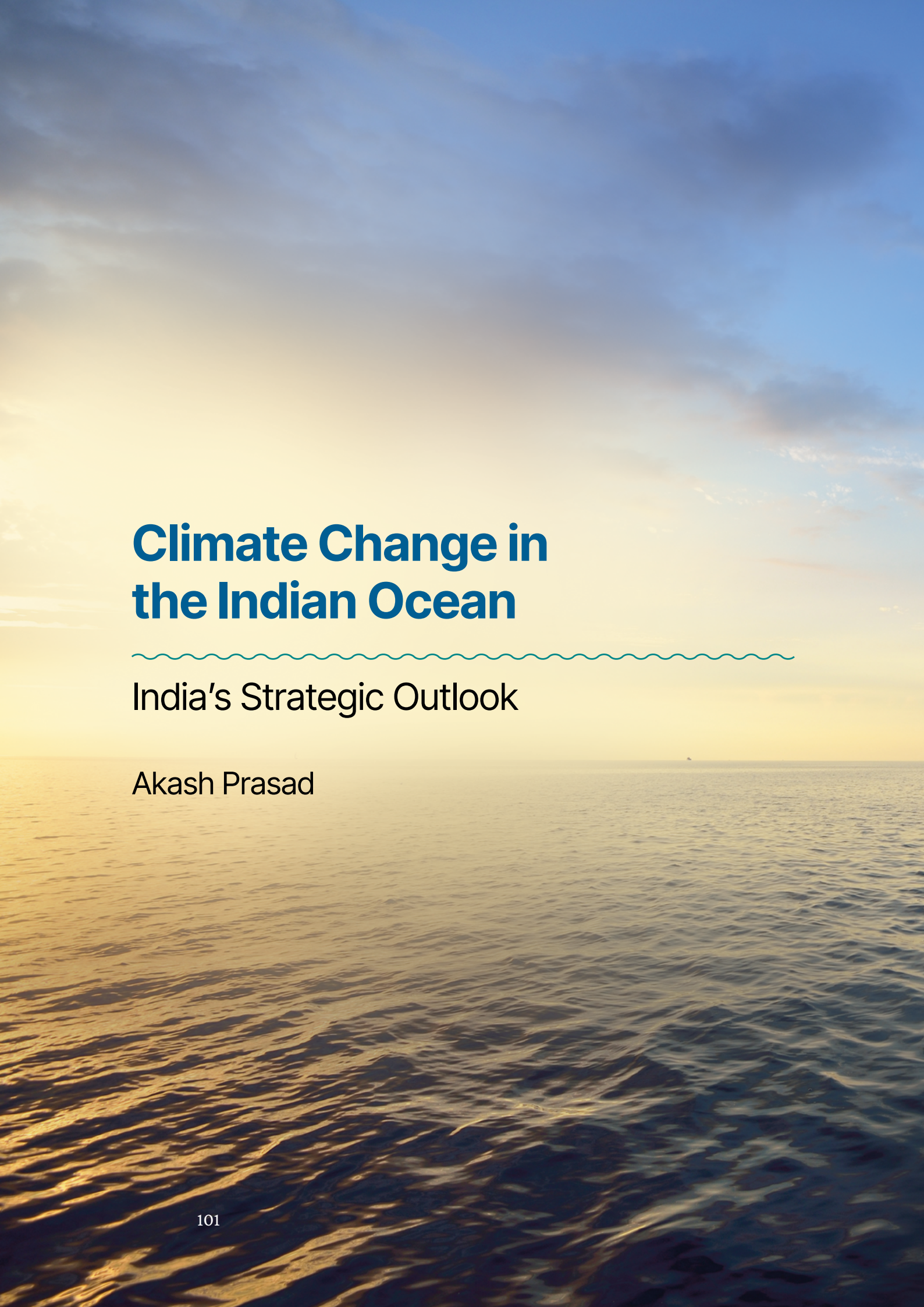
At the heart of this effort lies the understanding that sustainable ocean governance cannot be achieved through fragmented action. It requires a systems approach that connects ecological integrity, economic opportunity, and strategic stability. That's where India's strategic enabler—Underwater Domain Awareness (UDA)—enters the equation. UDA offers the precision tools needed to translate intent into impact: real-time data, modelling capacities, risk mapping, and spatial planning. In essence, UDA powers MAHA-SAGAR, turning it from a visionary doctrine into an operational blueprint—a measurable, adaptable, and forward-looking strategy for maritime resilience.

This combination—MAHA-SAGAR + UDA—is India's blueprint not just for its own prosperity, but for a collective ocean future shared with fellow developing nations. It

responds to the region's most pressing challenges: climate impacts on coastal communities, insecure supply chains, overexploited marine resources, and lack of representation in global ocean governance forums. More importantly, it offers solutions grounded in equity, indigenous knowledge, appropriate technology, and south-south solidarity.

Yet, no vision, no matter how robust, can succeed in isolation. The transformation of the Blue Economy must be co-created, with governments, academia, industry, and communities working together. It must empower fisherfolk and innovators alike, protect biodiversity while enabling trade, and build capacity not just in policy circles, but in classrooms, coastlines, and local enterprises.

India is not claiming to have all the answers—but it offers the frameworks, tools, and partnerships to ask the right questions and pursue them collectively. As we look to 2030 and beyond, the call is clear: Let us co-create the ocean economy of the future—a future defined not by extraction and exclusion, but by equity, insight, and shared stewardship. Through a MAHA-SAGAR with UDA, India is ready to walk with the Global South—towards a sustainable, secure, and sovereign blue future.



Climate Change in the Indian Ocean

India's Strategic Outlook

Akash Prasad

BACKGROUND

The Indian Ocean Region (IOR) is increasingly vulnerable to climate change, with rising sea levels, ocean acidification, and extreme weather events posing significant threats to coastal ecosystems, marine biodiversity, and livelihoods. Strengthening climate resilience and mitigation efforts through regional cooperation is essential to safeguarding the region's economic and environmental sustainability. A resilient blue economy depends on sustainable fisheries, marine conservation, and the integration of renewable energy into maritime activities. Additionally, Underwater Domain Awareness (UDA) is critical for monitoring ocean health, managing marine resources efficiently, and enhancing disaster preparedness.

To address shared climate risks, IOR nations must prioritize disaster preparedness, invest in green port infrastructure, and support research on ocean health and climate adaptation strategies. Enhancing monitoring and early warning systems, particularly through acoustic and sensor-based technologies under UDA, can mitigate the impact of extreme weather events, while eco-friendly policies and sustainable development practices can reduce long-term environmental degradation.

Regional collaboration is key to fostering climate-smart maritime governance, ensuring that economic growth aligns with ecological balance. Joint initiatives, knowledge-sharing platforms, and capacity-building programs can strengthen the collective ability to respond to climate challenges effectively. Initiatives such as India's SAGAR (Security and Growth for All in the Region) play a crucial role in promoting sustainable development and cooperative climate action. By integrating UDA into climate resilience maritime and governance, strategies, IOR nations can enhance maritime security, optimize resource utilization, and secure a sustainable future for the region.

INTRODUCTION

The Indian Ocean, a pivotal component of the global climate system, plays a crucial role in regulating global weather patterns and heat distribution, absorbing a significant portion of the excess heat trapped by anthropogenic

By integrating UDA into climate resilience maritime and governance, strategies, IOR nations can enhance maritime security, optimize resource utilization, and secure a sustainable future for the region.

greenhouse gas emissions and forming the core of a large-scale Tropical Warm Pool that profoundly affects both regional and global climate dynamics; the bordering nations, including India, are intrinsically linked to the Indian Ocean for their socio-economic well-being, relying on it for fisheries, trade, and various other activities, with approximately one-third of the world's population residing along its coastlines, making any significant changes within this oceanic basin have far-reaching consequences for a large segment of humanity. The urgency of addressing climate change in the Indian Ocean region is underscored by the observed accelerated warming trend, which surpasses that of other global oceans, with scientific evidence indicating that the surface of the Indian Ocean is warming at the fastest rate globally, experiencing a warming of 1.2°C per century between 1950 and 2020, and projections based on high greenhouse gas emission scenarios suggesting a further acceleration of this trend, with potential warming of 1.7-3.8°C per century between 2020 and 2100 [85]; this rapid warming is not limited to the surface, as the heat content in the upper 2000 meters of the Indian Ocean has also been increasing significantly, accounting for over 30% of the global ocean heat content increase in the past two decades, highlighting the alarming rate of change that necessitates a comprehensive understanding of the impacts and the development of effective strategies to mitigate and adapt to these evolving conditions. Given India's substantial stake in the Indian Ocean, a comprehensive understanding of these climate-induced changes and the development of effective strategies for mitigation and adaptation have become a strategic imperative. To address the evolving maritime landscape, India has articulated its vision through frameworks such as 'Security and Growth for All in the Region' (SAGAR), announced in March 2015.

85 Koll, R. M. (2022, July). Climate change in the Indian Ocean region [Presentation]. INCOIS. https://incois.gov.in/documents/ITCOocean/webinar0722_presentation.pdf

This vision aims to secure India's maritime interests, strengthen regional cooperation with littoral countries in the Indian Ocean Region (IOR), enhance Blue Economy initiatives, and establish India as the net security provider in the IOR. Building upon this foundation, India unveiled its more recent vision, 'MAHASAGAR' (Mutual and Holistic Advancement for Security and Growth Across Regions)[86], in March 2025. This evolved strategy broadens the scope beyond the IOR to encompass the entire Global South, indicating a strategic deepening and widening of India's maritime engagement, likely reflecting the increasing complexities of the maritime domain and India's growing geopolitical aspirations and responsibilities in the wider Indo-Pacific and Global South. This papers aims to provide an in-depth analysis of the multifaceted impacts of climate change on the Indian Ocean region, exploring the observed changes in sea level, temperature, extreme weather events, and ocean acidification, as well as the consequences for marine productivity and ecosystems, while also delving into the unique characteristics of the Indian Ocean that contribute to its vulnerability to climate change; recognizing the critical role of technology in addressing this global challenge, the report will investigate how digital transformation technologies can be applied to monitor, predict, and mitigate the impacts of climate change in the region, and given India's significant stake in the Indian Ocean, the paper will also assess the potential geopolitical implications of these climate-induced changes for the nation, finally underscoring the importance of climate modelling and simulation in understanding the complex interactions within the Indian Ocean system and in projecting future climate scenarios, while acknowledging the limitations and uncertainties associated with these tools.

IMPACTS OF CLIMATE CHANGE & UNIQUE CHARACTERISTICS OF INDIAN OCEAN REGION

The Indian Ocean region is already experiencing a multitude of impacts as a result of climate change, with far-reaching consequences for its environment and the populations

86 PIB Delhi. (2025, March 24). INDIAN NAVY's MAIDEN INITIATIVES OF INDIAN OCEAN SHIP SAGAR (IOS SAGAR) AND AFRICA INDIA KEY MARITIME ENGAGEMENT (AIKEYME) https://pib.gov.in/PressReleasePage.aspx?PRID=2114491#:~:text=With%20SAGAR%20entering%20its%20second,which%20are%20aimed%20at%20consolidating

that depend on it, as sea levels in the Indian Ocean are rising at a concerning rate, exceeding the global average with an annual rise of 3.7 millimetres[87], and along the Indian coast, the average rate of sea-level rise was approximately 1.7 mm/year during the 20th century, while specific regions like the Arabian Sea and the Bay of Bengal have witnessed a more pronounced increase, rising by 13 inches since 1880; notably, the southwestern part of the Indian Ocean is experiencing the fastest rate of rise, exceeding the global average by 2.5 mm/year, and globally, the mean sea level rose by about 15 cm in the 20th century, with the current rate being more than twice as fast, and projections suggesting a potential rise of up to 1.10 meters by 2100 if greenhouse gas emissions are not drastically reduced , primarily attributed to the thermal expansion of seawater as it warms and the addition of water from the melting of glaciers and ice sheets, leading to significant implications, particularly for low-lying coastal areas and island nations, which face increased risks of flooding, coastal erosion, and land loss. The Indian Ocean is also undergoing significant temperature changes, with surface warming being the fastest among all tropical oceans, with observations from 1950 to 2020 showing a warming rate of 0.12°C per decade, and future projections indicating an acceleration of this trend, with a potential surface warming of 1.4°C to 3°C between 2020 and 2100 under moderate to high emission scenarios; the heat content within the upper 2000 meters of the ocean is also increasing rapidly , with the northwestern part of the Indian Ocean, including the Arabian Sea, experiencing the most pronounced warming , pushing the Indian Ocean towards a state of near-permanent marine heatwaves, characterized by prolonged periods of extremely high ocean temperatures, which have profound effects on marine ecosystems, weather patterns, and the overall climate of the region . The Indian Ocean region has witnessed a notable increase in the frequency and intensity of extreme weather events, with the Arabian Sea experiencing a 52% increase in the number of cyclones, including a 150% surge in

87 Nand, J. (2023, February 15). Sea-level rise a major threat to India, other nations: WMO. Hindustan Times. https://www.hindustantimes.com/india-news/sealevel-rise-a-major-threat-to-india-other-nations-wmo-101676400422024.html

very severe cyclones, an 80% rise in the total duration of cyclones, and a 20%-40% increase in their intensity; marine heatwaves, defined as periods when ocean temperatures are exceptionally high, are becoming more common and intense, leading to widespread coral bleaching and other detrimental effects on marine habitats, and these marine heatwaves can also play a crucial role in the rapid intensification of cyclones; furthermore, the warming of the Indian Ocean is influencing monsoon patterns, leading to a weakening of the land-sea thermal gradient that drives the monsoon winds, and despite this weakening, episodes of high moisture can still result in extreme rainfall events and floods, indicating a disruption of traditional monsoon patterns. Ocean acidification is another significant consequence of climate change in the Indian Ocean, with the absorption of increasing amounts of atmospheric carbon dioxide by the ocean causing a decline in its pH, making it more acidic, and the Indian Ocean has been acidifying at an average rate of 0.015 per decade between 1980 and 2019, with an acceleration in this rate observed in the recent decade [88]; projections suggest that the surface pH of the tropical Indian Ocean could decrease below 7.7 by the end of the 21st century, compared to a pH above 8.1 in the early 20th century, posing a serious threat to marine organisms that rely on calcium carbonate. Climate change is also leading to a decline in marine productivity in the Indian Ocean, as surface warming increases the stratification of the ocean, which prevents the mixing of nutrient-rich deeper waters with the sunlit surface layer, thereby reducing the availability of nutrients for phytoplankton, the base of the marine food web, with data showing that tuna catch rates have declined and sardine catch rates are projected to decline significantly; marine heatwaves also contribute to habitat destruction, further impacting the fisheries sector. Beyond these major impacts, the Indian Ocean region is experiencing other significant environmental changes,

88 Prabhu, S., & Chitale, V. (2024, January 17). Decoding India's changing monsoon patterns. Council on Energy, Environment and Water (CEEW). https://www.ceew.in/publications/decoding-changing-monsoon-rainfall-patterns-due-to-climate-change-in-india

3 Nand, J. (2023, February 15). Sea-level rise a major threat to India, other nations: WMO. Hindustan Times. https://www.hindustantimes.com/india-news/sealevel-rise-a-major-threat-to-india-other-nations-wmo-101676400422024.html

including extensive coral bleaching, destruction of seagrass meadows and the loss of kelp forests, and a potential link between warming in the western Indian Ocean and locust swarms in East Africa.

The Indian Ocean possesses several unique characteristics that contribute to its distinct response to climate change and its heightened vulnerability, including its semi-enclosed nature, bounded to the north by the Asian landmass, which restricts its connection to the Arctic region and has significant implications for heat exchange and ocean circulation patterns, leading to heat accumulation within the basin [89]; the presence of shallow, semi-enclosed seas like the Arabian Gulf, which already experience high temperatures and salinity, makes them particularly susceptible to further warming and related impacts, and the northern part of the Indian Ocean, being largely confined to the tropics, lacks the sub-tropical convergence zone typically found in other ocean basins, further influencing its ventilation characteristics, making the Arabian Sea and the Bay of Bengal, ecologically and socioeconomically vital semi-enclosed basins, particularly vulnerable to the effects of climate change due to a steady increase in temperature. The Indian Ocean is also characterized by a prominent monsoon system, a seasonal reversal of winds driven by the strong land-sea thermal gradient, which is being altered by the warming of the Indian Ocean due to climate change; a warmer ocean weakens the land-sea thermal gradient, potentially leading to a weakening of the monsoon winds, and while climate simulations generally suggest an increase in overall monsoon rainfall due to the increased moisture content in the atmosphere from a warmer ocean, observations in recent decades indicate an increase in the frequency of deficit rainfall years, and rainfall patterns are becoming more chaotic and erratic, with heatwaves in the Indian Ocean also shown to influence monsoon patterns, which can have devastating consequences for food security, water resources, and overall socio-economic stability. The Indian Ocean plays a significant role in influencing regional climate patterns

89 Environment Agency–Abu Dhabi. (n.d.). [Webpage on marine habitat: Our seas]. Connect with Nature. https://connectwithnature.ae/knowledge-hub/habitat-our-seas

[1] Koll, R. M. (2022, July). Climate change in the Indian Ocean region [Presentation]. INCOIS. https://incois.gov.in/documents/ITCOocean/webinar0722_presentation.pdf

The Indian Ocean plays a significant role in influencing regional climate patterns and even global weather systems, with warming impacting major ocean circulation patterns like the Walker circulation and the Atlantic Meridional Overturning Circulation (AMOC), which can have cascading effects on rainfall and temperature patterns across the globe, and it also modulates atmospheric oscillations such as the Madden Julian Oscillation (MJO) and the monsoon intraseasonal oscillation, which in turn affect regional rainfall distribution and intensity.

and even global weather systems, with warming impacting major ocean circulation patterns like the Walker circulation and the Atlantic Meridional Overturning Circulation (AMOC), which can have cascading effects on rainfall and temperature patterns across the globe, and it also modulates atmospheric oscillations such as the Madden Julian Oscillation (MJO) and the monsoon intraseasonal oscillation, which in turn affect regional rainfall distribution and intensity; sea surface temperature anomalies in the Indian Ocean have been linked to various climate phenomena in the surrounding regions, and the Indian Ocean forms a crucial part of the Tropical Warm Pool, with its changes having implications for climate variability both regionally and globally, and the emergence of new regional climate modes within the Indian Ocean, such as the Ningaloo Niño, highlights the complex and evolving nature of its influence on climate. Given these unique characteristics, the coastal areas and island nations within the Indian Ocean region are particularly vulnerable to the impacts of climate change, especially sea level rise and extreme weather events, with many low-lying coastal cities and small islands facing an increasing risk of annual flooding and permanent land loss by 2050; island nations like the Maldives, Mauritius, and the Seychelles are exceptionally vulnerable, as are Southeast Asian nations such as Thailand and Indonesia, with estimates suggesting that a substantial proportion of the projected increase in coastal flood

victims globally by 2100 will occur in the Indian Ocean region, and for small island developing states in the Indian Ocean, the threat is existential, with major infrastructure often located along the coast and limited options for retreat from rising seas.

CHALLENGES IN MONITORING AND THE IMPERATIVE OF DIGITAL TRANSFORMATION FOR CLIMATE ACTION

Monitoring and managing climate impacts in the Indian Ocean is hampered by uneven observational coverage and data limitations. The region's monitoring networks are sparse – for example, the Indian Ocean Observing System (IndOOS) buoy array fell into "neglect and disrepair" during the COVID-19 pandemic, creating "gaps in observational data" critical to monsoon and cyclone. Many littoral states lack robust climate services, with significant gaps especially in Least Developed Countries (LDCs) and Small Island Developing States (SIDS). These deficits make it difficult to simulate key oceanic phenomena. Global climate models exhibit large biases in simulating the South Asian monsoon and regional sea-surface temperature, and recent studies warn that the Indian Ocean is moving toward near-permanent marine heatwaves. Addressing these challenges requires improved forecasting and warning systems. Accurate projections hinge on continuous, integrated ocean and early-warning initiatives and seamless data streams from satellites and buoys as foundational. In short, strengthening real-time observation networks and integrated data platforms is imperative to support timely warnings and climate

Strengthening real-time observation networks and integrated data platforms is imperative to support timely warnings and climate resilience across the Indian Ocean basin. Digital transformation offers a powerful suite of technologies that can significantly enhance our ability to understand, monitor, predict, and respond to the impacts of climate change in the Indian Ocean region.

resilience across the Indian Ocean basin. Digital transformation offers a powerful suite of technologies that can significantly enhance our ability to understand, monitor, predict, and respond to the impacts of climate change in the Indian Ocean region. Digital technologies are revolutionizing our capacity for monitoring and predicting climate change impacts, with Earth observation satellites equipped with advanced sensors providing a continuous stream of critical data on various environmental parameters, and the vast datasets generated can be analysed using artificial intelligence (AI) and big data analytics to identify trends, patterns, and anomalies with unprecedented accuracy; machine learning models can be trained to predict weather patterns, sea temperature changes, the intensity of extreme events, and other climate-related phenomena with increasing precision, while the Internet of Things (IoT) plays a crucial role in collecting real-time oceanographic data through smart buoys and underwater drones, continuously tracking parameters such as water temperature, salinity, pH levels, and the presence of pollutants; ocean analytics, involving the systematic use of data analysis techniques on vast amounts of maritime data, provides valuable insights for optimizing shipping operations, ensuring maritime security, and monitoring compliance with environmental regulations, making these advancements in monitoring and prediction essential for providing early warnings of impending disasters, understanding the evolving state of the ocean, and informing the development of effective climate action strategies. Digital tools are also playing an increasingly important role in climate change mitigation and adaptation efforts in the Indian Ocean region, with smart grids, enabled by digital communication technologies, facilitating the integration of renewable energy sources into existing power infrastructure, optimizing energy distribution and reducing reliance on fossil fuels [90]; IoT-enabled devices can optimize the distribution of scarce resources

90 Monitor Deloitte (2024). Digital as a Key Enabler for Climate Action: The Latin America Perspective. Deloitte. https://www2.deloitte.com/content/dam/Deloitte/il/Documents/digital-sprinters-2024/MonitorDeloitte_DigitalSprinters_LATAM.pdf
Environment Agency–Abu Dhabi. (n.d.). [Webpage on marine habitat: Our seas]. Connect with Nature. https://connectwithnature.ae/knowledge-hub/habitat-our-seas

like water and energy, detecting leaks and monitoring usage in real-time to minimize waste, while digitalization is enabling the development of sustainable transportation solutions, such as ride-sharing platforms and electric vehicle charging networks, which can help reduce emissions from the transport sector; AI is being applied to develop hyper-local flood forecasting models, providing targeted warnings to vulnerable communities, and blockchain technology offers a secure and transparent platform for tracking carbon emissions across supply chains, promoting accountability and compliance with environmental regulations; various United Nations initiatives, such as the World Environment Situation Room (WESR) and the International Methane Emissions Observatory (IMEO), leverage AI to monitor environmental conditions and mitigate greenhouse gas emissions, with UNDP supporting countries in the region in developing digital systems for tracking their progress on Nationally Determined Contributions (NDCs) under the Paris Agreement. While digital transformation offers tremendous potential for climate action, it is important to acknowledge the associated challenges and opportunities, including increased energy consumption from digital devices and data centres and the digital divide, alongside significant opportunities for innovation and collaboration in the Indian Ocean region; development policies that integrate both climate adaptation and the use of digital technologies can strengthen government commitments, and facilitating cross-border data sharing and encouraging regional cooperation are crucial for maximizing the impact of digital transformation on climate resilience, ensuring equitable access to data and innovative technologies for all communities [91].

While climate models serve as indispensable tools for understanding and projecting climate change, they also possess inherent limitations and uncertainties, particularly when applied to the unique characteristics of the Indian Ocean region [92]; accurately

91 World Bank. (2013, June 19). India: Climate change impacts. World Bank Group. https://www.worldbank.org/en/news/feature/2013/06/19/india-climate-change-impacts

92 UN Environment Programme. (2022, November 11). Why protecting the ocean and wetlands can help fight the climate crisis. UNEP. https://www.unep.org/news-and-stories/story/why-protecting-ocean-and-wetlands-can-help-fight-climate-crisis

Addressing the limitations of global climate models for South Asia & IOR and reducing related uncertainties necessitates ongoing efforts by India to improve climate models, enhance related spatial resolution, refine the representation of air-sea coupled processes, and improve model formulations for biogeochemical processes, alongside increased investment in collecting high-quality observational data for the Indian Ocean region to validate model outputs, including in cooperation with regional countries.

simulating regional specifics such as the complex monsoon system and intricate ocean current patterns remains a significant challenge for these models, with global climate models often exhibiting limitations in representing the fine-scale details and variability of the Indian summer monsoon rainfall; modelling upper-ocean processes and boundary currents in the Indian Ocean has also proven difficult, as evidenced by the struggle of some models to realistically represent the Arabian Sea Oxygen Minimum Zone. Climate change projections for the Indian Ocean region are also subject to various uncertainties arising from the range of possible future greenhouse gas emission scenarios and inherent limitations within the models themselves, leading to a spread in projections for parameters like surface warming and sea-level rise ; uncertainties also exist in monitoring changes in the total heat content of the Indian Ocean and its exchange with other ocean basins, and earth system models show inconsistencies in their projections of subsurface oxygen concentrations and net primary production. Addressing the limitations of global climate models for South Asia & IOR and reducing related uncertainties necessitates ongoing efforts by India to improve climate models, enhance related spatial resolution, refine the representation of air-sea coupled processes, and improve model formulations for biogeochemical processes, alongside increased investment in collecting high-quality observational data for the Indian Ocean region to validate model outputs, including in cooperation with regional countries.

GEOPOLITICAL IMPLICATIONS & SAGAR VISION FOR CLIMATE CHANGE MITIGATION

Climate change in the Indian Ocean region carries significant geopolitical implications for India, a major power with extensive interests in this strategic waterway, potentially exacerbating resource scarcity due to the warming of the Indian Ocean and its associated impacts in the long term, such as reduced fish stocks and altered monsoon patterns leading to water stress, posing direct threats to India's food security and economic stability; the potential decline in fish populations could impact the livelihoods of millions and increase competition for dwindling marine resources, while shifts in monsoon patterns and the melting of Himalayan glaciers could lead to water scarcity, The accelerated glacial melt in the Himalayas can disrupt the seasonal flow and availability of transboundary rivers like the Ganges, Brahmaputra, and Indus, which are crucial water sources for India and its neighbours such as Nepal, Bangladesh, and Pakistan. Variability in flow can lead to periods of both flooding and drought, intensifying competition over shared water resources and potentially heightening geopolitical tensions in an already sensitive region. Climate change impacts in the Indian Ocean region are also likely to drive significant human migration, with rising sea levels, intensified cyclones, and other extreme weather events potentially displacing millions of people in low-lying coastal areas and island nations, including those in India's vicinity, placing additional strain on resources and potentially affecting bilateral relations [93]; internal migration from climate-vulnerable rural areas to Indian cities is also a growing concern. Maritime security in the Indian Ocean is also expected to be affected by this phenomenon, Climate change-induced increases in tropical cyclones and storm surges threaten critical maritime infrastructure such as ports, naval bases, and shipping lanes, which are essential for trade and regional connectivity. Damage or disruption to these assets can weaken supply chains and economic

93 National Intelligence Council. (2009, May). India: The impact of climate change to 2030 – Geopolitical implications (Prepared by CENTRA Technology, Inc. and Citor Corporation). https://www.dni.gov/files/documents/2009%20Conference%20Report_India_The%20Impact%20of%20Climate%20Change%20to%202030.pdf

India could strengthen its relationships with smaller, more vulnerable states, offering support for adaptation and mitigation efforts, as demonstrated by India's leadership in initiatives like CDRI and its engagement with Pacific Island Countries.

stability. Simultaneously, declining fish stocks due to ocean warming and acidification may prompt nations to assert greater control over marine territories, leading to overlapping claims and potential maritime disputes, particularly in resource-rich but contested areas of the Indian Ocean. with the increasing frequency and intensity of tropical cyclones and storm surges posing a direct threat to coastal infrastructure, including ports and shipping lanes, which are critical for regional and global trade, and the potential decline in marine resources could lead to increased competition among nations for access to fishing grounds, potentially escalating maritime tensions; saltwater intrusion into coastal areas can also degrade groundwater quality and impact the habitability of coastal regions. Climate change in the Indian Ocean region will also have a significant influence on India's international relations, with India having a strategic interest in maintaining stability and promoting cooperation in the Indian Ocean through frameworks like IORA and IONS; India could strengthen its relationships with smaller, more vulnerable states, offering support for adaptation and mitigation efforts, as demonstrated by India's leadership in initiatives like CDRI and its engagement with Pacific Island

Capacity building under the SAGAR vision includes efforts to strengthen disaster response mechanisms for cyclones, tsunamis, and oil spills, as well as promoting climate-resilient infrastructure and coastal protection projects; India has also extended humanitarian assistance and disaster relief (HADR) to Indian Ocean littoral countries under this vision

Countries. India's SAGAR (Security and Growth for All in the Region) vision, articulated in 2015, represents India's strategic framework for maritime cooperation in the Indian Ocean region, emphasizing a climate of trust and transparency, respect for international maritime rules, and peaceful resolution of maritime issues; while its primary focus is on maritime security and economic growth, SAGAR also encompasses climate change mitigation and adaptation by promoting sustainable development and the blue economy, advocating for the sustainable use of ocean resources such as fisheries, marine tourism, and offshore renewable energy projects[94]. *The Sagarmala Project, an initiative focused on port-led development, also aims to incorporate sustainable practices within its framework*[10]. Capacity building under the SAGAR vision includes efforts to strengthen disaster response mechanisms for cyclones, tsunamis, and oil spills, as well as promoting climate-resilient infrastructure and coastal protection projects; India has also extended humanitarian assistance and disaster relief (HADR) to Indian Ocean littoral countries under this vision [95]. Furthermore, SAGAR promotes regional connectivity and maritime cooperation through engagement in forums like the Indian Ocean Rim Association (IORA) and the Indian Ocean Naval Symposium (IONS), facilitating collaboration on various issues including climate change and maritime security; India's partnerships, such as with the Quadrilateral Security Dialogue (QUAD), also align with the SAGAR vision by aiming to ensure security along vital trade routes in the Indian Ocean, considering climate-related threats.

THE NEED FOR AN UNDERWATER POLICY FRAMEWORK AND THE UDA FRAMEWORK

Current policy frameworks primarily address maritime issues occurring above the surface of the ocean, despite the fact that over 90% of ocean-related challenges, resources, and

94 Padmaja, G. (2018, April 25). Revisiting 'SAGAR' – India's template for cooperation in the Indian Ocean Region. National Maritime Foundation. https://maritimeindia.org/revisiting-sagar-indias-template-for-cooperation-in-the-indian-ocean-region/

95 Tongli, Deepak & Kumar, Chandan. (2024). SAGAR POLICY India's Doctrine of Maritime Cooperation in the Indian Ocean Region. 10.13140/RG.2.2.11812.49280.

Effective policy making is a cornerstone of climate change mitigation efforts in the Indian Ocean region, and India has demonstrated its commitment through the implementation of the National Action Plan on Climate Change (NAPCC) and its pledge to achieve net-zero emissions by 2070; furthermore, the National Policy on the Blue Economy, currently under development, signifies India's intent to promote the sustainable use of its ocean resources.

opportunities lie beneath the surface;[96] this disparity highlights a critical need for a comprehensive policy framework that governs the underwater domain to effectively address issues such as resource management, environmental protection, and security in this largely uncharted realm. The concept of Underwater Domain Awareness (UDA) extends beyond traditional military applications, aiming for a holistic understanding, monitoring, and strategic management of the diverse aspects of the underwater environment; the UDA framework is a structured, comprehensive, and inclusive approach designed to integrate the perspectives of four key stakeholders: Strategic Security, Blue Economy, Sustainability & Climate Change Risk Management, and Science & Technology (Digital Transformation). This framework operates on both horizontal and vertical constructs, which depicts the UDA framework's structure and stakeholders; the horizontal construct encompasses resource availability in terms of technology, infrastructure, capability, and capacity specific to the stakeholders, with acoustic capacity and capability forming the core, while the vertical construct outlines a hierarchy for establishing comprehensive UDA, starting with sensing the underwater domain, followed by data analysis to inform strategies, and culminating in the formulation and monitoring of regulatory frameworks at various levels. The UDA framework holds significant potential to contribute to

96 Maritime Research Center. (n.d.). Underwater Domain Awareness (UDA) Framework and the SAGAR Vision [Video]. YouTube. https://www.youtube.com/watch?v=Dj55Q9eDwxQ

India's SAGAR vision by providing a comprehensive approach to understanding and managing the underwater environment, which is crucial for both maritime security and sustainable growth, aligning with SAGAR's core objectives; by fostering a "User-Academia-Industry" partnership, the UDA framework can optimize resource deployment and enable nuanced policy and technology interventions tailored to the unique tropical conditions of the Indian Ocean region, supporting India's ambition for a smart, digital nation with high-end technology integration to overcome the specific challenges of the IOR.

Effective policy making is a cornerstone of climate change mitigation efforts in the Indian Ocean region, and India has demonstrated its commitment through the implementation of the National Action Plan on Climate Change (NAPCC) and its pledge to achieve net-zero emissions by 2070; furthermore, the National Policy on the Blue Economy, currently under development, signifies India's intent to promote the sustainable use of its ocean resources. Capacity building plays a vital role in addressing the impacts of climate change, and India actively provides technical, financial, and logistical support to Indian Ocean littoral countries, alongside initiatives like "Skill India" which aims to train a substantial number of people in sustainable development practices. The promotion of indigenous technology is also crucial for sustainable climate change mitigation, as traditional knowledge and practices offer valuable, time-tested solutions for water management, sustainable agriculture, and enhancing resilience to extreme weather events;

CONCLUSION AND WAY FORWARD

The Indian Ocean region is undergoing rapid and multifaceted changes due to climate change, with far-reaching consequences for its physical environment, ecosystems, and the socio-economic stability of surrounding nations particularly India. While digital transformation, India's SAGAR vision, and the UDA framework present promising avenues to address these evolving challenges, there remains a pressing need to explore more comprehensive and collaborative approaches. It may be valuable to consider developing targeted policy frameworks that

address underwater domain governance, a space still largely unregulated despite its strategic importance. Integrating climate adaptation and mitigation more explicitly into the SAGAR framework could also strengthen the region's collective resilience. Exploring ways to promote and scale indigenous technologies might help bridge the gap between modern innovation and traditional wisdom, especially in vulnerable coastal communities. Further, enhancing capacity-building efforts both at institutional and grassroots levels could support a more inclusive and locally grounded climate response. Facilitating broader adoption of digital tools for early warning systems and climate monitoring might prove instrumental in making the region more adaptive. Greater emphasis on regional cooperation, including cross-border data sharing and joint preparedness initiatives, could help address transboundary climate risks more effectively. Strengthening investments in climate modeling and scientific research may aid in refining projections and reducing uncertainties, particularly in the complex Indian Ocean system. Finally, ensuring inclusive access to climate information and embedding climate considerations more systematically into policymaking processes across sectors could pave the way for a more coordinated, sustainable, and equitable regional strategy. By reflecting on these potential directions, India can further its leadership role in fostering a climate-resilient Indian Ocean.

Modelling & Simulation Driven Marine Spatial Planning (MSP) for Sustainable Governance in the Indian Ocean Region

Shridhar Prabhuraman

BACKGROUND

India's recent efforts in Marine Spatial Planning (MSP) mark a significant step toward sustainable ocean governance in the Indian Ocean Region (IOR). However, traditional MSP approaches in India, much like global counterparts, often rely on isolated datasets—such as mapping ocean temperature, shipping routes, or marine biodiversity—without integrating them into comprehensive, impact-driven analyses. This fragmented approach limits the ability to anticipate environmental consequences, mitigate risks, and develop adaptive policies in a rapidly changing marine ecosystem. Given the strategic and ecological importance of the IOR, it is imperative that India moves beyond static mapping and embraces modelling and simulation-based MSP. This paper highlights the need for simulation-based MSP, which with advanced computational models, acoustic simulations, and AI-driven analytics can transform India's MSP efforts by shifting from mere spatial plotting to predictive, data-fused decision-making. Instead of simply mapping vessel density, a simulation-based approach quantifies and visualizes shipping noise propagation and predicts its impact on marine mammals at specific frequency ranges. Similarly, rather than just identifying coral reefs and fisheries, dynamic models can forecast habitat degradation, assess climate change vulnerabilities, and optimize marine conservation strategies. By employing computational models, acoustic simulations, hydrodynamic forecasting, and AI-driven scenario analysis, simulation- based MSP provides a data-fused, ecosystem-centric approach to marine governance. Furthermore, this paper explores how such integrated modelling techniques can enable policymakers to make informed, adaptive decisions, ensuring that marine activities are optimized for both economic growth and ecological sustainability.

Additionally, key policy recommendations are provided to facilitate the adoption of modelling & simulation-based Marine Spatial Planning (MSP) frameworks, paving the way for a more resilient and data-driven approach to ocean management.

Traditional MSP approaches in India, much like global counterparts, often rely on isolated datasets—such as mapping ocean temperature, shipping routes, or marine biodiversity—without integrating them into comprehensive, impact-driven analyses. This fragmented approach limits the ability to anticipate environmental consequences, mitigate risks, and develop adaptive policies in a rapidly changing marine ecosystem. Given the strategic and ecological importance of the IOR, it is imperative that India moves beyond static mapping and embraces modelling and simulation-based MSP. This paper highlights the need for simulation-based MSP.

To operationalize MSP, the Government of India, in collaboration with Norway's Ministry of Foreign Affairs, launched pilot MSP projects in Puducherry and Lakshadweep in 2021 frameworks, build local capacities, and integrate ecological, economic, and social data for sustainable decision-making.

INTRODUCTION

India's maritime sphere in the Indian Ocean Region (IOR) spans over 2 million km² of Exclusive Economic Zone (EEZ), rich in biodiversity and critical trade routes. The nation's maritime ambitions have grown in tandem with its economic development, leading to increased focus on sustainable ocean governance. Under the 'Vision of New India @ 75' and the emphasis on a Blue Economy, India recognizes that coastal and marine resources must be managed to balance ecological preservation with economic growth[97]

Marine Spatial Planning (MSP) is a place-based approach to ocean management that aligns with global sustainability frameworks like the UN Sustainable Development Goals (SDGs)—especially SDG 14 (Life Below Water)—and international commitments under the Convention on Biological Diversity. MSP enables countries to optimize resource use, minimize conflicts among stakeholders (e.g., fishing, shipping, tourism, offshore energy), and conserve marine ecosystems. According to the Intergovernmental Oceanographic Commission of UNESCO, MSP is a key tool for ecosystem-based management[98].

To operationalize MSP, the Government of India, in collaboration with Norway's Ministry of Foreign Affairs, launched pilot MSP projects in Puducherry and Lakshadweep in 2021[99] frameworks, build local capacities, and

97 NITI Aayog. (2021). Vision of New India @75. Retrieved from https://incois.gov.in/documents/Blue_Economy_policy.pdf .

98 Intergovernmental Oceanographic Commission of UNESCO. (2017). Marine Spatial Planning: A Step-by-Step Approach. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000186559

99 Ministry of Earth Sciences. (2021). Pilot Marine Spatial Planning Projects. Retrieved from . These projects aim to develop customized MSP

integrate ecological, economic, and social data for sustainable decision-making. Preliminary results underscore the potential for multi- stakeholder engagement and technology adoption in guiding coastal and offshore developments.

Underwater Domain Awareness (UDA) plays a pivotal role in enabling this transition from sectoral planning to a holistic, data-driven ocean governance paradigm. UDA ensures continuous monitoring and understanding of the undersea environment—acoustic signatures, sediment profiles, biodiversity patterns, and human activity footprints— thereby enhancing the quality and scope of traditional Marine Spatial Planning (MSP), therefore we call this UDA driven enhanced Marine Spatial Planning to be Modelling and Simulation based MSP. It provides the scientific and strategic foundation necessary to build high-fidelity models and forecasts, crucial for adaptive marine planning. Furthermore, UDA is central to the realization of India's SAGAR (Security and Growth for All in the Region) vision, which aims to ensure inclusive, sustainable maritime development across the Indian Ocean. By facilitating interoperability, surveillance, and data-sharing between maritime stakeholders, UDA strengthens regional maritime diplomacy, environmental stewardship, and disaster resilience—cornerstones of effective MSP. In this context, simulation-based MSP becomes both a governance tool and a strategic enabler for India's leadership in the IOR.

LIMITATIONS OF TRADITIONAL MSP IN INDIA

As mentioned in the world bank report from 2020 on "Enhancing Coastal and Ocean Resource Efficiency Project", traditional Marine Spatial Planning (MSP) and coastal management in India have often been fragmented and reactive. Multiple agencies operate in silos with unshared datasets, leading to uncoordinated decisions. This disjointed approach results in *information gaps* and missed early warnings – for example, many states have struggled to even formulate integrated marine plans due to limited data sharing and technical capacity[100]

100 World Bank. (2020). Enhancing Coastal and Ocean Resource Efficiency Project. Retrieved from https://documents1.worldbank.org/curated/en/281421588384912205/txt/India- Enhancing-Coastal-and-Ocean-Resource-Efficiency-Project-as-Phase-1-of-the-Multiphase-Programmatic-Approach.txt .

Lack of local stakeholder engagement in traditional Marine Spatial Planning (MSP) has often hindered policy implementation. A stark example is the Vizhinjam port project in Kerala. Planned as a major transshipment hub, it proceeded with minimal consideration of local fisherfolk's spatial needs.

THE CONSEQUENCES ARE EVIDENT IN REAL-WORLD CASES

Coastal Erosion and Ecological Impacts: In Tamil Nadu, hard shoreline defenses (rocky sea walls and groynes) were installed to curb local erosion, without holistic forecasting of regional effects. While they shielded some spots, they simply shifted the erosion problem down shore. Adjacent fishing hamlets saw beaches disappear and even turtle nesting declined as shorelines receded. Critics note that this "siloed" fix ignored sediment dynamics, failing to consider how sediment flows, and wave patterns change seasonally or with climate induced variability – the result was worsened erosion in nearby areas, an unforeseen ecological impact that a broader, simulation-based marine spatial plan might have predicted.

Notably, India's top environmental court in 2022 ordered states to adopt comprehensive coastal plans instead of ad-hoc hard structures, but many regions still relied on outdated methods, effectively defying the ruling[101]- Stakeholder Conflict and Delayed Interventions: Lack of local stakeholder engagement in traditional Marine Spatial Planning (MSP) has often hindered policy implementation. A stark example is the Vizhinjam port project in Kerala. Planned as a major transshipment hub, it proceeded with minimal consideration of local fisherfolk's spatial needs. By 2018–2022, fishing communities began protesting in mass, alleging that the port's construction caused severe coastal erosion and threatened their livelihood. The conflict escalated into a blockade of the port site, stalling the $900 million project. Here, a top-down plan (focused only on infrastructure) missed social and ecological risks that

101 5 Dialogue Earth. (2022). India's Coasts are Eroding as States Fail to Plan Properly. Retrieved from https://dialogue.earth/en/ocean/indias-coasts-are-eroding-as-states- fail-to-plan-properly/

Dynamic MSPs use real- time environmental and human activity data, stakeholder feedback, and adaptive rulesets to revise spatial strategies iteratively.

a multi- stakeholder MSP process might have flagged. Only after protests did authorities belatedly commission studies on shoreline impacts. This underscores how excluding local stakeholders can lead to costly delays or policy failure – engagement from the outset might have reconciled port development with fishery zones, avoiding an impasse[102]. Overall, India's experience shows that traditional Marine Spatial Planning (MSP) approaches – characterized by compartmentalized data, static plans, and limited public input – tend to overlook cumulative risks until they manifest as crises. The need for a more integrated, forward- looking approach is evident from these missteps.

THE CASE FOR MODELLING & SIMULATION-BASED MSP

Simulation-based MSP offers a paradigm shift. It provides two transformative advantages which when added to traditional MSPs, can directly addresses the above limitations:

- **Dynamism:** Simulation-based MSP is inherently adaptive. It contains the ability to continuously adapt to changing marine conditions, stakeholder needs, and scientific inputs. This goes beyond periodic updates—dynamic MSPs use real-time environmental and human activity data, stakeholder feedback, and adaptive rulesets to revise spatial strategies iteratively.
  - » For example, fishing exclusion zones could expand during spawning season based on live catch reports, or infrastructure zones could be reclassified after a storm alters sediment profiles.
  - » Dynamism is powered by feedback loops, where simulation results and real-world observations continuously inform and reshape planning decisions. This enables resilient, real-time governance rather than fixed plans based on past conditions.

102 Reuters. (2022). Indian Tycoon Adani's Mega Port Hangs in Balance Amid Fishing Community Protests. Retrieved from https://www.reuters.com/world/india/indian- tycoon-adanis-mega-port-hangs-balance-fishing-community-protests-2022-11-23/

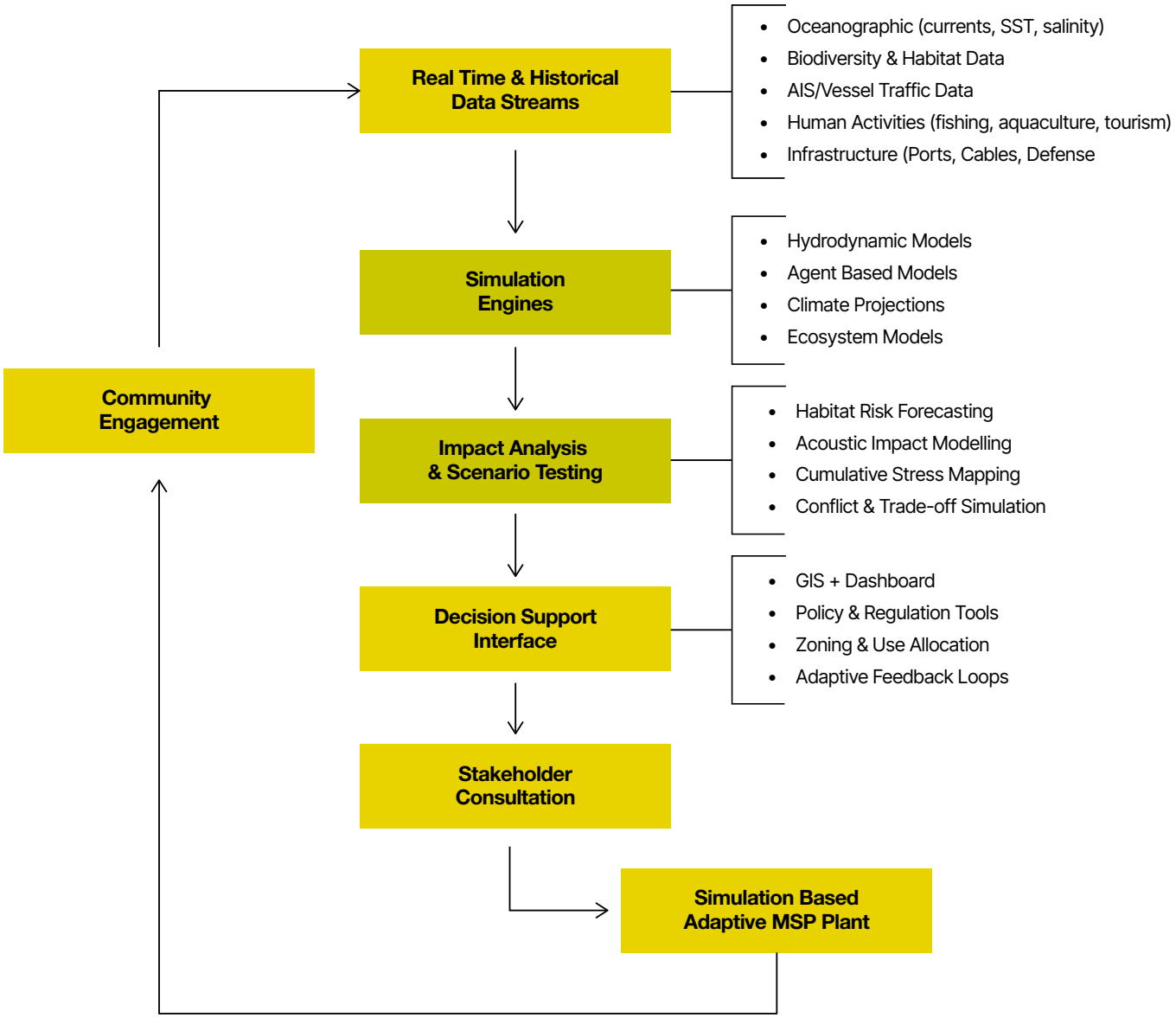


Figure 1: Flow Diagram depicting Simulation Based Marine Spatial Planning framework. The simulation engine, impact analysis and scenario testing depict additions to the traditional MSP framework.

- **Impact Modelling:** Instead of drawing boundaries based only on current data, they leverage computational models to forecast and visualize future scenarios. It computes how actions—like dredging, marine traffic, aquaculture expansion, or port development—will affect ecosystems, noise levels, sediment flows, or stakeholder access.
  - » For instance, hydrodynamic models can simulate ocean currents, tides, and storm surges under different conditions – helping planners foresee flooding

hotspots or pollutant dispersal from a new coastal project. Agent- based models, meanwhile, can mimic the behaviors of individual "agents" (e.g. fishing vessels, marine animals, or even regulatory enforcers) to see how they interact in a shared space[103].

- This allows exploration of emergent conflicts or resource competition before they happen. Other tools include climate simulation models (for sea-level rise, ocean warming, marine heatwave frequency) and decision- support systems like Marxan or InVEST that optimize site allocation for conservation or development under various criteria[104]. This shift from visualization to impact-driven insight is what makes simulation essential for evidence-based, risk-informed decision-making.

Figure 1 illustrates the architecture of a Simulation-Based Adaptive MSP Framework. It emphasizes how real-time and historical data—including oceanographic conditions, biodiversity, shipping activity, infrastructure, and importantly, local knowledge and human activity patterns gathered through community engagement—feed into simulation engines. These engines generate impact scenarios that are evaluated using decision-support tools and subjected to multi-stakeholder consultation. The decision support tools include a user-friendly graphical interface that allows local communities and stakeholders to contribute and gather suitable information. The resulting adaptive MSP plan is continuously refined based on new data, environmental feedback, and evolving community needs. This iterative feedback loop is a core strength of simulation-based MSP. It ensures that planning is not a one-time activity, but a living process that grows smarter over time. With an effective decision-support interface, a simulation-based MSP can test multiple "what-if" scenarios – for example, what happens to fisheries and tourism if a certain area is designated for mining, or how coastal habitats will fare in 10, 20, 50 years given different climate trajectories.

As an illustration of the practical application of simulation-based Marine Spatial Planning (MSP) in the Indian context, Figure 2 showcases a

103 MDPI. (2023). Role of Agent-Based Models in Marine Spatial Planning. Retrieved from https://www.mdpi.com/2071-1050/16/23/10447 .

104 NSF Public Access Repository. (2020). Decision Support Systems for Marine Spatial Planning. Retrieved from https://par.nsf.gov/servlets/purl/10109028

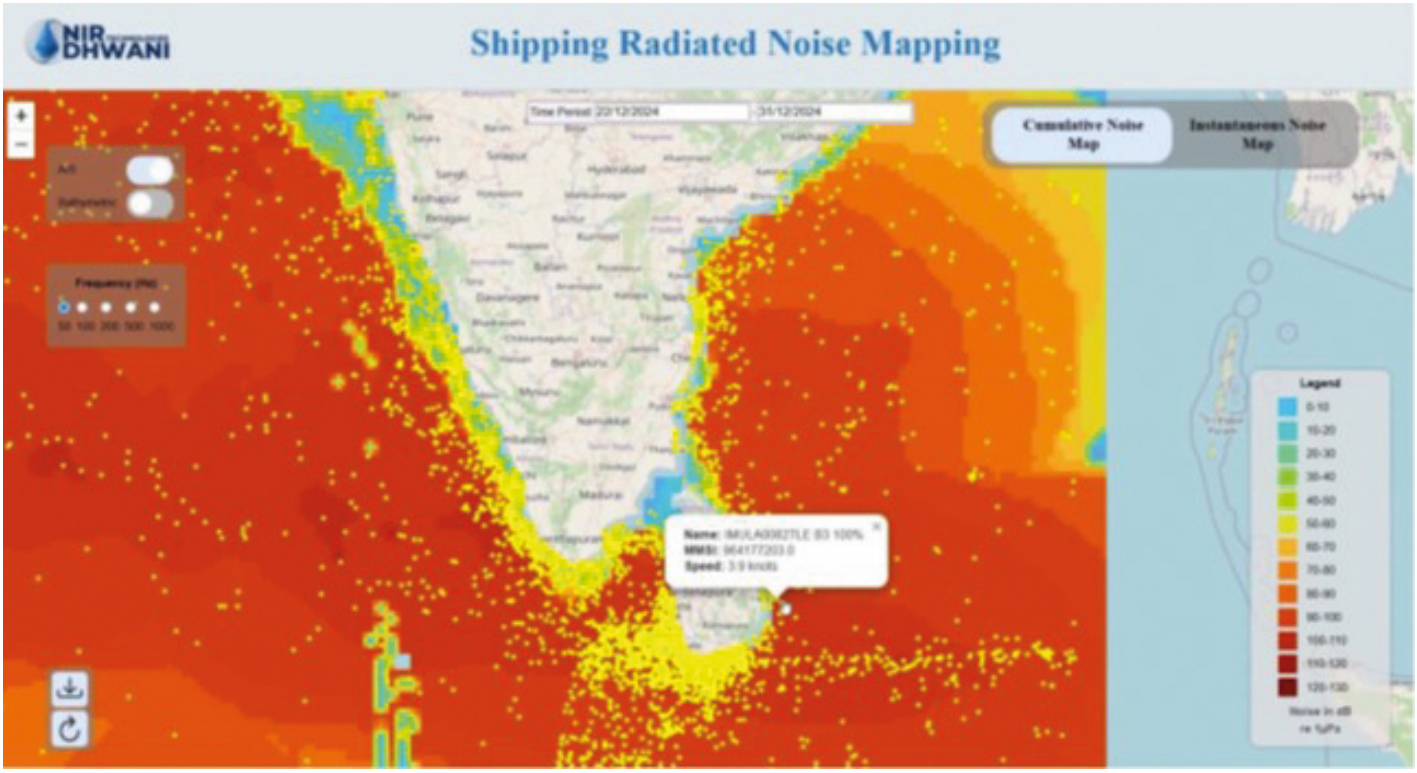


Figure 2: Prototype of a Shipping Radiated Noise Mapping Tool Developed by NirDhwani Technologies and Maritime Research Center, Pune, Demonstrating Cumulative Acoustic Impact Visualization for Indian Waters

Shipping Radiated Noise Mapping tool developed by NirDhwani Technologies in collaboration with the Maritime Research Center, Pune. The tool enables real-time and cumulative acoustic impact assessment across India's Exclusive Economic Zone (EEZ), integrating vessel Automatic Identification System (AIS) data and bathymetric layers. Such tools demonstrate the feasibility and importance of modelling-driven MSP approaches for evidence-based decision-making.

Crucially, this approach enables *informed, proactive decisions*. Where siloed planning reacts late (or not at all) to issues, a simulation-based MSP can highlight risks early. A practical illustration is mapping the interaction between fisheries and port development (a common tension in the Indian Ocean region). By using an agent-based simulation of fishing boats alongside shipping traffic data, planners can identify hotspots of spatial competition or safety hazard. In the case of Vizhinjam Port (India) discussed earlier, such mapping would have shown the heavy usage of the proposed port area by artisanal fishers before the project commenced, raising red flags early.

Simulation tools can map noise propagation which affects marine life and identify sensitive habitats to guide routing decisions.

In summary, modelling and simulation-based MSP provides an adaptive, scenario-driven planning process. It embraces complexity by linking oceanographic models, ecological forecasts, and socio-economic simulations. This stands in contrast to static plans that often assume yesterday's conditions will hold. By capturing temporal changes and cross- sector interactions, a simulation-based approach yields a more resilient and responsive marine spatial plan – one that can support sustainable blue economy growth while safeguarding ecosystem health[105]

APLICATIONS IN THE INDIAN OCEAN REGION

To illustrate the value of simulation-based MSP, here are several key applications relevant to the Indian Ocean Region, each with real or hypothetical examples. These use cases do not occur in isolation – they are highly interdependent and cut across sectors, reinforcing the need for an integrated modelling approach:

- **Shipping Noise Modelling:** The Indian Ocean sees heavy maritime traffic (from oil tankers to container ships) that generates underwater noise, affecting marine life. Simulation tools can map noise propagation which affects marine life and identify sensitive habitats to guide routing decisions. For example, off the coast of Sri Lanka, scientists modelled the overlap between busy shipping lanes and the habitat of a unique blue whale population. They found that rerouting ships slightly southward would significantly reduce noise and deadly ship strikes in whale feeding grounds[106] research led to calls – now being heeded by industry and the International Maritime Organisation (IMO) – to adjust shipping corridors for wildlife

105 World Bank PROBLUE. (2020). Marine Spatial Planning for a Resilient and Inclusive Blue Economy Toolkit. Retrieved from https://www.worldbank.org/en/programs/problue/publication/marine-spatial-planning- for-a-resilient-and-inclusive-blue-economy-toolkit .

106 The Guardian. (2022). Change Lane, Whales Ahead: Sri Lanka Urged to Reroute Shipping Traffic. Retrieved from https://www.theguardian.com/environment/2022/feb/07/change-lane-whales-ahead-sri-lanka-urged-to-reroute-shipping-traffic .This

In the Indian Sundarbans, scientists used a Sea Level Rise model coupled with shoreline dynamics to assess mangrove futures. The sobering result: under a business-as-usual climate scenario, the Sundarbans mangroves could lose 42–80% of their area by 2100. On a positive note, the model also showed that proactive measures (like managed realignment of coastal defenses) could mitigate some loss.

protection. By simulating acoustic impacts before altering routes, planners can protect biodiversity while maintaining efficient trade. Notably, outputs from noise models can feed into broader cumulative impact models (see below), since noise is one of many stressors on the ecosystem.

- **Habitat Impact Forecasting:** Modelling and simulation enable forecasting of ecological impacts under various development or climate scenarios – a step often missing in traditional plans. For coral reefs and mangroves (two critical Indian Ocean habitats), simulations have proven invaluable. Researchers can predict reef degradation by inputting projected sea temperature rise and acidification levels into ecosystem models. Globally, such simulations warn that over 70% of the world's coral reefs are projected to suffer serious degradation by 2030 under current emission trends[107] a statistic that undoubtedly includes vulnerable reefs in the Indian Ocean. Regionally, in the Indian Sundarbans, scientists used a Sea Level Rise model coupled with shoreline dynamics to assess mangrove futures. The sobering result: under a business-as-usual climate scenario, the Sundarbans mangroves could lose 42–80% of their area by 2100[108]

On a positive note, the model also showed that proactive measures (like managed realignment of coastal defenses) could mitigate some loss. These forecasts allow policymakers to pinpoint "high-risk" habitats – e.g. a coral reef likely to bleach out, or a mangrove belt likely to retreat – and prioritize them for conservation, restoration, or climate adaptation efforts. Importantly, habitat models often draw on inputs from climate simulations (temperature, sea-level) and can be combined with socio-economic scenarios (like future tourism pressure), making them a nexus of cross-sector data. The Western Indian Ocean is pioneering this approach through a tool called Western Indian Ocean (WIO) Symphony. Co-developed for the Nairobi Convention member states, WIO Symphony

107 Smithsonian Magazine. (2015). Majority of Coral Reefs Will Be Damaged by 2030 Due to Rising Greenhouse Gases. Retrieved from https://www.smithsonianmag.com/science-nature/majority-of-coral-reefs-will-be- damaged-by-2030-due-to-rising-greenhouse-gases-39519235/ . –

108 ScienceDirect. (2023). Exploratory Modelling of the Impacts of Sea Level Rise on Mangroves. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S004896972305249X .

compiles over 80 maps of ecosystem components and human uses at 1×1 km resolution. Using a region-specific sensitivity matrix, it calculates how vulnerable each marine habitat cell is to the sum of pressures present.[109]

- **Climate Vulnerability Simulations:**

  The Indian Ocean Rim countries face varied climate risks – from sea-level rise threatening low-lying islands and deltaic coasts, to marine heatwaves that cause fishery collapses. Simulation-based MSP incorporates these long-term vulnerabilities into planning. For instance, coastal inundation models can map areas of cities or ports that would flood under different sea-level rise projections (say 0.5m vs 1m by 2100), enabling governments to climate-proof infrastructure location and setback lines. Likewise, oceanographic simulations of temperature and currents help anticipate marine heatwaves or coral bleaching events. The devastating 1998 coral bleaching in the Indian Ocean (with over 70% coral mortality at some sites) has been extensively studied to improve models that now project the frequency of such events. Planners can use these models to designate climate refugia (areas less prone to warming) as marine protected areas, or to schedule activities (e.g. dredging, military exercises) in ways and places that avoid compounding natural stress events. By visualizing future climate impacts on a map, decision-makers in places like the Maldives, Seychelles, or Indian coastal states can proactively integrate adaptation into MSP – aligning reef protection, coastal defenses, and fishery policies with the coming changes. These simulations cut across sectors: for example, a sea-level rise impact map might influence urban development plans, disaster management and environmental conservation simultaneously [110]

In all these applications, the interdependencies are clear. Shipping noise models contribute data to cumulative impact assessments, which in turn inform conflict zoning (e.g., whether a new shipping route will push stress beyond a threshold

109 Havochvatten. (2023). WIO Symphony: New Tool on Ocean Impact Launched. Retrieved from https://www.havochvatten.se/en/eu-and-international/international- coopera-tion/news/news/2023-05-09-new-tool-on-ocean-impact-launched.html .

110 Ocean-Climate.org. (2020). Coral Bleaching: An Imminent Threat to Marine Biodiversity. Retrieved from https://ocean-climate.org/wp-content/uploads/2020/01/5.- Coral-bleaching-an-imminent-threat-to-marine-biodiversity-scientific-sheets-2019.pdf

India's new Digital Ocean platform by Indian National Centre for Ocean Information Services (INCOIS) is a step in the direction to assuage uneven data availability – it serves as a one-stop solution for organizing and sharing heterogeneous oceanographic data for scientists, industry, and policymakers.

in a fishing ground). Habitat forecasts depend on climate simulations, and their results feed into conflict resolution (for instance, if a fishing ground is forecast to collapse from climate stress, diversifying livelihoods becomes part of spatial planning). This interconnected nature means modelling exercises cannot be siloed: they require collaboration between oceanographers, ecologists, social scientists, and policy-makers. A simulation-based MSP platform essentially becomes a shared, cross-sector decision-support system.

Overall, embracing a modelling and simulation-based approach to MSP equips policymakers in India and the broader Indian Ocean Region with the tools to anticipate and avert environmental impacts and user conflicts before they escalate, enabling more timely and sustainable policy interventions.

DATA & TECHNOLOGY REQUIREMENTS

Implementation of simulation-driven Marine Spatial Planning (MSP) demands robust data and technological infrastructure. Marine observation systems form the backbone: networks of sensors, buoys, and autonomous platforms (like Argo floats, wave rider buoys, and robotic gliders) continuously monitor ocean conditions. These in-situ systems need to be complemented by satellite remote sensing, coastal radar, and underwater observatories (including cabled seafloor sensors) to capture real-time multidimensional data. High-performance computing (HPC) and cloud platforms are equally critical – complex ocean models and digital twins require significant processing power. India, for instance, has deployed an High Performance Computing (HPC) system named *Tarang* to run

operational ocean models, improving the accuracy of tsunami and ocean state forecasts[111].

Artificial intelligence (AI) tools can further aid by assimilating diverse datasets and optimizing simulations for scenario analysis. However, practical challenges abound. High costs and maintenance hurdles limit ocean observations – and is prone to damage (e.g. by fishing activities).

Maintaining research vessels and sensor networks over India's vast Exclusive Economic Zone is resource intensive. Uneven data availability is another issue: some coastal regions and parameters are well-studied while others remain "data deserts," hampering comprehensive modelling. Moreover, data from different sources (physical oceanography, ecological surveys, socio-economic use patterns) often reside in silos across agencies.

Data-sharing agreements and interoperable platforms are needed to fuse these inputs. India's new Digital Ocean platform by Indian National Centre for Ocean Information Services (INCOIS) is a step in the direction to assuage uneven data availability – it serves as a one-stop solution for organizing and sharing heterogeneous oceanographic data for scientists, industry, and policymakers. [112]

Yet, fully leveraging such technology requires closing institutional gaps in data management. Currently, limited coordination across marine data initiatives means capacity-building is needed so that various ministries, state agencies, and research institutions can contribute to and benefit from integrated data infrastructure [113]

Bridging these gaps will ensure simulations are fed by reliable,

A pilot MSP framework led by National Centre for Coastal Research (NCCR) is being tried in Lakshadweep and Puducherry, but scaling it will require clear role demarcation and cooperation among all stakeholders

111 The New Indian Express. (2024). INCOIS Mulls Cable-Based Observation System for Better Tsunami Prediction. Retrieved from https://www.newindianexpress.com/states/odisha/2024/Nov/22/incois-mulls-cable- based-observation-system-for-better-tsunami-prediction-4 .

112 Press Information Bureau (PIB), Government of India. (2020). Digital Ocean Platform Launch. Retrieved from https://pib.gov.in/PressReleseDetailm.aspx?PRID=1684418 .

113 ibid

In the Gulf of Kutch, for instance, oil pipelines and infrastructure were permitted inside a Marine National Park, threatening biodiversity – a situation that better coordination and planning might have averted.

comprehensive data, strengthening MSP outcomes.

INSTITUTIONAL G POLICY GAPS

Effective MSP in the Indian Ocean Region necessitates coordination across numerous institutions, but fragmented governance and policy gaps impede progress. Key ministries in India – the Ministry of Earth Sciences (MoES), Ministry of Environment, Forest and Climate Change (MoEFCC), Ministry of Ports, Shipping and Waterways (MoPSW), and others like the Department of Fisheries – each hold pieces of the marine management mandate. Their agencies (for example, MoES's National Institute of Ocean Technology and National Centre for Coastal Research, and MoEFCC's National Centre for Sustainable Coastal Management) collect data or regulate uses, but operate with limited integration. There is no single statutory authority for MSP; instead, sectoral plans (e.g. port development under Sagarmala, or state-level coastal zone management plans) proceed in parallel. This often leads to overlaps or gaps – for instance, conservation and fisheries agencies may not be fully consulted when maritime infrastructure is planned, resulting in conflicts or delays. A pilot MSP framework led by National Centre for Coastal Research (NCCR) is being tried in Lakshadweep and Puducherry, but scaling it will require clear role demarcation and cooperation among all stakeholders[114].

Policy and regulatory barriers compound the challenge. Environmental Impact Assessments (EIAs) for projects focus on site-specific, short-term impacts, with no mandate to account for cumulative or long-range changes through dynamic modelling. A recent audit found that even for mega coastal projects, ecological

114 India Science and Technology Portal. (n.d.). Ocean Initiatives in India. Retrieved from https://www.indiascienceandtechnology.gov.in/listingpage/ocean-initiatives

assessments were "not holistic" and key risks were downplayed. Such gaps illustrate the absence of MSP principles in mainstream regulation. There is currently no requirement that development proposals align with an overarching marine spatial plan or utilize simulation tools to test outcomes.[115]

The lack of an integrated policy framework has real costs. Poor inter-agency coordination and siloed decision-making have led to inefficiencies and environmental harm. In the Gulf of Kutch, for instance, oil pipelines and infrastructure were permitted inside a Marine National Park, threatening biodiversity – a situation that better coordination and planning might have averted. [116]

Likewise, uncoordinated coastal engineering in Puducherry contributed to decades of shoreline erosion that devastated local livelihoods before belated restoration efforts. These examples underscore how institutional gaps – whether overlapping jurisdictions, weak enforcement of ecosystem- based approaches, or absence of stakeholder consultation – can derail sustainable ocean governance. Strengthening inter-ministerial mechanisms (such as a national MSP committee) and updating policies to embed simulation-based planning are critical next steps.

GLOBAL BEST PRACTICES

Around the world, countries are evolving best practices for simulation-integrated MSP that India can learn from.

- The European Union's MSP Directive (2014) requires member states to adopt an ecosystem-based maritime spatial plan by 2021, encouraging use of scientific tools to balance uses. Many EU nations have developed sophisticated digital platforms to support this. For example, Australia's Marine Spatial Information System (AMSIS) provides an interactive mapping and decision-support tool that integrates data on maritime boundaries, ecology, fisheries, and industry in one place.[117] Such

115 Hindustan Times. (2022). Coastal Road, MTHL Bypassed Critical Environmental Scruti-ny: CAG Audit. Retrieved from https://www.hindustantimes.com/cities/mumbai- news/coastal-road-mthl-bypassed-critical-environmental-scrutiny-cag-audit- 101660158283754.html .

116 ResearchGate. (2023). Marine Biodiversity of Gulf of Kutch in India. Retrieved from https://www.researchgate.net/publication/369366708_Marine_Biodiversity_of_Gulf_of_Kutch_in_India

117 Geoscience Australia. (n.d.). Australian Marine Spatial Information System (AMSIS). Retrieved from https://www.ga.gov.au/scientific-topics/marine/jurisdiction/amsis .

geoportals give planners and stakeholders a common operating picture for scenario analysis.

- The United States uses similar approaches – National Oceanic and Atmospheric Administration (NOAA) and partner agencies maintain MarineCadastre.gov, an open data portal with hundreds of spatial layers (from shipping lanes to fishing grounds) to inform offshore energy siting and conservation planning. These systems illustrate the value of an open-data culture: making diverse datasets accessible in standardized formats so they can feed into simulation models and "digital twin" representations of the marine environment.
- Advances in Digital Twin technology are particularly noteworthy. National Oceanic and Atmospheric Administration (NOAA), for instance, is collaborating with tech partners to build a digital twin of Earth's oceans that fuses real-time observations with predictive models[118]. Such tools offer dynamic, 4D simulations of ocean conditions under different scenarios.

As one National Oceanic and Atmospheric Administration (NOAA) scientist noted, a well-designed digital twin becomes a "one-stop shop" providing researchers and decision-makers a timely, globally visualized sandbox to test climate and policy impacts[119]. Co-development with stakeholders is another pillar of global best practice. In Europe, iterative consultation – sometimes via simulation "games" where fishermen, energy developers, and conservationists jointly explore spatial trade-offs – has improved plan acceptance and outcomes. For example, maritime spatial plans in the North Sea and Baltic Sea benefited from stakeholder inputs to optimize locations of wind farms relative to fishing zones, reducing conflicts.

WHY INDIA NEEDS SIMULATION-BASED MSP

For India, simulation-based MSP is not just a best practice—it's a strategic necessity. India's marine environment presents a distinct set of challenges

118 NextGov. (2022). NOAA Building Digital Twin of Earth to Study Climate Change. Retrieved from https://www.nextgov.com/digital-government/2022/11/noaa-building- digital-twin-earth-study-climate-change/379666/ .

119 24 ibid . In the context of MSP, this means planners can virtually assess before making real-world decisions.

that traditional MSP frameworks struggle to manage effectively:

Extreme variability: India's coasts face high spatial and temporal variability in climate (monsoons, cyclones), biodiversity, and human activity (e.g., festival tourism, seasonal fishing). Simulation models allow forecasting and adaptive responses that static MSP cannot offer.

- **Resource constraints:** As a developing economy, India cannot afford blanket deployment of expensive monitoring systems. Simulation tools provide a cost-effective solution by reducing dependence on full-scale field observations (e.g., using numerical acoustic models for noise estimation which can be further validated by selective hydrophone deployment).
- **Densely populated and livelihood-dependent coasts:** Millions of people rely on nearshore waters for daily sustenance. Simulation-based tools can model cumulative pressures—e.g., seasonal fishing and tourism, aquaculture, port development, —and help design equitable spatial strategies that protect livelihoods while reducing environmental risks.
- **Data fragmentation:** With marine data spread across agencies, simulation platforms provide a unifying framework that can integrate disparate datasets (e.g., AIS data, bathymetry, biodiversity), enabling holistic policy thinking.
- **Governance complexity:** With many overlapping mandates (MoES, MoEFCC, MoPSW, state authorities), a digital, model-driven approach offers transparency, interoperability, and replicability, essential for inter-agency collaboration.

Leveraging existing legal frameworks—such as the Environmental Protection Act or Coastal Regulation Zone (CRZ) rules—can provide only an interim regulatory foundation. Ultimately, India should enact a comprehensive MSP Act that legally mandates periodic spatial planning for its coastal and Exclusive Economic Zone (EEZ) regions, integrates simulation-driven scenario analysis, and embeds marine spatial plans into national development and environmental clearance processes.

While India can adopt several tools and protocols from global leaders, success will require contextual adaptation.

- India must prioritize ecosystem-based planning (like the EU) but also embed socio-cultural dimensions like customary fishing rights and sacred coastal landscapes.
- Participatory processes must be tailored to Indian contexts—translated into local languages, supported by local governance structures, and inclusive of traditionally marginalized voices.

Digital Ocean, developed by Indian National Centre for Ocean Information Services (INCOIS) and, is a promising start and can evolve into India's equivalent of European Marine Observation and Data Network (EMODnet) or Marine Cadastre.gov—provided it is scaled up with more data types and broader institutional buy-in[120] however as suggested India needs more than a platform that accumulates data, it needs a platform that simulates actionable and data-driven outcomes from this data. The Marine Spatial Planning tool being developed by NirDhwani Technology[121] aims to realize this simulation-based MSP strategy, however the strategy requires greater legal actions and data collaboration as detailed in the upcoming section.

POLICY RECOMMENDATIONS

To operationalize a simulation-based MSP framework in India, a multi-pronged approach is needed across legislation, capacity-building and technological investments[122]. The following recommendations are grouped by focus.

Legislative Action – Strengthening legal mandates and integration

- India must move swiftly to formalize Marine Spatial Planning (MSP) through a dedicated National Marine Spatial Planning Policy or Bill. This legal instrument should establish ecosystem-based and multi-sectoral principles, mandate coordination across ministries and coastal states, and require that all

120 Press Information Bureau (PIB), Government of India. (2020). Digital Ocean Platform Launch. Retrieved from https://pib.gov.in/PressReleseDetailm.aspx?PRID=1684418

121 NirDhwani Technologies Pvt Ltd, Shipping Radiated Noise Estimation Tool. Retrieved from https://nirdhwani.in/project/shipping-radiated-noise-estimation-tool/

122 India Science and Technology Portal. (n.d.). Ocean Initiatives in India. Retrieved from https://www.indiascienceandtechnology.gov.in/listingpage/ocean-initiatives

A robust legal framework is essential to institutionalize MSP beyond pilot efforts. International examples show the importance of enforceable mandates: South Africa's MSP Act (2018) requires all state organs to align their decisions with approved spatial plans, reducing policy conflicts and streamlining development. Similarly, the European Union's MSP Directive compels member states to coordinate across borders and adopt ecosystem-based planning approaches. India's legislation should similarly ensure that sectoral ministries—such as shipping, fisheries, energy, and tourism—are legally bound to conform to national MSP guidelines, and that Environmental Impact Assessments (EIAs) reflect cumulative and long-term spatial models.

major marine infrastructure and development projects undergo spatial planning assessments. The policy should also explicitly mandate stakeholder participation, transparent data integration, and inter-agency alignment. Leveraging existing legal frameworks—such as the Environmental Protection Act or Coastal Regulation Zone (CRZ) rules—can provide only an interim regulatory foundation. Ultimately, India should enact a comprehensive MSP Act that legally mandates periodic spatial planning for its coastal and Exclusive Economic Zone (EEZ) regions, integrates simulation-driven scenario analysis, and embeds marine spatial plans into national development and environmental clearance processes.

- **Justification:** A robust legal framework is essential to institutionalize MSP beyond pilot efforts. International examples show the importance of enforceable mandates: South Africa's MSP Act (2018) requires all state organs to align their decisions with approved spatial plans, reducing policy conflicts and streamlining development. Similarly, the European Union's MSP Directive compels member states to coordinate across borders and adopt ecosystem-based planning approaches. India's legislation should similarly ensure that sectoral ministries—such as shipping, fisheries, energy, and tourism—are legally bound to conform to national MSP guidelines, and that Environmental Impact Assessments (EIAs) reflect cumulative and long-term spatial models.

Capacity-Building – Enhancements to Institutional and Human Capacity

- Effective MSP demands coordination among ministries such as Ministry of Earth Sciences (MoES), Ministry of Environment, Forest and Climate Change (MoEFCC), Ministry of Ports, Shipping and Waterways (MoPSW), Fisheries, Tourism, and Defense, as well as coastal state governments. India must develop a multi-tiered institutional architecture to support simulation-based Marine Spatial Planning (MSP). At the national level, an Inter-Ministerial MSP Committee—ideally chaired by NITI Aayog or the Prime Minister's

Office—should be established to align policies, facilitate inter-agency coordination, and prioritize marine governance. To localize implementation, dedicated MSP units should be created within each coastal state government, linked to the national committee, and supported by technical cells in key agencies like NCCR and NCSCM. These units must be staffed with trained marine planners, Geographic Information System (GIS) analysts, and simulation experts. Furthermore, a dedicated National Institute for Marine Spatial Planning should be established to drive cross-disciplinary training, host practitioner workshops, and facilitate stakeholder dialogue across sectors.

- **Justification:** Effective MSP requires both top-down coordination and bottom- up participation. Norway's integrated marine plans succeed by engaging local county officials and fishers, ensuring spatial strategies are grounded in local realities. India's coastal regions—ranging from the Sundarbans to Lakshadweep—face distinct ecological and socio-economic conditions that necessitate tailored planning. Creating state-level MSP units will allow region- specific implementation while feeding local data into national simulation models. A central training institute—akin to Canada's Ocean Management Research Network or the UNESCO-IOC's MSP Global training hubs—can build a cadre of marine planners proficient in Geographic Information System (GIS), modeling, and participatory methods.

Technology Investments – Advanced Tools, Open Data and Collaboration

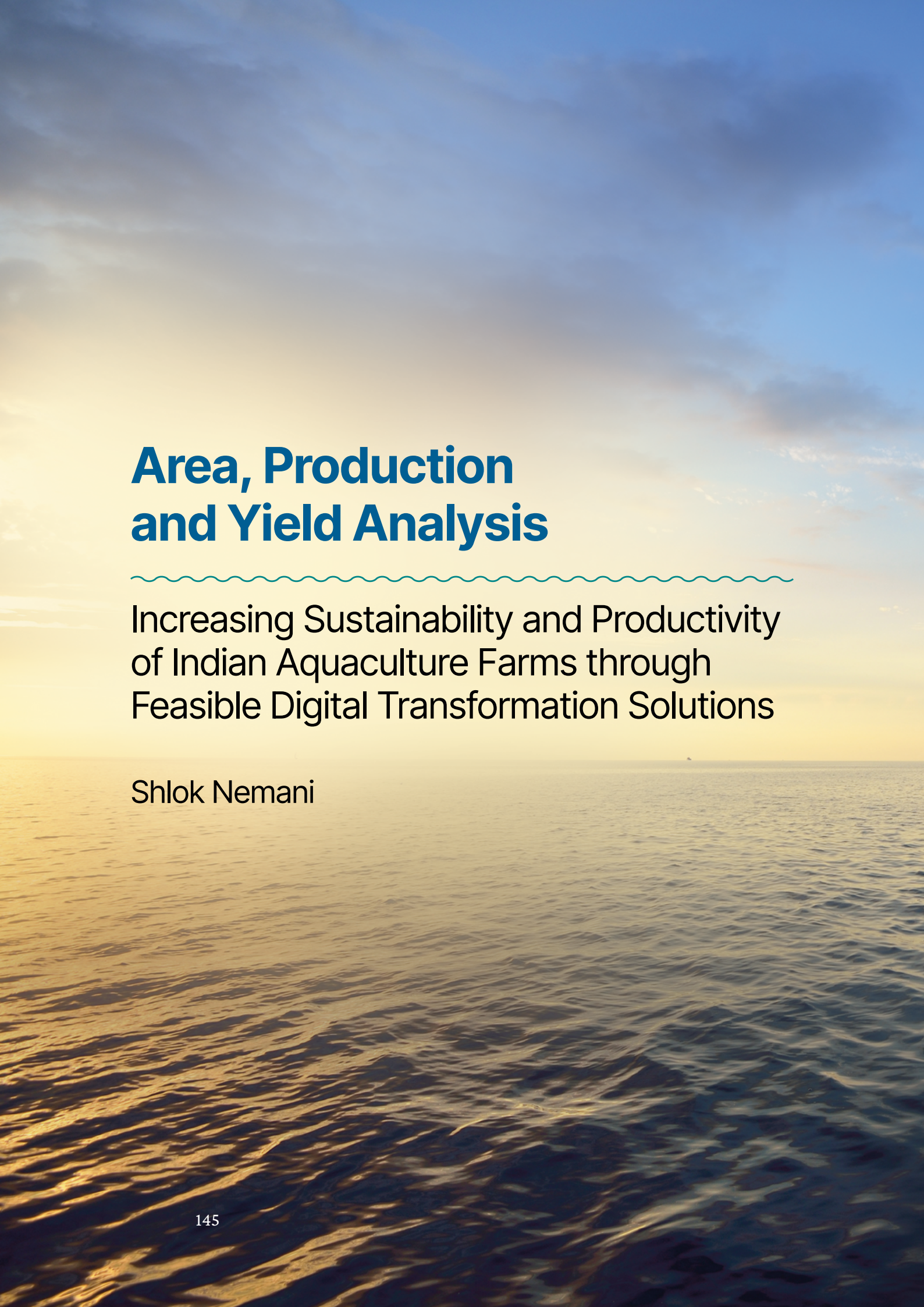
- India must significantly enhance its ocean observation systems and digital infrastructure to support a simulation-based MSP framework. This includes expanding the Digital Ocean platform, integrating modelling toolkits like Nir Dhwani's, and ensuring centralized access to real-time datasets—such as bathymetry, vessel traffic, and ecological indicators—through interoperable APIs. Development of a Digital Twin of the Indian Ocean should be prioritized, bringing together oceanographic, ecological,

and socio-economic models into a dynamic simulation environment. This will require scalable high-performance computing (HPC), cloud- based workflows, and Artificial Intenlligence-powered data assimilation pipelines. In parallel, India should promote community-led data collection by deploying low-cost sensors on fishing boats, establishing permanent underwater observatories, and participating in global efforts like the UN Decade of Ocean Science. Each of these recommendations works in tandem – legal backing, capacity building, and technological empowerment are all necessary to implement MSP effectively.

- **Justification:** A simulation-based MSP plan is only as effective as the data it consumes. India must focus not only on building domestic observation capabilities but also on connecting with global data ecosystems. Europe's European Marine Observation and Data Network (EMODnet) and Copernicus platforms, and the U.S. MarineCadastre.gov, offer models for open access, standardized marine data portals. Linking Digital Ocean to such global sources will enrich India's marine datasets with high- resolution maps, satellite observations, and regional forecasts. To build the Digital Twin, collaboration with National Oceanic and Atmospheric Administration (NOAA), NASA, and other international efforts will offer access to cutting-edge digital modelling techniques. Domestically, scaling High Performance Computing (HPC) infrastructure like the Tarang supercomputer and adopting cloud platforms can democratize access for universities and researchers running simulation models across the country. Importantly, cost-effective innovations such as community-sourced data—like Smart Fin in the U.S. or Argo floats— can bridge observational gaps in India's vast coastline. Engaging fishers and local stakeholders in sensing networks not only enhances spatial coverage but builds trust in the MSP process. Finally, promoting innovation challenges and public-private partnerships (akin to NOAA's coastal resilience grants) can spur localized apps and decision tools tailored for ports, communities, and conservation zones. These combined investments will create a robust, adaptive, and inclusive digital infrastructure for evidence-driven ocean planning in India.

CONCLUSION

Adopting a simulation-based Marine Spatial Planning approach in India is vital for the sustainable and secure development of its marine resources. As India's coasts and ocean economy face increasing pressures, the ability to anticipate and avert conflicts and environmental impacts before they escalate is a game-changer. International experiences show that when advanced modelling is combined with strong laws, capable institutions, and inclusive processes, marine governance becomes more adaptive and resilient. By implementing the improved policy measures suggested – from enacting robust MSP legislation and building multi-level capacity, to investing in cutting-edge open-data infrastructure – India can lead the Indian Ocean Region in modern ocean governance. These reforms will not only help balance economic growth with ecological protection, but also empower stakeholders with a transparent, science-driven framework. In sum, embracing simulation-based MSP now will pay dividends in healthier oceans, safer coastal communities, and a future-ready Blue Economy for India, validating the paper's vision with actionable steps toward sustainable ocean governance.



Area, Production and Yield Analysis

Increasing Sustainability and Productivity of Indian Aquaculture Farms through Feasible Digital Transformation Solutions

Shlok Nemani

BACKGROUND

India's seafood exports reached around Rs. 60,000 crores in FY 2023-24, driven by high-quality local production and rising global demand. Most of this supply comes from aquaculture (farmed fisheries). However, the industry faces challenges like low productivity and disease risks, largely due to limited farmer training in optimal farm management. To meet demand, there's been heavy reliance on expanding cultivation areas, which is unsustainable, especially in coastal regions where land is shared with agriculture and salt plains. To address this, a holistic approach called Area, Production and Yield (APY) analysis has been developed and discussed in this paper. The focus is on boosting farm productivity and improving management practices rather than expanding land use. This is achieved in two ways: (1) developing mathematical models to simulate culture growth under different environmental conditions, so as to provide the most optimal conditions for the growth and (2) integrating seaweeds into Indian shrimp aquaculture to improve water quality by absorbing nitrates and phosphates generated from shrimp waste. These efforts align with the goals of the *Pradhan Mantri Matsya Sampada Yojana* (PMMSY), which promotes sustainable aquaculture and increased productivity of aquaculture farms. Under PMMSY, the Indian government has set the seaweed production target of 1.2 million metric tons for FY 2025. The paper presents the involved methodology and showcases a framework to realise this digital transformation in a way, which is easily adaptable for farmers, provided there's adequate government support.

INTRODUCTION

India's extensive coastline of over 11,000 kilometres[123] and its strategic position in the Indian Ocean Region (IOR) underpin a robust blue economy that is vital for the nation's food security, livelihoods, and trade. The fisheries sector, a cornerstone of this economy, sustains approximately 30 million people, particularly within marginalized and vulnerable

123 Press Information Bureau. (22/11/24). CULMINATION OF PAN-INDIA COASTAL DEFENCE EXERCISE - 'SEA VIGIL 24', Accessed on 05/04/25, Retrieved from https://pib.gov.in/PressReleseDetailm.aspx?PRID=2076147

communities[124]. Notably, India ranks as the world's second-largest fish producer, contributing 8% to global fish production[125]. This sector not only ensures nutritional security but also significantly bolsters economic prosperity and rural development. Maritime trade further amplifies the importance of India's blue economy. Approximately 95% of India's trade by volume and 70% by value is conducted via maritime routes. The nation operates 12 major ports and around 200 smaller ports, collectively handling a substantial cargo throughput[126].

This extensive port infrastructure not only facilitates international commerce but also serves as a significant source of foreign exchange earnings. As reported by Marine Products Export Development Authority (MPEDA), during the financial year 2023-24, India exported 17,81,602 MT of Seafood worth ₹ 60,523.89 Crores[3]. The Indian Ocean itself is a critical conduit for global trade, with nearly 46% of the world's trade traversing its sea lanes[127].

India's strategic location along these routes enhances its role in international maritime commerce, providing opportunities to influence regional trade dynamics and security. Tourism, particularly coastal and marine-based, is another vital component of India's blue economy. The country's scenic beaches, rich marine biodiversity, and cultural heritage attract millions of domestic and international tourists annually, generating employment and contributing to foreign exchange reserves.

Despite these advantages, the blue economy's contribution to India's GDP is approximately 4%, which is relatively modest given the nation's vast maritime resources[128]. This indicates significant potential for growth through sustainable development practices. Emphasizing sustainability is crucial to prevent overexploitation of marine resources, ensure ecological

124 Press Information Bureau. (12/12/24). Year End Review 2024: Department of Fisheries (Ministry of Fisheries, Animal Husbandry and Dairying), Accessed on 05/04/25, Retrieved from https://pib.gov.in/PressReleseDetailm.aspx?PRID=2083813

125 Press Information Bureau. (12/12/24). Casting Nets, Catching Success; India's Fisheries on the Rise. Accessed on 05/04/25, Retrieved from https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2103444

126 Wikimedia Foundation. (16/04/24). Security and growth for all in the region (SAGAR). Wikipedia. Accessed on 02/04/25, Retrieved from https://en.wikipedia.org/wiki/Security_and_Growth_for_All_in_the_Region

127 Amoss, L. D. (17/11/24). India, Blue Economic Growth, and shared maritime security in the Indo-Pacific. orfonline.org. Accessed on 05/04/25, Retrieved from Ahttps://www.orfonline.org/english/expert-speak/india-blue-economic-growth-and-shared-maritime-security-in-the-indo-pacific

128 (PDF) Shenoi S. S. C. (25/01/24) Nurturing the blue economy: a call for sustainable ocean utilization, CURRENT SCIENCE, VOL. 126, NO. 2, Accessed on 05/04/25, Retrieved from https://incois.gov.in/documents/ResearchPapers/RP673.pdf

balance, and maintain the livelihoods of coastal communities. In response, the Indian government has initiated policies aimed at enhancing the blue economy's contribution to national development.

The "National Policy for India's Blue Economy-2021" outlines strategies to promote sustainable utilization of ocean resources, improve coastal infrastructure, and bolster marine research and development[129]. These initiatives aim to balance economic growth with environmental sustainability, ensuring long-term benefits for coastal populations and the broader economy. The Blue economy framework of India highlights the contribution of 4% to India's GDP from Blue economy related activities, while recognising the potential for exponential growth. The 11,000 Km coastline, an Exclusive Economic Zone (EEZ) of 2.02 million sq. km, and about 1,382 islands, offers immense marine resource potential.

It also brings out the need for innovations like marine biotechnology, ocean energy, and Marine (and Maritime) Domain Awareness (MDA) to tap into emerging sectors. Investment in deep ocean exploration and seabed mining, including Deep Ocean Mission as a priority. It highlights the requirement for inclusive growth, noting that over 3 million people in India are directly dependent on marine fisheries.

Integrating artisanal fishers, coastal women, and tribal communities into value chains is emphasized, supported by targeted skilling, financial access, and infrastructure. Technological innovations such as IoT in ports, improved data Collection (by Launching *data buoys* across the coastline), software for satellite surveillance for fisheries, and usage of Artificial Intelligence and Machine Learning for marine spatial planning are seen as enablers for inclusive participation. Climate-resilient infrastructure and community-based disaster risk reduction are key to ensuring that growth does not exclude vulnerable coastal populations.

India's SAGAR Vision to Nurture Sustainable Blue Economy

Prime Minister Narendra Modi introduced the concept of SAGAR, which stands for "Security and Growth for All in the Region," during a visit to Mauritius on March 12,

129 Economic Advisory Council, Government of India. (2021) India's Blue Economy: A draft policy framework. Indian National Centre for Ocean Information Services (INCOIS). Accessed on Retrieved from https://incois.gov.in/documents/Blue_Economy_policy.pdf

2015. This vision underscores India's commitment to fostering cooperative and sustainable maritime practices in the Indian Ocean Region (IOR) and aligns with India's broader maritime strategy, including the "Act East" policy, and reflects its aspirations to be a net security provider in the region[130]. The core objectives of the SAGAR vision include:

- **Enhancing Maritime Security:** Ensuring a climate of trust and transparency in the IOR, with respect for international maritime rules and norms by all countries.
- **Building Regional Cooperation:** Deepening economic and security cooperation among IOR nations to facilitate smooth economic trade and maritime security.
- **Promoting Collective Action:** Encouraging collective responses to natural disasters and maritime threats such as piracy and terrorism.
- **Sustainable Development:** Advocating for sustainable utilization of marine resources to ensure ecological balance and economic growth.

Over the past decade, the SAGAR vision has been operationalized through various initiatives, reflecting India's proactive role in the IOR. For instance, the Indian Navy's deployment of the Indian Ocean Ship (IOS) SAGAR, with personnel from nine friendly nations, exemplifies India's commitment to regional peace, prosperity, and collective security[131]. In March 2025, marking the 10th anniversary of SAGAR, Prime Minister Modi introduced the "MAHASAGAR" vision, an acronym for "Mutual and Holistic Advancement for Security and Growth Across Regions"[132]. This new policy aims to extend the principles of SAGAR to the broader Global South, emphasizing collaborative growth and security beyond the Indian Ocean.

Introduction to Underwater Domain Awareness

Underwater Domain Awareness (UDA) is an emerging strategic framework that addresses the need to monitor, understand, and sustainably

130 Press Information Bureau. (05/04/25). Raksha Mantri flags-off INS Sunayna as Indian Ocean Ship SAGAR from Karwar with 44 personnel of nine friendly nations of Indian Ocean Region, Accessed on 05/04/25, Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=2119246

131 Press Trust of India (12/03/25). PM Modi announces India's Mahasagar Vision for Global South. The Pioneer. Accessed on 05/05/25, Retrieved from: https://www.dailypioneer.com/2025/top-stories/pm-modi-announces-india-s-mahasagar-vision-for-global-south.html

132 Murtugudde, R., & Annamalai, H. (2004). Role of the Indian Ocean in regional climate variability. Geophysical monograph, 147, 213-246.

utilize the undersea environment. Given the growing relevance of the maritime domain for economic and strategic interests, particularly in the Indian Ocean Region (IOR), UDA aims to provide a comprehensive understanding of underwater activities, resources, and threats. India, with its vast coastline and evolving blue economy, requires a robust mechanism for undersea situational awareness that supports security, environment, and policy goals. The UDA framework advocates for a multi-stakeholder approach involving the Navy, maritime industry, marine scientific community, and policymakers. This is essential not only for military preparedness—such as tracking undersea threats and protecting sea lines of communication—but also for supporting civilian applications like disaster warning, marine biodiversity conservation, Marine Spatial Planning (MSP) and sub-sea resource mapping. Current gaps in underwater sensing, particularly in tropical littoral waters, make it imperative to develop indigenous technology and institutional capacity. The UDA framework thus offers a holistic model, aligned with India's SAGAR (Security and Growth for All in the Region) vision, to transform maritime governance through strategic and sustainable underwater awareness[133] [134].

UDA as a Key Enabler for Implementing SAGAR

The Underwater Domain Awareness (UDA) Framework, a broader aspect of the Maritime Domain Awareness Framework (MDA)[135] can act as a powerful enabler for India's SAGAR vision, providing the strategic and operational foundation required to secure and sustainably harness the nation's vast aquatic domains. By promoting a multi-stakeholder, technology-enabled, and inclusive framework for comprehending and managing the underwater domain, the UDA Framework ensures a cohesive approach to maritime

133 Verma, K. (2024, June 12). Indian Council of World Affairs. Underwater Domain Awareness: Challenges and Opportunities for India. Retrieved from https://www.icwa.in/show_content.php?lang=1&level=3&ls_id=10959&lid=6965

134 (PDF) Das A. (2024) Maritime Research Center. Underwater Domain Awareness (UDA) Framework. Accessed on 05/04/25. Retrieved from https://maritimeresearchcenter.com/wp-content/uploads/2024/04/Underwater-Domain-Awareness.pdf

135 Das H. (2021) Maritime Domain Awareness in India: Shifting Paradigms. National Maritime Foundation. Accessed on 05/04/25. Retrieved from https://maritimeindia.org/maritime-domain-awareness-in-india-shifting-paradigms/

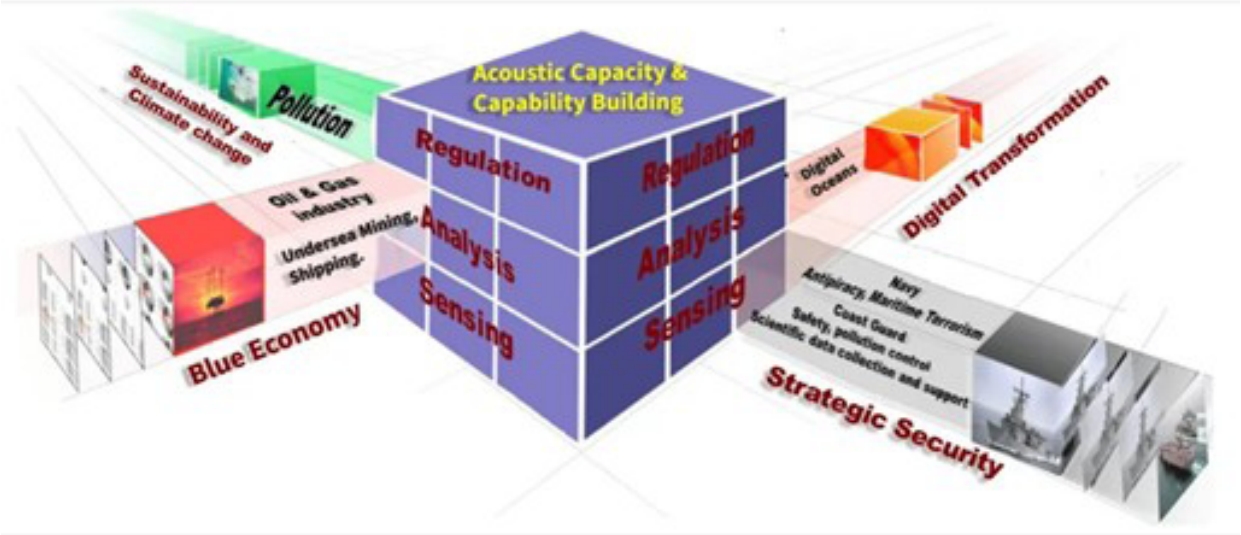


Fig. 1. The multifaceted Underwater Domain Awareness Framework proposed by Maritime Research Center (MRC) Pune. (Maritime Research Center (2025). UDA Framework Accessed on 05/04/25. Retrieved from https://udafoundation.in/)

security, resource governance, and environmental sustainability—positioning itself as a vital tool for policymakers in informed decision-making processes. It empowers defense forces with critical acoustic capabilities to detect and counter underwater threats, thereby securing Sea Lines of Communication (SLOCs) and coastal assets. Simultaneously, it supports the blue economy by guiding sustainable exploitation of underwater resources like fisheries as well as underwater minerals (including polymetallic nodules), and by ensuring navigability for maritime trade and inland water transport. UDA also contributes to climate risk mitigation and ecological conservation by enabling accurate monitoring of underwater habitats and geophysical activities.

Through its four-dimensional structure—Strategic Security, Blue Economy, Environmental Sustainability (and climate change), and Digital Transformation—UDA aligns diverse national efforts under one coherent framework. This integration minimizes fragmentation among ministries, agencies, and communities, enhancing governance, capacity building, and policy implementation. Hence, the UDA Framework offers a comprehensive lens through which the integration of science, research, and technology

enhances our understanding of the underwater domain. In doing so, it acts as a strategic force multiplier, advancing the core objectives of the SAGAR vision—namely regional stability, sustainable economic development, and environmental preservation[11].

SIGNIFICANCE OF TROPICAL WATERS AND THE UNIQUE CHARACTERISTICS

Tropical waters, spanning between the Tropic of Cancer and Capricorn, play a pivotal role in global maritime trade, blue economy development, and geopolitical stability. These regions host some of the world's busiest shipping lanes, including the Indian ocean region, which facilitate over 75% of global maritime trade and Malacca strait, a vital part of Indo-pacific, facilitating over 60% of global maritime trade[136]. The warm, ice-free waters enable year-round navigation, reducing logistical costs compared to temperate routes. However, tropical cyclones and monsoon winds pose significant risks to shipping, causing an estimated $3 billion in annual trade disruptions[137]. The blue economy in tropical nations relies heavily on these waters for fisheries, tourism, and energy. Coral reefs, which are predominantly tropical, support $375 billion in economic activity annually through tourism and coastal protection[138]. Meanwhile, 90% of the world's tuna catch comes from tropical Pacific and Indian Ocean waters, sustaining livelihoods in Small Island Developing States (SIDS)[139]. Demographically, tropical coastal zones host 40% of the global population, with many megacities (e.g., Mumbai, Jakarta) within the vicinity of the waters, dependent on marine resources[140]. Yet, these

136 Pitakdumrongkit K. (2023). The Strait of Malacca's Impact on Regional Trade. The National Bureau of Asian Research. Accessed on 05/04/25. Retrieved from https://www.nbr.org/publication/geoeconomic-crossroads-the-strait-of-malaccas-impact-on-regional-trade/

137 Peduzzi, P., Chatenoux, B., Dao, H., De Bono, A., Herold, C., Kossin, J., Mouton, F., & Nordbeck, O. (2012). Global trends in tropical cyclone risk. Nature Climate Change

138 Spalding, M., Burke, L., Wood, S. A., Ashpole, J., Hutchison, J., & zu Ermgassen, P. (2017). Mapping the global value and distribution of coral reef tourism. Marine Policy, 82, 104-113

139 Bell, J. D., Allain, V., Allison, E. H., Andréfouët, S., Andrew, N. L., Batty, M. J., Blanc, M., Dambacher, J. M., Hampton, J., Hanich, Q., Harley, S., Lorrain, A., McCoy, M. A., McTurk, N., Nicol, S., Pilling, G., Sharp, M. K., Vivili, P., & Williams, P. (2015). Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. Marine Policy, 51, 584-591

140 Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment. PLOS ONE, 10(3), e0118571

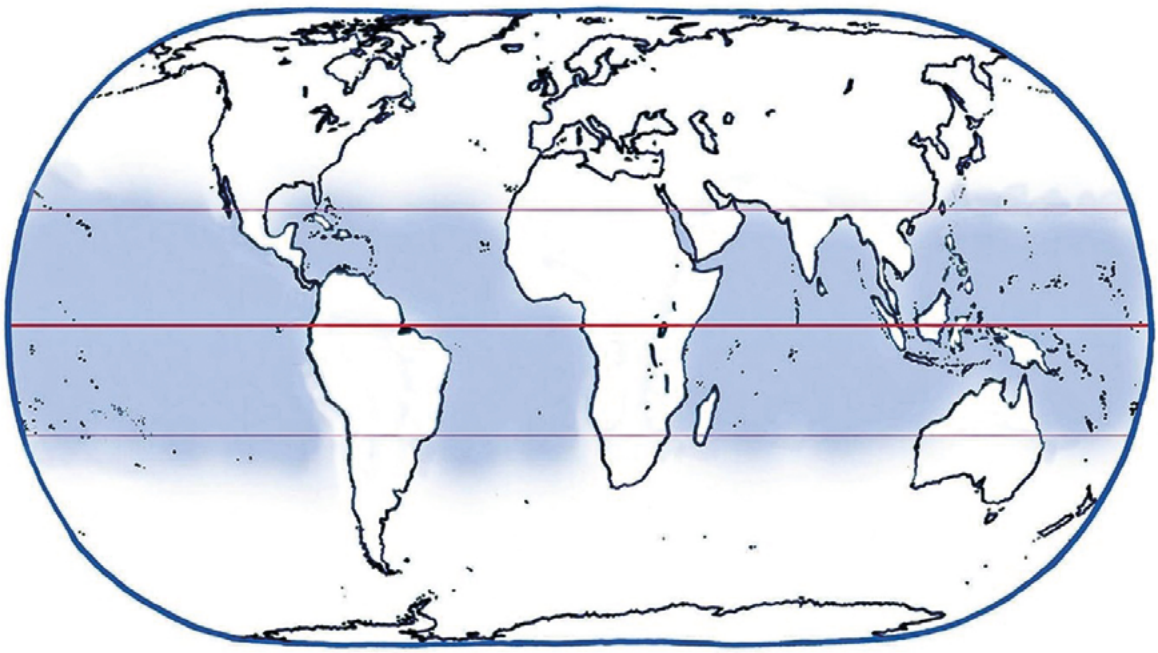


*Fig. 2. The Tropical Oceans shown on the World map (in blue highlight). Indian Ocean Region (IOR) events shows characteristics of Tropical climate. (*Tropical Open Oceans. Ecosystem Guides. Accessed on 05/04/25. Retrieved from https://www.ecosystem-guides.com/tropical-open-ocean.html)

regions face disproportionate climate impacts—rising sea levels threaten $1 trillion in coastal infrastructure by 2050[141] and erratic climatic patterns risking the self-sufficiency of food production in these regions[142].

Tropical regions, particularly nations like India, Indonesia, the Philippines, Bangladesh, Vietnam, and Ecuador, are pivotal in global fish and shrimp production, significantly contributing to their economies and livelihoods. India stands as the world's second-largest fish producer, with an annual output of approximately 9.58 million tons, generating export revenues around USD 7.5 billion[3][143]. The sector employs about 30 million individuals, underscoring its economic and social importance. Indonesia ranks fourth globally in aquaculture production, yielding an estimated 14.4 million tons in 2014. Key exports include shrimp, fish, and seaweed, bolstering the nation's economy and providing substantial

141 Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. Nature Climate Change, 3(9), 802-806.

142 Global Climate and Health Alliance. (2025) How rising sea levels are threatening the food security and health of coastal communities. Accessed on 05/04/25. Retrieved from https://climateandhealthalliance.org/article/how-rising-sea-levels-are-threatening-the-food-security-and-health-of-coastal-communities/

143 Wikimedia Foundation. Fishery Survey of India. Accessed on 05/04/25. Retrieved from https://en.wikipedia.org/wiki/Fishery_Survey_of_India

employment opportunities[144]. The Philippines produced 826,010 tons of aquaculture products in 2018, valued at USD 1.89 billion, accounting for 41.82% of its fisheries' value[145]. Notably, shrimp farming, particularly of tiger prawns, has been a significant contributor, though challenges like disease outbreaks have impacted production. Bangladesh has seen its hilsa fish production rise from 299,000 ns in 2008–09 to 550,000 tons in 2019–20, contributing approximately 1% to the national GDP. This sector supports around 2.5 million people, emphasizing its role in employment and economic stability[146]. Vietnam is among the top shrimp exporters globally, with the industry playing a crucial role in its economy. However, shrimp farmers have faced challenges due to the pursuit of lower wholesale prices by large Western supermarkets, leading to reduced earnings and labour issues[147]. Ecuador has emerged as the world's largest shrimp exporter, adopting an industrial approach to shrimp farming[148].

Collectively, these nations highlight the critical intersection of aquaculture with economic development and livelihoods in tropical regions. While these figures reflect significant economic contributions, critical gaps remain—ranging from inadequate infrastructure and disease management to sustainability challenges and labour exploitation. Weak regulatory oversight and limited access to technology further hinder inclusive growth, threatening long-term viability and equitable benefit-sharing across communities dependent on the sector for their livelihoods.

Gaps in the Fisheries Industry

In tropical regions, fisheries productivity is often hindered by overfishing, habitat degradation, and climate change. Overfishing depletes fish stocks, leading to reduced catches and income for fishers. Habitat degradation, such as the destruction

144 Wikimedia Foundation. Aquaculture in Indonesia. Accessed on 05/04/25. Retrieved from https://en.wikipedia.org/wiki/Aquaculture_in_Indonesia

145 Wikimedia Foundation. Fisheries in the Philippines. Accessed on 05/04/25. Retrieved from https://en.wikipedia.org/wiki/Fisheries_in_the_Philippines

146 Wikimedia Foundation. Ilish (Hilsa Fish). Accessed on 05/04/25. Retrieved from https://en.wikipedia.org/wiki/Ilish

147 Rising D. (2024). As big supermarkets pursue profits, new research shows growing exploitation of shrimp farmers. AP News. Accessed on 05/04/25. Retrieved from https://apnews.com/article/shrimp-workers-exploitation-vietnam-indonesia-india-supermarket-d29e3c24a1a20d3815f5418829a6bbe9

148 Piedrahita Y. (2018). Shrimp farming industry in Ecuador. Global Seafood Alliance. Accessed on 05/04/25. Retrieved from https://www.globalseafood.org/advocate/shrimp-farming-industry-in-ecuador-part-1/

of mangroves and coral reefs, further diminishes fish populations. Climate change exacerbates these issues by altering ocean temperatures and currents, affecting fish distribution and breeding patterns. Disease outbreaks significantly impact aquaculture in tropical nations. High-density farming practices facilitate the rapid spread of pathogens, leading to substantial economic losses[149]. For instance, the Early Mortality Syndrome (EMS) in shrimp has caused crop failures for numerous producers in Asia and Latin America. Similarly, the Tilapia Lake Virus has affected production in several countries. In India, bacterial and parasitic infections are prevalent in freshwater aquaculture, often resulting in decreased fish survival rates[150]. The White Spot Syndrome Virus (WSSV) caused widespread mortality in shrimp farms across Asia, including India, in the 1990s[151]. The lack of advanced diagnostic tools and effective disease management strategies exacerbates these challenges. Thus, the fisheries sector faces several challenges, including productivity issues, disease outbreaks, supply chain constraints, and environmental concerns.

DISTURBING THE DELICATE BALANCE

The expansion of aquaculture, particularly shrimp farming, has significantly contributed to social imbalances and the degradation of vital coastal ecosystems like mangroves and coral reefs. Over the past 50 years, approximately 20-35% of the world's mangrove forests have been lost, with aquaculture development identified as a major driver (more than 50% contribution) of this decline[152]. In tropical regions, aquaculture accounts for over 38% of all mangrove destruction, exacerbating environmental vulnerabilities[153].

149 Irshath, A. A., Rajan, A. P., Vimal, S., Prabhakaran, V. S., & Ganesan, R. (2023). Bacterial Pathogenesis in Various Fish Diseases: Recent Advances and Specific Challenges in Vaccine Development. Vaccines, 11(2), 470. https://doi.org/10.3390/vaccines11020470

150 IDH – The Sustainable Trade Initiative. (2024). Disease management to achieve sustainability goals in tropical aquaculture has a clear business case. Accessed on 05/04/25. Retrieved from https://idh.org/news/disease-management-to-achieve-sustainability-goals-in-tropical-aquaculture-has-a-clear-business-case

151 Wikimedia Foundation. (2024). White spot syndrome virus. Wikipedia. Accessed on 02/04/25, Retrieved from https://en.wikipedia.org/wiki/White_spot_syndrome

152 Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human‐driven mangrove loss. Global Change Biology. doi:10.1111/gcb.15275

153 McSherry M, Davis RP, Andradi-Brown DA, Ahmadia GN, Van Kempen M and Wingard Brian S (2023) Integrated mangrove aquaculture: The sustainable choice for mangroves and aquaculture? Front. For. Glob. Change 6:1094306. doi: 10.3389/ffgc.2023.1094306

Shrimp farming, while economically lucrative, presents several significant environmental challenges. One major concern is farm abandonment, often caused by the ecological degradation of ponds due to disease outbreaks and organic pollution. These abandoned farms not only represent economic loss but also contribute to long-term environmental damage and land-use issues[154]. Another critical issue is the discharge of wastewater into adjacent ecosystems. Effluents from shrimp ponds, rich in organic matter and nutrients, can lead to eutrophication, disrupting aquatic ecosystems by depleting oxygen levels and promoting harmful algal blooms, as observed in coastal regions of Eastern China[155]. The use of farm bedding and chemicals, including antibiotics, lime, and fertilizers, further exacerbates the problem. These substances can leach into the ground, contaminating groundwater and leading to salinization, which affects drinking water sources and agricultural productivity, as reported by the individuals from Ratnagiri district of Maharashtra State, India[156]. Additionally, the high volume of water withdrawals necessary for farm maintenance puts pressure on local freshwater resources, often leading to resource conflicts in water-scarce areas[36]. Collectively, these impacts highlight the urgent need for sustainable practices and stricter regulatory controls in the shrimp aquaculture sector.

INEQUALITIES BETWEEN LARGE-SCALE AND SMALL-SCALE FARMERS

Tradition farming practices are deeply rooted in cultural norms and historical knowledge, and small famers may perceive modern technologies as complex, capital-intensive, or threatening to their autonomy. Resistance to change, coupled with limited access to education and training, perpetuates low productivity and higher vulnerability to environmental shocks. Additionally, the rise of large-scale shrimp farming

154 Flaherty, M., & Vandergeest, P. (1998). "Low-salinity shrimp farming in Thailand." Ambio, 27(8), 663–668

155 Lin, C. K., Lin, K. J., & Lin, S. H. (2003). "Impact of intensive shrimp farming on the water quality of adjacent coastal creeks from Eastern China." Environmental Pollution, 123(2), 231–244.

156 Patil, D. N., Shinde, L. P., & Sable, P. R. (2019). "Environmental impacts of shrimp farming with special reference to groundwater quality in Ratnagiri, India." Applied Water Science, 9(4), 1–12. https://doi.org/10.1007/s13201-019-1097-3

operations has exacerbated inequities. Recent case studies highlight significant disparities between large-scale and small-scale fishers in terms of production volumes, economic returns, and influence over policy decisions. In India, mechanized fishing vessels, representing the large-scale sector, accounted for 82% of the total catch in 2022, amounting to 2.85 million tons. In contrast, non-motorized, small-scale fishers contributed merely 1% of the total landings, approximately 0.04 million tons. This stark difference underscores the challenges faced by small-scale fishers in maintaining their livelihoods amid the dominance of industrial fishing operations[157].

Industrial farms often dominate market dynamics, leading to reduced bargaining power for smallholders. Large-scale farmers benefit from economies of scale, superior technologies, and preferential access to resources such as land, water, and capital. This has pushed smaller farmers into economic marginalization and heightened pressure to compete on unfair terms. Social stratification within farming communities has also intensified due to the expansion of industrial aquaculture. Wealthier farmers, often politically connected, influence local policies, leaving smallholders with limited access to decision-making processes.

Policy influence further exacerbates these disparities. The flagship scheme of Indian government for the communities involved in fisheries, that is Pradhan Mantri Matsya Sampada Yojana (PMMSY), is launched in 2020 with the target investment of ₹20,050 crore for the fisheries sector. This scheme has been criticized for favouring large-scale industrial fishing. The focus on machinery and infrastructure development and industrialized fishing under PMMSY[158] has raised apprehensions about the potential neglect of small-scale fishers' needs and the sustainability of their livelihoods. While the scheme aims to address critical gaps in the fisheries value chain, traditional and small-scale fishers have expressed concerns about being marginalized in policy-making processes and resource allocation.

157 Good Food Movement. (2024) India urgently needs to rethink its fishing policy. Accessed on 05/04/25. Retrieved from https://gfm.akshayakalpa.org/read/feature-article/india-needs-to-rethink-its-fishing-policy

158 (PDF) Department of Fisheries (2021). Guidelines on Formation and Promotion of Fish Farmer Producer Organizations (FFPOs). Accessed on 05/04/25. Retrieved from https://www.ncdc.in/documents/notice-circular/3218280721FFPOs-Guidelines.pdf

Climatic Variability and Extreme Climatic Events

Tropical waters, such as those surrounding the Indian subcontinent, are governed by complex ocean-atmosphere interactions that give rise to distinctive climate phenomena. These include strong seasonal monsoons, elevated sea surface temperatures, and frequent cyclonic activity, all of which are modulated by intraseasonal and interannual variability. The Indian Ocean's role in driving the South Asian monsoon system is particularly critical, with even subtle changes in oceanic conditions producing significant shifts in rainfall patterns. In recent decades, anthropogenic climate change has exacerbated this variability, resulting in more erratic monsoons, rising sea levels, and an increase in the intensity of tropical cyclones—especially over the Bay of Bengal[38].

One such instance was of Cyclone (or 'Super Cyclone') Amphan, which struck in May 2020[159], exemplifies the escalating climate variability in the Indian Ocean region, profoundly impacting coastal communities, particularly fishermen. In Odisha, approximately 19,200 fishermen faced a cumulative employment and income loss estimated at ₹7.68 crore due to a mandated cessation of fishing activities from May 15 to 25[160]. The cyclone also inflicted significant damage on fishing infrastructure, including the partial destruction of *Paradeep Fishing Harbour* and severe damage to *Dhamara Fishing Harbour*, amounting to losses of around ₹12 lakh. In West Bengal's North and South 24 Parganas districts, saltwater intrusion devastated freshwater fish ponds, leading to losses exceeding ₹1,500 crore in fish production[161].

Bangladesh's southwestern coastal regions—especially *Khulna*, *Satkhira*, and *Bagerhat*—have faced repeated devastation from tropical cyclones, significantly affecting communities dependent on shrimp farming. Cyclone Aila in 2009 exemplified this challenge: tidal surges breached embankments, submerging shrimp ponds with saline water and rendering large swaths

159 Press Information Bureau. (19/05/20). Super Cyclonic Storm 'AMPHAN' over West central Bay of Bengal: Cyclone Warning for West Bengal and north Odisha coasts: Orange Message, Accessed on 02/04/25, Retrieved from https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=1625146

160 Raju, S & Roul, Subal & Das, Chandra & Ghosh, Shubhadeep & Kumar, R. (2020). Impact of Cyclone Amphan on marine fisheries of Odisha

161 Chaudhuri S. (26/05/20). Fish growers in neck-deep losses, The Telegraph Online, Accessed on 02/04/25, Retrieved from https://www.telegraphindia.com/west-bengal/cyclone-amphan-in-west-bengal-fish-growers-in-neck-deep-losses/cid/1776140

of land unproductive. Thousands of farmers lost their entire harvests and, in many cases, the capacity to farm in future seasons due to increased soil salinity. For many smallholders, the economic shock was severe—loss of income, rising debts, and damaged infrastructure left families destitute. As aquaculture was their primary livelihood, many were forced to migrate to urban areas or take up low-paying labor. Recovery was slow and unequal; wealthier farmers were often able to reinvest and rebuild, while poorer communities lacked access to credit or government support[162].

These dynamics pose acute challenges for coastal nations like India, and its maritime neighbours, where a significant portion of the population depends on climate-sensitive sectors such as agriculture and fisheries. Coastal communities face heightened vulnerability due to sea-level rise, coastal erosion, saltwater intrusion, and the disruption of marine ecosystems. The confluence of high population density, limited adaptive infrastructure, and exposure to tropical hazards underscores the urgent need for improved prediction systems, localized climate services, and sustainable coastal planning across the Indian coastline.

Global Warming

Global warming significantly impacts tropical nations, exacerbating environmental and socioeconomic challenges. In the tropical Americas, temperature increases are projected to rise by at least 2°C by 2050, leading to shifts in forest biomes and species composition, thereby threatening biodiversity and ecosystem services[163]. Economically, developing countries in tropical regions face substantial GDP losses due to climate change, with projections indicating a median decrease of 13% under a 2°C warming scenario, highlighting the vulnerability of these economies to climatic shifts[164]. Furthermore, climate change intensifies tropical cyclones, resulting in increased rainfall and sea-level rise, which exacerbate flooding and infrastructure

162 Ashrafuzzaman M, Artemi C, Santos FD and Schmidt L (2022) Current and Future Salinity Intrusion in the South-Western Coastal Region of Bangladesh. Span. J. Soil Sci. 12:10017. doi: 10.3389/sjss.2022.10017

163 Diffenbaugh, N. S., & Burke, M. (2023). Global warming has increased global economic inequality. Proceedings of the National Academy of Sciences, 120(14), e2026117119. https://doi.org/10.1073/pnas.2026117119

164 Esquivel-Muelbert, A., Baker, T. R., Dexter, K. G., Lewis, S. L., Brienen, R. J. W., Feldpausch, T. R., ... & Phillips, O. L. (2024). Tropical forests in the Americas are changing too slowly to track climate change. Science, 375(6577), 1501-1504. https://doi.org/10.1126/science.adl5414

damage in coastal tropical areas[165]. Additionally, urban centres in tropical climates experience amplified heat due to the combined effects of global warming and urbanization, leading to higher temperatures that adversely affect public health and energy consumption[166]. These multifaceted impacts underscore the urgent need for comprehensive mitigation and adaptation strategies tailored to the unique vulnerabilities of tropical nations.

IUU Fishing Activities

While Exclusive Economic Zones (EEZs) gave coastal nations control over most fish resources, many lacked the resources to manage them effectively. By the late 1980s, overfishing and unregulated fishing rose as a major concern for the world. The FAO developed a Code of Conduct for Responsible Fisheries, offering a framework of principles for sustainable fishing practices. Adopted on October 31, 1995, this FAO Code provides the necessary structure for both national and international endeavours to coordinate effectively, aiming to promote the sustainable utilization of marine resources[167]. FAO also developed a global plan, the International Plan of Action (IPOA-IUU), to fight illegal, unreported, and unregulated fishing activities, which was accepted in 2001 by Committee focused on fisheries (COFI)[168]. The Plan of action offered a diverse range of measures applicable to various situations, targeting not only governments (coastal states, port states, and flag states) but also industry stakeholders (fishers, NGOs, and markets). The IPOA also gave the crucial responsibility on the nations to curate respective National Plan of Action (NPOA) addressing their region, market, coastal and port specific concerns[169] [170].

165 Knutson, T. R., Sirutis, J. J., Zhao, M., Tuleya, R. E., Bender, M., Vecchi, G. A., ... & Villarini, G. (2022). Global projections of intense tropical cyclone activity for the late twenty-first century from dynamical downscaling of CMIP6 models. Journal of Climate, 35(3), 857-875. https://doi.org/10.1175/JCLI-D-21-0213.1

166 Estrada, F., Botzen, W. J. W., & Tol, R. S. J. (2021). A global economic assessment of city policies to reduce climate change impacts. Nature Climate Change, 11(9), 834-840. https://doi.org/10.1038/s41558-021-01168-3

167 Code of Conduct for Responsible Fisheries, 1995, Food and Agricultural Organization (FAO) Accessed on 05/04/25. Retrieved from https://openknowledge.fao.org/server/api/core/bitstreams/4a456053-db08-4362-875a-2fdc723c1346/content

168 Food and Agricultural Organization (FAO), What is IUU Fishing? Accessed on 05/04/25. Retrieved from https://www.fao.org/iuu-fishing/background/what-is-iuu-fishing/en/

169 FAO. International Plan of Action to prevent, deter and eliminate illegal, unreported and unregulated fishing. Rome, FAO. 2001. 24p Accessed on 05/04/25. Retrieved from https://openknowledge.fao.org/handle/20.500.14283/y1224e

170 Food and Agricultural Organization (FAO) Committee on Fisheries, International Plan of Action - Illegal, Unreported and Unregulated (IPOA-IUU) Fishing (1999), Accessed on 05/04/25. Retrieved from https://www.fao.org/iuu-fishing/international-framework/ipoa-iuu/en/

Indigenous innovation is crucial for enhancing maritime security and advancing the blue economy, particularly for tropical nations like India and other Small Island Developing States (SIDS). Rather than relying on the service providers, developing homegrown technologies and solutions fosters self-reliance, reduces dependency on foreign systems, and ensures that strategies are tailored to specific regional challenges.

Still today, FAO estimates that IUU fishing accounts for up to $23 billion annually, severely impacting economies and ecosystems, particularly in developing coastal nations[171]. In the Caribbean region, IUU fishing constitutes approximately 20 to 30 percent of total fish landings, valued between $700 million and $930 million, exacerbating the overexploitation of 40 percent of commercially harvested stocks[172]. According to the FAO's 2022 assessment, only 64.6 percent of global fishery stocks were within biologically sustainable levels, a decline from previous years, highlighting the ongoing pressures from overfishing and IUU activities[173].

OPPORTUNITIES

Despite the pressing challenges, tropical nations hold immense untapped potential within their blue economies. Rich in marine biodiversity, strategic maritime routes, and youthful coastal populations, these regions offer significant opportunities for sustainable fisheries, eco-tourism, renewable ocean energy, and inclusive growth—positioning them as key drivers of future ocean-based prosperity.

171 Wilcox, C., Mann, V., Cannard, T., Ford, J., Hoshino, E and Pascoe, S. 2021. A review of illegal, unreported and unregulated fishing issues and progress in the Asia-Pacific Fishery Commission region. Bangkok and Hobart, FAO.

172 FAO. (2023). Combatting Illegal, Unreported and Unregulated (IUU) Fishing in the wider Caribbean. Accessed on 05/04/25. Retrieved from https://www.fao.org/americas/news/news-detail/Combatting-Illegal-Unreported-and-Unregulated-%28IUU%29-Fishing-in-the-wider-Caribbean/en

173 FAO. (2022). The state of world fisheries and aquaculture. Accessed on 05/04/25. Retrieved from https://openknowledge.fao.org/server/api/core/bitstreams/9df19f53-b931-4d04-acd3-58a71c6b1a5b/content/sofia/2022/status-of-fishery-resources.html

Seaweeds are emerging as one of the most versatile and sustainable marine resources, offering solutions across multiple Sustainable Development Goals (SDGs). According to the UNCTAD report , seaweeds can be used for food, livestock and aquatic feed, pharmaceuticals, nutraceuticals, biofertilizers, textiles, bioplastics, cosmetics, and even as sustainable building materials.

Promotion of Indigenous Innovations

Indigenous innovation is crucial for enhancing maritime security and advancing the blue economy, particularly for tropical nations like India and other Small Island Developing States (SIDS). Rather than relying on the service providers, developing homegrown technologies and solutions fosters self-reliance, reduces dependency on foreign systems, and ensures that strategies are tailored to specific regional challenges. This approach not only strengthens national security but also stimulates the domestic defence industry, promoting economic growth and technological advancement. For SIDS, indigenous innovations are vital for sustainable development. By integrating traditional knowledge with modern practices, these nations can create culturally relevant and effective solutions to local challenges. Under MDA Initiatives, Navy has proactively pursued self-reliance and indigenization to modernize its forces and maintain combat readiness[174]. This integration enhances resilience, supports sustainable livelihoods, and preserves cultural heritage, all of which are critical for long-term viability. Furthermore, fostering indigenous innovation in maritime sectors allows these nations to harness their unique marine resources effectively. By investing in local research and development, they can develop sustainable practices that balance economic growth with environmental conservation[175]. This approach not only

174 Shah K. (2022). Indian Navy on the Course of Indigenisation. Indian Aerospace and defence bulletin. Accessed on 05/04/25. Retrieved from https://www.iadb.in/2022/05/03/indian-navy-on-course-for-indigenisation-vadm-sn-ghormade-vcns-speaks-to-iad/

175 (PDF) UNDP. Rising up for the SIDS. Accessed on 05/04/25. Retrieved from https://www.undp.org/sites/g/files/zskgke326/files/migration/bb/undp-bb-Full_SIDS-Offer-Rising-Up-for-SIDS.pdf

The Government of India's Blue Economy Policy highlights seaweed mariculture as a key component for expanding the Blue Revolution. It identifies seaweed and algae harvesting as important emerging areas under aquaculture and mariculture. The policy proposes promotion through a comprehensive National Mariculture Policy, with focus on sustainable marine capture, algae production, to provide alternate source of livelihood in a sustainable manner.

bolsters the blue economy but also positions these nations as leaders in sustainable maritime practices.

Promotion of Seaweed Farming for SDGs, Triple Bottom Line and Achieving Sustainable Prosperity for All

Reducing land reliance in agriculture has become crucial due to multiple challenges such as land degradation, freshwater scarcity, climate change, and food security concerns. Intensive farming has led to over-exploitation of land, decreased soil fertility, and increased greenhouse gas emissions. Agriculture already consumes over 70% of freshwater resources, and expanding farmlands to meet growing food demands threatens biodiversity and natural ecosystems[176]. Seaweeds are emerging as one of the most versatile and sustainable marine resources, offering solutions across multiple Sustainable Development Goals (SDGs). According to the UNCTAD report[177], seaweeds can be used for food, livestock and aquatic feed, pharmaceuticals, nutraceuticals, biofertilizers, textiles, bioplastics, cosmetics, and even as sustainable building materials. Their use in biodegradable packaging and as plastic alternatives contributes to SDG 12 (responsible consumption), while their role in carbon sequestration—up to 173 million metric tons of CO_2 annually—addresses SDG 13 (climate action). Additionally, seaweeds being

176 Sultanta, F. e. (2023). Seaweed farming for food and nutritional security, climate change mitigation and adaptation, and women empowerment: A review. Aquaculture and Fisheries. doi:10.1016/j.aaf.2022.09.001.

177 United Nations Publications. (2024). An Ocean of Opportunities: The Potential of Seaweed to Advance Food, Environmental and Gender Dimensions of the SDGs. Geneva: United Nations publication issued by the United Nations Conference on Trade and Development. Retrieved from https://unctad.org/system/files/official-document/ditcted2024d1_en.pdf

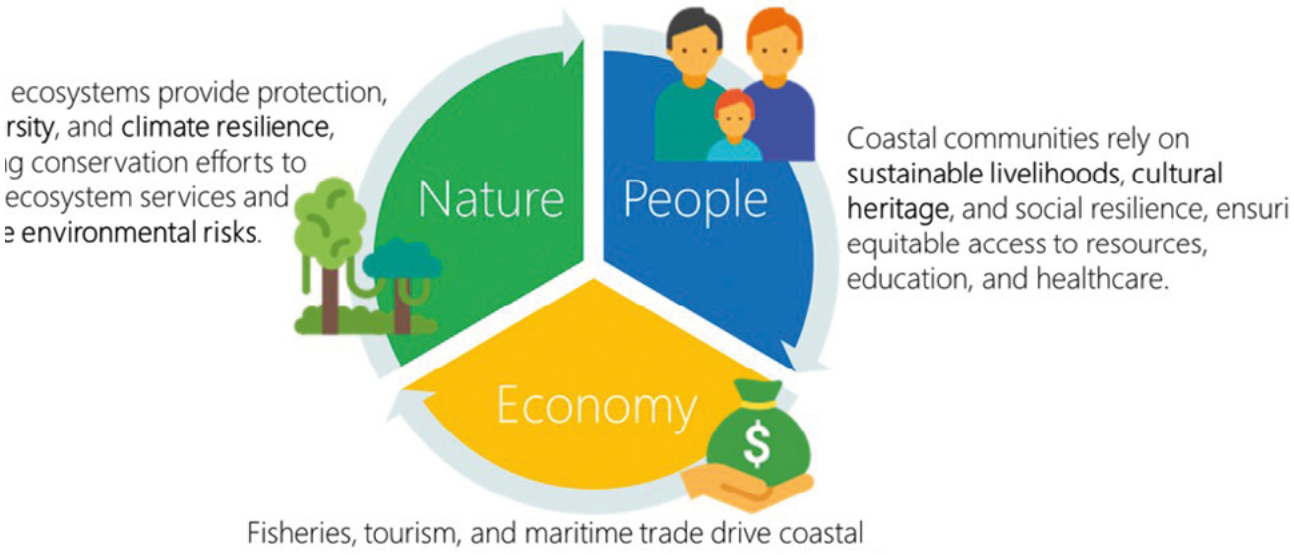


Fig. 3. Application of the Triple Bottom line Approach (People, Profits (or Economy) and Planet (or Nature)) to the interactions between the human activities of coastal communities and the regional flora and fauna, and the resultant economic benefits from these activities

excellent carbon sequesters positions themselves as a low-cost climate mitigation tool. Seaweeds also improve wastewater treatment and reduce the need for synthetic fertilizers, making them useful in circular economy applications. Economically, the global seaweed market was valued at $17 billion in 2021 and is projected to reach $85 billion by 2026[57]. Sectors such as biostimulants, pet food, and bio-additives are expected to grow rapidly, with emerging markets alone projected at $4.4 billion by 2030[57].

The Government of India's Blue Economy Policy highlights seaweed mariculture as a key component for expanding the Blue Revolution. It identifies seaweed and algae harvesting as important emerging areas under aquaculture and mariculture. The policy proposes promotion through a comprehensive National Mariculture Policy, with focus on sustainable marine capture, algae production, to provide alternate source of livelihood in a sustainable manner.

Fig. 3. Application of the Triple Bottom line Approach (People, Profits (or Economy) and Planet (or Nature)) to the interactions between the human activities of coastal communities and the regional flora and fauna, and the resultant economic benefits from these activities

It also emphasizes the potential of marine biotechnology beyond food applications, advocating for a national-level Institute for Marine Biotechnology to develop new commercial

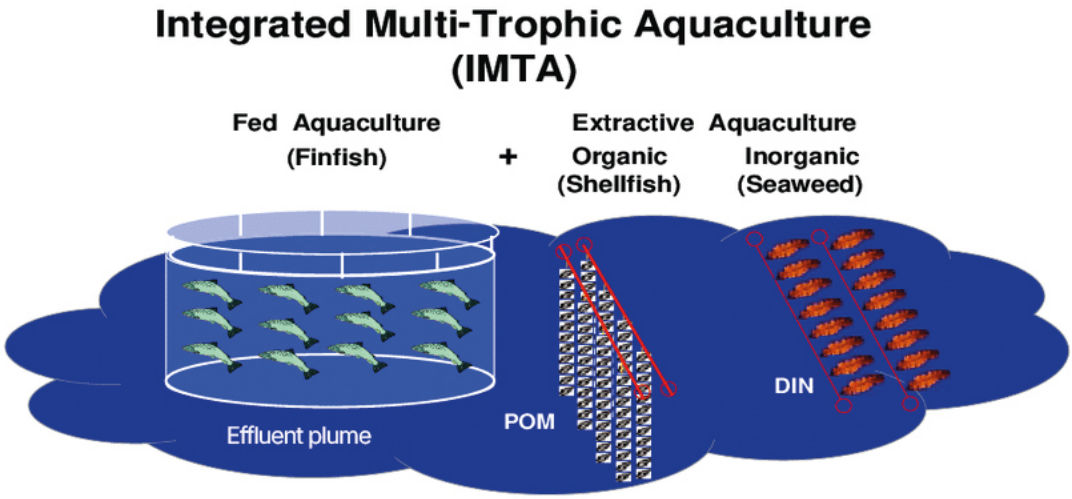


Fig. 4. Integrated Multi-Trophic Aquaculture (IMTA) system to show the integration of fed aquaculture (e.g., finfish (or shrimp)) with organic extractive aquaculture (e.g., shellfish), which utilizes the increase in particulate organic matter (POM), and inorganic extractive aquaculture (e.g., seaweeds), which benefits from the rise in dissolved inorganic nutrients (DIN) [60].

technologies, including those derived from seaweed resources[7, 178].

FOCUSING ON INTEGRATED MULTI TROPHIC AQUACULTURE

Fish and shrimp produce nitrates and phosphates primarily through metabolic processes, feed waste, and microbial activity. Protein-rich shrimp feed results in nitrogenous waste, with excess nitrogen excreted as ammonia, which is oxidized into nitrates by nitrifying bacteria. Uneaten feed and fecal matter decompose, further contributing to nitrate accumulation.

Phosphorus, essential for shrimp growth, is supplemented in feed, but much of it is excreted as phosphate, leading to water enrichment with phosphates. Additionally, microbial decomposition of organic matter in pond sediments releases nitrates and phosphates, exacerbating eutrophication risks in shrimp monoculture systems. Traditional systems often rely on water exchange (to replace the pond water with new fresh water over time) to manage excessive nitrogen compounds. This creates increased withdrawals of the freshwater thus stressing the water availability in the region.

178 Sri-uam, Puchong & Donnuea, Seri & Powtongsook, Sorawit & Pavasant, Prasert. (2016). Integrated Multi-Trophic Recirculating Aquaculture System for Nile Tilapia (Oreochlomis niloticus). Sustainability. 8. 592. 10.3390/su8070592.

Integrated Multi-Trophic Aquaculture (IMTA) is a sustainable farming approach that cultivates multiple species from different trophic levels in a shared ecosystem. A trophic level refers to the position an organism occupies in a food chain, determined by its feeding relationships[179] [180]. Primary producers (e.g., plants) are at the first level, herbivores at the second, and predators at higher levels (energy flows from lower to higher levels, with efficiency decreasing at each step)[59, 60]. This ensures a true ecological diversification as this approach creates synergies within ecosystems, addresses environmental imbalances, and supports more stable energy flows. The core principle of having the IMTA setup is to use waste from one species (e.g., fish) as nutrients for another (e.g., seaweed or shellfish), creating a balanced and efficient system. Economic diversification as offered by IMTA also extends beyond conventional seafood products. For seaweeds, opportunities lie in exploring marine-derived bioactive compounds for pharmaceuticals, nutraceuticals, and other high-value industries[181].

One of the major benefits of IMTA system is that the extractive aquaculture consumes organic waste and dissolved inorganic compounds like nitrates and phosphates, reducing eutrophication and thus improving water quality[182].

DIGITAL TRANSFORMATION AND APY ANALYSIS FOR SUSTAINABLE EXPANSION OF AQUACULTURE

Researchers at Maritime Research Center Pune, have come up with an innovative digital transformation solution known as APY Analysis, that involves holistic analysis of the Area, Production and Yield of the Aquaculture farms in order to identify the gaps in the management of the farm leading to hampered growth and reduced productivity.

179 Chopin, T., Buschmann, A. H., Halling, C., Troell, M., Kautsky, N., Neori, A., ... Neefus, C. (2001). INTEGRATING SEAWEEDS INTO MARINE AQUACULTURE SYSTEMS: A KEY TOWARD SUSTAINABILITY. Journal of Phycology, 37(6), 975–986. doi:10.1046/j.1529-8817.2001.01137.x

180 Chopin, T., Robinson, S. M. C., Troell, M., Neori, A., Buschmann, A. H., & Fang, J. (2008). Multitrophic Integration for Sustainable Marine Aquaculture. Encyclopedia of Ecology, 2463–2475. doi:10.1016/b978-008045405-4.00065-3

181 Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A. ., Kautsky, N., & Yarish, C. (2003). Integrated mariculture: asking the right questions. Aquaculture, 226(1-4), 69–90. doi:10.1016/s0044-8486(03)00469-1

182 Neori, A., Chopin, T., Troell, M., Buschmann, A. H., Kraemer, G. P., Halling, C., ... & Yarish, C. (2004). Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture, 231(1-4), 361-391.

The paper[183] highlights the APY approach as a framework to quantify farm performance by measuring spatial footprint (area), total output (production), and efficiency (yield per unit area). The novelty lies in its integration with predictive growth models driven by physical parameters like *temperature, salinity, pH, Dissolved oxygen levels* (DOL) and *stocking density*. Unlike traditional methods relying on empirical observations or static benchmarks, this paper's APY analysis leverages machine learning and curve-fitting techniques to dynamically predict shrimp growth based on real-time water quality data. The model developed in the paper, for instance, helps predicting the final weight of the shrimp (post-harvest) with a mean error of just 0.1g. This data-driven approach eliminates the need for costly manual monitoring, offering a scalable solution for optimizing aquaculture productivity. The study also emphasizes its applicability to small-scale Indian farms, where fragmented landholdings and resource constraints make precision tools critical. By linking APY metrics to environmental condition inputs, the analysis provides actionable insights—such as adjusting stocking density or aeration—to maximize yield without requiring additional infrastructure, a significant advancement over conventional trial-and-error practices. The paper also identifies several critical challenges in shrimp aquaculture that APY analysis aims to address. First, traditional shrimp farming often relies on subjective experience and generalized practices, leading to inconsistent yields and inefficiencies. Small-scale farmers, who dominate the industry in countries like India, lack access to

By precisely monitoring and analysing area utilization, production output, and yield efficiency, aquaculture farmers can make informed decisions about stocking densities, aeration, feeding schedules, and water quality management in a significant advancement over traditional trial and error practices.

183 Nemani, S., Prabhuraman, S., & Das, A. (2024). Physical Parameter driven models for modelling the growth of shrimp. Indian Journal of Geomarine sciences.

data-driven tools to optimize pond conditions, resulting in suboptimal growth rates and financial losses. Second, environmental variability—such as fluctuating temperatures, salinity levels, and dissolved oxygen—directly impacts shrimp health but is rarely monitored systematically. This unpredictability exacerbates risks like disease outbreaks or stunted growth. Third, the overexpansion of aquaculture has ecological consequences, including mangrove destruction and water pollution from uneaten feed and waste. The current lack of precision in farm management worsens these issues. By integrating APY analysis with predictive modelling, the study tackles these problems by enabling farmers to quantify how specific water quality parameters affect yield. For example, the model reveals that maintaining temperatures near 27°C and pH around 7.5-9 maximizes growth, while deviations suppress productivity. This scientific approach replaces guesswork with actionable metrics, helping farmers mitigate risks and stabilize output. Additionally, the framework's reliance on low-cost IoT sensors makes it feasible for resource-limited settings, bridging the gap between small-scale operations and industrial aquaculture efficiency.

By precisely monitoring and analysing area utilization, production output, and yield efficiency, aquaculture farmers can make informed decisions about stocking densities, aeration, feeding schedules, and water quality management in a significant advancement over traditional trial and error practices. The paper demonstrated how maintaining optimal conditions through this analysis can increase growth rates while reducing feed conversion ratios (FCR), directly boosting profitability. For smallholders operating on thin margins, even marginal improvements in yield per unit area translate to substantial economic gains - the paper cites how the achieved 0.5% error in biomass prediction could mean just 450g difference in a typical 90kg harvest.

The paper also identifies that high stocking densities, while increasing production, can negatively impact shrimp health and survival rates if not carefully managed through the APY framework. The environmental implications of implementing APY analysis in shrimp aquaculture are significant and multifaceted.

By prioritizing productivity and precision over unsustainable spatial expansion, APY analysis under UDA provides a data-driven foundation for optimizing farm performance, particularly for resource-constrained smallholders.

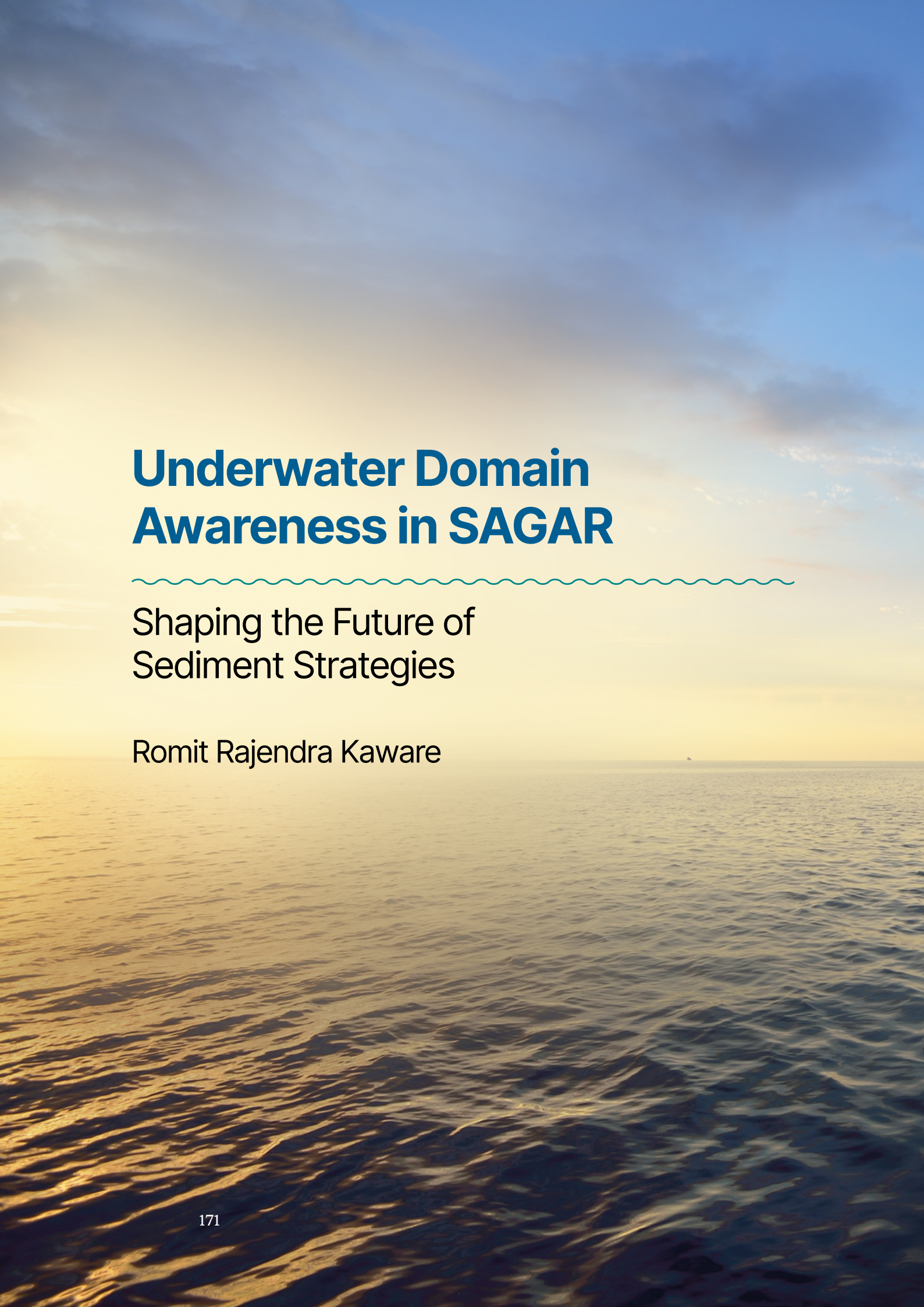
By optimizing growth conditions through precise monitoring of water quality parameters, the system could reduce several negative ecological impacts currently associated with shrimp farming including low productivity, high vulnerability to disease outbreaks and prevalent non-precision farming. The paper highlights how maintaining ideal temperature, salinity and dissolved oxygen levels can improve feed efficiency, potentially reducing the amount of uneaten feed that contributes to water pollution thereby also reducing the stress on adjacent water bodies and associated ecosystem. This addresses the nutrient overload problem that causes algal blooms and dead zones.

The authors acknowledged that intensive aquaculture practices can lead to pollution through nitrogen and phosphorus release, though they argued that optimized systems like Integrated Multi Trophic Aquaculture (IMTA) and Recirculation Aquaculture Systems (RAS) would minimize such occurrences. The authors note that proper implementation of APY analysis could help balance productivity with sustainability by preventing the worst-case scenarios of unmonitored, poorly managed ponds. By providing small-scale farmers with tools to achieve higher yields on existing operations, the pressure to convert additional natural habitats to aquaculture will be reduced.

CONCLUSION

Hon'ble PM Narendra Modi emphasized a collaborative approach for the SAGAR (Security and Growth for All in the Region) vision to ensure collective maritime security and shared prosperity in the Indian Ocean Region (IOR). These also translates to the sustainable development of the fisheries where the people in the bottom rung also have equitable access to resources as others. This paper highlighted the transformative

potential of digital innovations in advancing India's aquaculture sector through the APY (Area, Production, and Yield) analysis framework. By prioritizing productivity and precision over unsustainable spatial expansion, APY analysis under UDA provides a data-driven foundation for optimizing farm performance, particularly for resource-constrained smallholders. The integration of physical parameter-based predictive modelling and low-cost IoT solutions enables real-time monitoring of environmental variables, empowering farmers to make informed, responsive decisions to maximize yield while minimizing ecological impact. APY analysis under UDA framework strategically aims to promote and effectively realise the SAGAR (Security and Growth for All in the Region) vision and Blue Economy policy. Moreover, the integration of seaweed farming and Indigenous innovation within aquaculture systems strengthens the circular economy, enhances nutrient recycling, and promotes self-reliance—particularly in tropical nations and small island economies. Overall, the developed APY framework is not just a technological intervention but a strategic enabler of sustainable prosperity. With appropriate technological interventions, policy backing, capacity-building, and institutional support, this approach has the potential to reshape India's aquaculture landscape and serve as a replicable model for climate-resilient, inclusive blue growth across the Global South.



Underwater Domain Awareness in SAGAR

Shaping the Future of Sediment Strategies

Romit Rajendra Kaware

BACKGROUND

The *Security and Growth for All in the Region (SAGAR)* vision is a significant declaration to position India in a leadership role in the entire region. Tropical waters of the Indo-Pacific present unique characteristics in terms of sediment transport and variation. Effective management of the sediments will have far-reaching impacts across various applications, ranging from managing floods, erosion, transportation, fisheries, aquaculture, sustainability, watershed management, underwater resource extraction, and more. The Government of India has strongly committed to sustainable development in marine and freshwater ecosystems through ambitious projects like Sagarmala, Bharatmala, Gati-Shakti, Jal Jeevan, and Inland Water Transport. The coastal and riverine communities can thrive with better ecosystem management and effective governance mechanisms.

Real-time understanding of the underwater domain enables well-informed policy interventions. The Underwater Domain Awareness (UDA) Framework developed by the Maritime Research Centre (MRC) in Pune has the potential to promote collaboration among regional nations and deter external powers.

Launched in March 2015 as the flagship programme of the Indian Prime Minister Narendra Modi, the Security and Growth for All in the Region (SAGAR) initiative aimed to catalyse India's economic development by leveraging its extensive 7500 km coastline and 14500 km of potential inland waterways. With SAGAR reaching its decadal anniversary, it has become increasingly vital to Indian engagement within the Indian Ocean Region (IOR). SAGAR offers a comprehensive framework for maritime trade, aiming to reduce the logistic costs for import, export and domestic trade. It seeks to modernise ports, strengthen inland

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connectivity and develop multimodal transportation hubs.

In March 2025, during his visit to Mauritius, Prime Minister Modi, during his bilateral discussions with Mauritian Prime Minister Navinchandra Ramgoolam, announced MAHASAGAR, or the "Mutual and Holistic Advancement for Security and Growth Across Regions", which would serve as India's new vision for the global south aiming for enhanced bilateral cooperation and strategic partnerships in the IOR. With the rise in China's attempt to expand its influence in the Indian Ocean, the MAHASAGAR and SAGAR would evolve into a strategic paradigm[184].

Against this backdrop, the coastal and marine ecosystems would form the foundation for the SAGAR Vision, necessitating the management of sediments. This growing challenge has emerged as a critical area of focus. The sediment management intersects with vital themes such as port development, inland navigation, dredging, siltation, coastal protection and environmental sustainability, thus shaping the maritime infrastructure. As we mark ten years of SAGAR, we can reflect on the sediment management domain. Reviewing the progress and identifying the gaps helps us come up with a nuanced understanding of the fundamental processes shaping marine development. This calls on technological advancements and institutional reforms to align the broader goals of secure and sustainable marine development [185]. The knowledge of the tropical conditions unique to the IOR becomes essential in this context. We will discuss these unique characteristics in the next section. Further, the discussion will focus on the existing challenges in sediment management and the transformative opportunities leading to integrated sediment management. We will conclude with an assessment of the role of underwater domain awareness (UDA) in advancing sediment management goals in the SAGAR framework.

UNIQUE TROPICAL CHARACTERISTICS

Understanding the unique characteristics of the IOR is essential for addressing the climatic,

184 "Prime Minister Narendra Modi Unveils 'Mahasagar Vision' in Mauritius, Emphasises Maritime Security and Trade." India Today. Accessed on 30 Mar. 2025. https://www.indiatoday.in/india/story/prime-minister-narendra-modi-mahasagar-vision-mauritius-maritime-security-trade-navinchandra-ramgoolam-2692904-2025-03-13

185 Kaware, Romit Rajendra. Sediment Strategies in Sagarmala. Research Note, Module 13, Maritime Research Center, Pune.

sedimentary and acoustic challenges that affect the implementation of projects like SAGAR. The tropical Indian Ocean constitutes much of the Earth's warm pool between Africa, Asia, Australia, and the Indian subcontinent. The elevated equatorial temperatures of the Indian Ocean influence the intensity of the Asian monsoon system, which exhibits substantial seasonal variability and various inter and intra-seasonal climate changes. Variations in temperature, salinity, and pressure in the Indian Ocean influence sound speed, particularly in the warmer northern regions where sound speed is faster due to higher temperatures and salinity[186]. The tropical nature also harbours significant coastal and marine biodiversity. This marine diversity presents substantial challenges for underwater sound surveillance, impacting the effectiveness of sonar systems used for underwater surveys. Such unique acoustic behaviour of IOR is characterised by the Sound Fixing and Ranging (SOFAR) channel, which influences sound transmission between the ocean surface and the seabed. In tropical seas, the SOFAR channel is deeper, which results in tropical waters behaving acoustically like shallow waters, even at depths of 3000 meters. The presence of active and dormant underwater volcanoes in the Indian Ocean creates a complex sedimentary environment, leading to increased multipath propagation and higher levels of acoustic signal distortion. Therefore, any effort to assess acoustic habitat degradation in the Indian Ocean region will be subject to limitations imposed by its tropical littoral conditions[187].

Tropical conditions equally influence sediment dynamics in the Indian Subcontinent. The region is one of the most significant contributors to global sediment flux, with rivers from the Indian subcontinent accounting for approximately 2500 million tonnes annually—about 15–20% of the global sediment load. The Ganga–Brahmaputra and Indus rivers dominate this flux, while peninsular rivers contribute the remainder. Such high sediment load stems from natural geomorphic processes and intensified human activities, including deforestation, agriculture, mining, and road construction, especially in the

186 Kaware, Romit Rajendra. Tropical Waters and Unique Characteristics: Physical Characteristics of the Indian Ocean. Maritime Research Center, Pune, Apr. 2024, https://mrc.foundationforuda.in/tropical-waters-and-unique-characteristics-physical-characteristics-of-the-indian-ocean/.

187 Kaware, Romit Rajendra. Tropical Waters and Unique Characteristics: Acoustic Challenges in the Indian Ocean. Maritime Research Center, Apr. 2024, https://mrc.foundationforuda.in/tropical-waters-and-unique-characteristics-acoustic-challenges-in-the-indian-ocean/

Himalayan and sub-Himalayan zones. In fact, over half of India's landmass is affected by soil erosion, with western basins such as the Yamuna, Chambal, and Mahi facing severe degradation[188].

India's rivers are also marked by high monsoonal variability, with 80–95% of annual sediment transport occurring during the monsoon season. Intense, short-duration rainfall leads to rapid runoff and flooding following extended dry spells, causing significant geomorphic transformations such as channel deepening, floodplain scouring, and complex channel-in-channel formations[189]. The alteration of El Niño-La Niña events due to rising global temperatures would affect the monsoon cycles, leading to more extreme flooding and drought events. The Indian rivers are described as having positive skewness, high variability, and high average flow[190]. This helps us conclude that most sediment transport happens in short windows during high-flow events. Such high-magnitude flooding can have effects that last for a long time, drastically reshaping the riverine landscapes, river trajectories and marine ecology, potentially hampering the downstream conditions. This calls for a comprehensive sediment management strategy with the SAGAR framework.

CHALLENGES IN SEDIMENT MANAGEMENT

Sediment management has generally been overlooked during the phases of marine infrastructure. This, however, has implications not only on the infrastructure sustainability but also on the ecology and the socio-economics of the communities around the marine regions. This section will look into the significant sediment related challenges in the marine realm.

Port Management

One of the significant challenges faced by the Indian ports is the continuous and unpredictable sedimentation. Ports are a vital link for international trade, and their output is directly tied to the national economy. The effectiveness of operations depends on the coastal

188 Kaware, Romit Rajendra. Tropical Waters and Unique Characteristics: Indian Freshwater Systems. Maritime Research Center, IIT Delhi, Feb. 2024, https://maritimeresearchcenter.com/wp-content/uploads/2024/02/SM4_Research-Note-Module-2.pdf.

189 Kale, Vishwas S. "Geomorphic effects of monsoon floods on Indian rivers." Flood problem and management in South Asia (2003): 65-84.

190 Garde, R. J., and U. C. Kothyari. "Flood estimation in Indian catchments." Journal of Hydrology 113.1-4 (1990): 135-146.

The excessive sediment hampers the port efficiencies. The lack of specific studies to understand the local dynamics and the effect of port operations on the redeposition of sediments leads to repeated dredging works, overshooting the cost and time constraints. This also requires continual adjustments of navigational aids such as buoys and beacons.

dynamic sediment transport in their vicinity. This is dependent on the natural hydrodynamic forces such as waves, tides, and currents, as well as on anthropogenic factors like propeller movement and dredging. The deposition of sediments, particularly in the navigational channels, reduces the available depth[191], reducing the accessibility to larger vessels and increasing the turnaround times, leading to excessive dredging and elevated costs. Research studies at Jawaharlal Nehru Port Trust (JNPT) Mumbai indicated how the port operations significantly influence the sediment dynamics, requiring more detailed studies on the port operations. The Kolkata Port, located in the Hooghly River, showcases minimal sediment influx with upstream sediment deposition and minimal littoral drift, yet it still requires extensive dredging of navigational channels[192].

The excessive sediment hampers the port efficiencies. The lack of specific studies to understand the local dynamics and the effect of port operations on the redeposition of sediments leads to repeated dredging works, overshooting the cost and time constraints. This also requires continual adjustments of navigational aids such as buoys and beacons. Around the berthing structures, the deposited sediments may lead to structural degradation, thus making them vulnerable to extreme weather events. Excessive sediment removal may lead to scouring, undermining infrastructure stability and impacting navigation.

191 Guarnieri, A., Saremi, S., Pedroncini, A., Jensen, J. H., Torretta, S., Vaccari, M., & Vincenzi, C. (2021). Effects of marine traffic on sediment erosion and accumulation in ports: a new model-based methodology. Ocean Science, 17(2), 411-430.

192 Khanna, Rishika. Port and Coastal Sediment Management – JNPT Case Study. Maritime Research Center, Pune, 2023.

Inland navigation is based on effective sediment management in freshwater. The extensive monsoon systems, with the substantial sediment loads from the Himalayas or peninsular regions, constrain the year-round use of inland water transport.

Dredging is performed during the construction of new ports, and sediment is deposited into infrastructure like berths, breakwaters, and quay walls. This degrades water quality by transporting pollutants into port waters, disrupting marine habitats. The coastal engineering structures would also alter sediment flows, leading to erosion downstream and acceleration on the updrift side [193]. This requires extensive sediment modelling to incorporate the wave, tide, and current data. However, such capacity remains underdeveloped; leveraging UDA technologies and IoT-based digital transformations would improve the efficiency of the current monitoring systems.

Inland Navigation

India has an extensive network of inland waterways, including rivers, canals and lakes, providing a cost-effective and environmentally sustainable alternative to inland transportation. However, inland navigation is based on effective sediment management in freshwater. The extensive monsoon systems, with the substantial sediment loads from the Himalayas or peninsular regions, constrain the year-round use of inland water transport. The elevated sediment influx from the upper catchments is driven by deforestation, unsustainable land use, and inadequate soil conservation, which alleviates soil erosion and disrupts downstream dynamics. The Sediment dynamics are shaped by complex interactions, coupled with the diversity of chemical and biological composition. Moreover, the stochastic nature of the sediment movement, underscores the need for robust meddling approaches.

The development of dams, embankments, and floodplains have excessive sedimentation rates, with the Central Water Commission estimating the national average loss to be around

193 Kaware, Romit Rajendra. Sediment Transport Studies in Littoral and Inland Regions. Research Note, Maritime Research Center, Pune, 2025.

15%, with some experiencing up to 30% loss in storage[194][195]. This reduces reservoir capacities and making them more vulnerable to failures. The combined effects lead to excessive release of water and sediment in monsoon seasons, affecting the accessibility of the navigation channel and demanding frequent dredging.

Changes in the sediment transport patterns can also impact the health and distribution of aquatic ecosystems, including wetlands. Erosion of riverbanks and deposition in floodplains can lead to loss of agricultural land and pose challenges to settlements near the waterways. The shifting of alluvial rivers during high-magnitude monsoons causes substantial annual losses in damage and disruptions to economic activities, businesses, and infrastructure. Climate change adds complexity, altering hydrological cycles, intensifying extreme events, reducing flow velocities in key basins, and aggravating sedimentation. An illustrative example is the Kosi disaster in August 2008[196], showcasing the devastating impact of shifting river courses and subsequent inundation in the sub-Himalayan region[197]. Integrated watershed management is thus essential to regulate the sediment flow and enhance the riverine ecology.

Coastal Erosion

The coastal areas of India are home to about 170 million of the 1.4 billion people who live here. These areas face rising sea levels, erosion, and natural disasters like tropical storms and cyclones. Cyclone Amphan, the biggest storm to hit the Bay of Bengal in decades, forced several million people to leave their homes in May 2020. This shows the vulnerability to extreme climatic events. Between 1990 and 2016, India lost 235 square kilometres of land to coastal erosion,

194 Handbook for Assessing and Managing Reservoir Sedimentation. Doc. No. CDSO_GUD_DS_04_v1.0, Central Water Commission, Feb. 2019, https://damsafety.cwc.gov.in/ecm-includes/PDFs/Handbook_Reservoir_Sedimentation.pdf#:~:text=Reservoir%20sedimentation%20is%20a%20crucial%20issue%20faced,to%20sedimentation%2C%20in%20due%20course%20of%20time.&text=Based%20on%20experience%20of%20Central%20Water%20Commission%2C,sector%20in%20a%20comprehensive%20and%20holistic%20way.

195 Compendium on Sedimentation of Reservoirs in India. Watershed & Reservoir Sedimentation Directorate, Environment Management Organisation, Water Planning and Projects Wing, Central Water Commission, 2020, https://cwc.gov.in/sites/default/files/compendium1122020.pdf.

196 Kothyari, UMESH C. "Sediment problems and sediment management in the indian sub-himalayan region." Sediment problems and sediment management in Asian river basins 349 (2011).

197 Kaware, Romit Rajendra. Sediment Transport Studies in Littoral and Inland Regions. Research Note, Maritime Research Center, Pune, 2025.

placing people's homes and livelihoods at risk and making them migrate to other places.

Coastal erosion is caused by the action of wind, waves, currents and sea-level changes, as well as by human intervention that accelerates the erosion rate. At present, 23% of the shoreline along the Indian mainland is affected by erosion. The shoreline analysis suggests that 34% of the coast is eroding, 28% is accreting, and 38% is stable[198]. The western Indian coastline, particularly in Kerala and Karnataka, is highly susceptible to erosion. Coastal erosion poses a significant threat to society and the economy, particularly to tourism.

Rising sea levels are already eroding shorelines, gradually flooding low-lying areas and altering the shoreline configuration. These sea-level changes, high tides, waves, and storm surges can cause long-term flooding. The dynamic nature of the erosion and accretion has made the coastal ecosystems vulnerable. The changes in the shoreline configuration in the past and present can help us understand coastal reactions to rising sea levels in the future. Natural coastal ecosystems like mangrove forests, coral reefs, and seagrass beds must face maximum impact. Important Mangrove areas are being turned into aquaculture sites, mangroves are being cut down for firewood, fuelwood, and land reclamation. It is said that shrimp farming has killed mangrove forests on thousands of acres in Guntur and Nellore districts. In Gujarat, the salt business and cutting down trees for sale have hurt the mangroves. This calls for the national action plan for climate change to address the coastal vulnerabilities[199].

Dredging

The tropical regions are characterised by their complex environmental and socio-economic challenges, as discussed above. The excessive sedimentation caused at the river mouths can lead to significant drainage issues and widespread flooding. Dredging becomes essential to mitigate the excessive buildup and restore the flow conditions. Dredging facilitates uninterrupted operations in major ports by maintaining the navigation

198 Kankara, R. S., Murthy, M. R., & Rajeevan, M. (2018). National Assessment of Shoreline changes along Indian Coast: Status report for 26 years (1990–2016). NCCR Publication.

199 Prasad, Ritika, and Bhanwar Vishvendra Raj Singh. "Shoreline change and its impact on coastal livelihoods in Navsari and Valsad districts of Gujarat, India." Focus On Geography 65 (2022): 1-16.

channel depths[200][201]. The dredging process is carefully done by specifying the minimum distance or depth from the shore with a permitted volume. The direct effect of dredging is quantified by assessing the volume of dredged material. However, currently, this depends on spot sampling over time, and the real-time monitoring of the exact quantities of dredged material is still a challenge. This might require the use of geospatial data, integration of AI, IoT devices etc.

Moreover, the dredging activities can have significant environmental impacts. One of the most concerning impacts is habitat destruction. Dredging can obliterate critical habitats such as coral reefs, mangroves, and seagrass beds. These ecosystems are crucial for maintaining marine biodiversity and play a vital role in coastal protection[202]. Coral reefs act as natural barriers against storm surges and waves, while mangroves and seagrass beds stabilise shorelines and reduce erosion. The destruction of these habitats can lead to biodiversity loss, weakened coastal defences, and disrupted livelihoods for communities that depend on these ecosystems.

Another significant environmental impact of dredging is increased turbidity in the water column. During dredging operations, sediments are resuspended, leading to higher turbidity levels[203]. This reduces light penetration, impairing the growth and health essential for photosynthesis in aquatic plants, which serve as the foundation of the marine food web. The disturbance of sediments during dredging can also release trapped pollutants into the water column, posing serious risks to marine life and human health. Sediments often contain a variety of pollutants, including heavy metals, organic contaminants, and nutrients. Disturbing these sediments can mobilise pollutants into the water, where aquatic creatures can absorb them[204]. The pollutant bioaccumulation can harm marine life's development, reproduction, and survival. Consumption of polluted seafood and water can also harm

200 National Framework for Sediment Management. Ministry of Jal Shakti, Department of Water Resources, River Development & Ganga Rejuvenation, https://nmcg.nic.in/writereaddata/fileupload/52_National%20Framework%20for%20Sediment%20Management%20-%20English%20(1).pdf.

201 "Cleaning Up: Strategies for Dredging at National Waterways." Indian Infrastructure, 30 June 2022, https://indianinfrastructure.com/2022/06/30/cleaning-up/.

202 Rehitha, T. V., Ullas, N., Vineetha, G., Benny, P. Y., Madhu, N. V., & Revichandran, C. (2017). Impact of maintenance dredging on macrobenthic community structure of a tropical estuary. Ocean & coastal management, 144, 71-82.

203 Rehitha, T. V., Ullas, N., Vineetha, G., Benny, P. Y., Madhu, N. V., & Revichandran, C. (2017). Impact of maintenance dredging on macrobenthic community structure of a tropical estuary. Ocean & coastal management, 144, 71-82.

204 Arulanandan, S. Sediment Management (Focused on Dredging): Final Report. Maritime Research Centre.

Establishing sediment monitoring networks using advanced technologies, such as remote sensing and in-situ measurements, is essential for proactive management. The integration of IoT sensors can track fuel consumption, carbon emissions, and engine performance while relaying real-time information on sediment quantities that can allow for dynamic adjustments based on current environmental conditions, reducing extra dredging and improving resource utilisation.

humans. Hence, dredging requires a nuanced approach. That can help mitigate risks and ensure that projects remain on track despite the challenging environmental conditions.

OPPORTUNITIES IN SAGAR

The strategic sediment management offers a transformative opportunity to advance the SAGAR initiative. The above section discussed the constraints of sediment load thru the SAGAR perspective. Sediment induced challenges can be effectively addressed through science-based approaches incorporating modern technologies, data analytics, and sustainable processes. This would require a detailed study of the effects on people, economy, and nature [205]. Such interventions would improve the reliability of water transport and enhance habitat restoration, local employment, and sustainable infrastructure development.

Navigability

A key benefit of sediment management is improved navigability and port and IWT operations enhancement. Efficient dredging strategies are an essential part. Establishing sediment monitoring networks using advanced technologies, such as remote sensing and in-situ measurements, is essential for proactive management. The integration of IoT sensors can track fuel consumption, carbon emissions, and engine performance while relaying real-time information on

205 Kaware, Romit Rajendra. Sediment Management for Water Resource Management. Research Note, Maritime Research Center, Pune.

sediment quantities that can allow for dynamic adjustments based on current environmental conditions, reducing extra dredging and improving resource utilisation[206]. Extensive studies must be conducted to carry out baseline sediment studies and aid in decision-making regarding choosing alternative techniques instead of frequent dredging. A combination of soft and complex engineering solutions should be implemented to protect port and inland waterway shorelines from erosion. Soft solutions, such as mangrove reforestation and beach nourishment, offer more sustainable long-term benefits, while complex structures like breakwaters can be effective in specific circumstances. For inland waterways, bank stabilisation methods, including riprap, vegetation buffers, or geo-synthetics, can help control sediment inflow from land-based sources. For instance, designing and developing sediment traps in critical port zones can help capture sediment before it obstructs the navigational channels or waterways [207].

The Inland Water Transport Authority (IWAI) has identified 106 new waterways in India for their phased development (Inland Waterways Authority of India, 2024[208]. Accordingly, the IWT offers considerable potential for the private sector in providing services, operating vessels, and developing infrastructure such as terminals and river ports, mainly through public or public-private partnership (PPP) models. Any intervention, however, should be supported by scientific studies, physical or mathematical modelling and remote sensing data. This would lead to interstate data sharing mechanisms, with a digital database containing the flow characteristics across the spatial and temporal ranges, ultimately leading to unhampered navigation in the Indian waters.

Marine Ecology

India's fisheries and aquaculture sector are key contributors to food security, rural livelihoods and the broader blue economy. The coastal and estuarine

206 Chou, Jui-Sheng, Pei-Lun Chong, and Chi-Yun Liu. "Deep learning-based chatbot by natural language processing for supportive risk management in river dredging projects." Engineering Applications of Artificial Intelligence 131 (2024): 107744.

207 Kaware, Romit Rajendra. Sediment Management in Inland Water Transport. Research Note, Maritime Research Center, Pune.

208 "106 New Waterways." Inland Waterways Authority of India, https://iwai.nic.in/waterways/new-waterways/106-new-waterways.

The regulation of sediment flow enables the restoration of the beaches sand shoreline stability, thus protecting the coastal infrastructure. The restoration of degraded wetlands through improved sediment practices also leads to agricultural productivity, improvement in water quality, and reduction in sediment pollutants.

ecosystems provide critical spawning and feeding habitats for fish sensitive to sediment dynamics. In aquaculture, particularly in coastal and brackish water zones, the sediment quality directly affects pond health, water quality, and overall yield. Proper sediment management can prevent contamination from industrial pollutants accumulated in sediments, which can degrade pond bottoms and disrupt aquaculture cycles[209] [210]. Rehabilitating natural sediment dynamics in deltaic and estuarine regions also creates new opportunities for integrated farming systems, such as fish-rice farming and cage culture.

The stabilisation of the coastal geomorphic also positively impacts the fisheries. Sedimentation can destroy fishing harbours and aquaculture farms. When such stability measures integrated with marine spatial planning (MSP) are employed for a well-managed sediment flow and a sustainable fishing zone, aquaculture clusters can be developed, reducing the conflict between economic activities and enhancing productivity.

Technological tools are also primarily used to control sediment to maintain breeding grounds and marine biodiversity. Biological valuation mapping (BVM) is one such tool for identifying areas based on ecological or biological importance and identifying high-risk-prone regions[211]. Such information over a vast area can be stored in a comprehensive open-access database consolidating the

209 Chapman, Jacqueline M., et al. "Clear as mud: a meta-analysis on the effects of sedimentation on freshwater fish and the effectiveness of sediment-control measures." Water research 56 (2014): 190-202.

210 Cattanéo, Franck, et al. "Mitigation of ecological impacts on fish of large reservoir sediment management through controlled flushing–The case of the Verbois dam (Rhône River, Switzerland)." Science of the total Environment 756 (2021): 144053.

211 "Marine Biological Valuation Maps - An Example from Belgium." Coastal Wiki, https://www.coastalwiki.org/wiki/Marine_biological_valuation_maps_-_an_example_from_Belgium

sedimentological and biochemical parameters of the sediments based on either direct field studies or peer review studies. This could aid in mitigating the impacts of excessive anthropogenic activities and climate change, thus offering a pathway for climate-resilient aquaculture[212].

Socio-Economics of Local Communities

Rapid large-scale infrastructure development, exploitation of resources and the degradation of ecological assets have led to severe soil erosion and increased sediment loads. Hence, coastal communities become more vulnerable to flooding, erosion, and cyclones. The regulation of sediment flow enables the restoration of the beaches sand shoreline stability, thus protecting the coastal infrastructure. The restoration of degraded wetlands through improved sediment practices also leads to agricultural productivity, improvement in water quality, and reduction in sediment pollutants. This reduces the health risks while guaranteeing the stability of rural livelihood and shrinking the fiscal pressure on the state governments[213].

Integrated sediment management offers a variety of job opportunities across multiple sectors, including dredging, construction, logistics, fisheries, shipping and tourism. Moreover, controlled sediment loads would lead to efficient inland water transport development, significantly lowering transportation costs and promoting domestic trade, thereby fostering economic inclusivity in the nation. The reduced dependence on rail and road transport would reduce carbon emissions, impacting pollution-related health risks.

Moreover, there is a vast untapped potential in the re-utilisation of dredged materials. Based on initial biochemical and engineering assessments, the dredged sediments can be reused in agriculture to improve soil quality or create new farmland, contributing to food security. The dredged material also finds its application in land reclamation or as a fill material in the construction industry. The reused sediments in land reclamation or beach nourishment projects would preserve the shoreline, providing new land for industrial setup

212 Kaware, Romit Rajendra. Digital Transformation for Sediment Management in India. Research Note, Module 17, Maritime Research Center, Pune.

213 Zhong, Xue, et al. "The impact of socio-economic factors on sediment load: A case study of the Yanhe River Watershed." Sustainability 12.6 (2020): 2457.

The reliance on Western firms, especially in areas like acoustic sensors and sonars, poses risks of strategic data being shared with non-state actors. India must prioritise the development of Indigenous marine capabilities catered to the local conditions, enhancing Atma-Nirbharta or self-reliance.

or beachfront properties and driving the local economy[214].

Geo-Strategic Importance

Globally, North American and European developed economies have predominantly led marine experiments and scientific data collection projects. With their financial, technical, and scientific competence, they have developed research infrastructure, data collection networks, and private enterprises in the maritime domain. The Indian Ocean region currently remains comparatively underexplored and lacks well-established scientific foundations. The reliance on Western firms, especially in areas like acoustic sensors and sonars, poses risks of strategic data being shared with non-state actors. India must prioritise the development of Indigenous marine capabilities catered to the local conditions, enhancing Atma-Nirbharta or self-reliance.[215].

One of the primary geostrategic advantages of sediment management is the enhancement of port readiness and maritime infrastructure integrity. Efficient sediment monitoring and management ensure that key ports, including strategically located ones such as Kandla, Paradip, and Vizhinjam, remain operational year-round, enabling seamless movement of naval and coast guard fleets. In strategically sensitive coastal areas, sediment-related processes such as erosion or deposition can threaten naval bases, shipyards, and coastal defence infrastructure especially in regions like the Andaman and Nicobar Islands or Lakshadweep, which are vital for India's forward maritime posture and surveillance operations. Furthermore, sediment management strengthens India's coastal and marine

214 Arulanandan, S. Sediment Management (Focused on Dredging): Final Report. Maritime Research Centre.

215 Kaware, Romit Rajendra. Technological Challenges and Opportunities in Sediment Management. E-Learning Module 3, Maritime Research Center,

domain awareness. Technologies used for sediment mapping—such as acoustic seabed imaging and bathymetric surveys—also support the detection of undersea features, seabed research, rescue and recovery, and unauthorised intrusions[216]. This dual-use potential of sediment data enhances India's ability to safeguard its Exclusive Economic Zone (EEZ), protect critical infrastructure, and monitor chokepoints such as the Malacca Strait and the Persian Gulf approaches.

Arnab Das[217] highlights the potential of the region's demographic advantage in achieving the goal of "Towards a Resilient Region, Prosperous Economies, and Healthy People." Collaborative systems should prioritise outreach, engagement, and sustainability. By showcasing sustainable coastal development practices through Sagarmala, India can lead regional cooperation in maritime ecology, disaster resilience, and port development. This balance is essential for projecting influence and ensuring peace in the Indo-Pacific—a region marked by increasing maritime competition.

UNDERWATER DOMAIN AWARENESS (UDA) FOR SEDIMENT MANAGEMENT

The Underwater Domain Awareness (UDA)[218] is a key enabler for implementing effective sediment management strategies under the Sagarmala programme. As India advances its port-led development agenda, sustainable sediment practices must be underpinned by a robust UDA framework, which integrates advanced technologies, data intelligence, and multi-domain coordination. Developed by the Maritime Research Centre (MRC), the UDA framework significantly contributes to global policy and capacity building, particularly in the Indian Ocean Region (IOR).

To See, To Understand, To Share Model for Acoustic Capacity.

Autonomous Underwater Vehicles (AUVs) have been increasingly utilised

216 Sun, K., Cui, W., & Chen, C. (2021). Review of underwater sensing technologies and applications. Sensors, 21(23), 7849.

217 Das, Arnab. "UDA Framework for BIMSTEC and the Way Forward." The Daily Guardian, https://thedailyguardian.com/uda-framework-for-bimstec-and-the-way-forward-2/

218 Maritime Research Center. "Underwater Domain Awareness." Maritime Research Center, https://maritimeresearchcenter.com/uda/.

in shallow-water applications, though specific environmental constraints challenge their deployment. Shallow waters introduce complexities in acoustic signal propagation due to repeated interactions with the seabed and surface, while elevated ambient noise levels—stemming from both natural sources (e.g., marine life, waves, and precipitation) and anthropogenic activities (e.g., shipping, dredging, sonar)—further impede acoustic performance. The Indian Ocean, in particular, is acoustically complex due to the high noise levels from natural and anthropogenic sources - the ambient noise makes sonar operations less efficient, with potential reductions in performance from 60 to 70%. This necessitates the development of region-specific systems. The "To See, To Understand, and To Share" model of Underwater Domain Awareness (UDA) offers a structured approach to address these challenges[219].

The "To See" phase involves precise acoustic and optical mapping of the seabed, informed by sensor placement strategies and supported by high-performance computing. Indigenous development of data interpretation frameworks tailored to regional needs is crucial, especially when high infrastructure costs and data classification hinder collaboration. Appropriate acoustic sensors—such as SBES, MBES, Side Scan Sonars, and Sub-Bottom Profilers—must be selected based on mission objectives and deployed via AUVs, ROVs, or research vessels, each with varying capabilities.

The "To Understand" component uses AI and machine learning to focus on noise filtering, error reduction, and data interpretation. It requires long-term environmental datasets and expert knowledge in oceanography, acoustics, and signal processing. Accurate sediment modelling, supported by real-time monitoring and digital twins, allows dynamic dredging strategies and proactive sediment management.

The "To Share" aspect emphasises secure, interoperable data dissemination. Communication infrastructure and user-friendly interfaces (e.g., mobile apps, GIS-integrated dashboards) must deliver tailored insights to policymakers, researchers, and security agencies.

219 Kaware, Romit Rajendra. Acoustic Capacity & Capability for Sediment Management. Research Note, Module 14, Maritime Research Center, Pune.

The UDA framework plays a key role in the identification of ecologically sensitive zones particularly vulnerable to sediment-related disturbances. The integration of economic zones can further lead policymakers, port developers and engineers to design projects with minimal ecological disruption. By systematically identifying and analysing underwater environmental data, the UDA framework helps delineate the roles and expectations of all stakeholders, ensuring their concerns and inputs are comprehensively addressed.

Access protocols should ensure data security while enabling authorised collaboration supporting operational, strategic, and ecological objectives.

Stakeholder Engagement

At its core, the UDA calls for effective stakeholder engagement in the marine realm. As Prime Minister Modi advocates, fostering cooperative systems focused on outreach, engagement, and sustainability is vital[220]. Outreach should inform stakeholders of the strategic importance of UDA, while engagement aims to garner support for its implementation. Sustainability involves creating projects that develop policies, technologies, and skills to ensure long-term benefits.

The UDA framework plays a key role in the identification of ecologically sensitive zones particularly vulnerable to sediment-related disturbances. The integration of economic zones can further lead policymakers, port developers and engineers to design projects with minimal ecological disruption. By systematically identifying and analysing underwater environmental data, the UDA framework helps delineate the roles and expectations of all stakeholders, ensuring their concerns and inputs are comprehensively addressed. This method fosters transparent and consistent communication among all parties, building trust and facilitating collaborative problem-solving. Given the multidimensionality of sediment

220 5th BIMSTEC Summit." Press Information Bureau, Government of India, 30 Mar. 2022, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1811269.

Digital transformation should be embedded at all levels of the current policy framework. Policies should mandate the use of digital tools such as Geographic Information Systems (GIS), remote sensing, and satellite monitoring to track sediment movement, erosion patterns, and deposition in coastal zones, ports, rivers, and reservoirs.

management, a collaborative effort is required from multiple sectors, including shipping, environment, underwater communication, port operators, Inland Waterways Authority of India, Dredging companies, Coast Guard, navy, academia and the local communities[221].

Additionally, the UDA framework aids in developing robust policies by providing a structured approach to understanding the diverse impacts of dredging activities on the underwater environment. This results in more informed decision-making, balancing economic growth with ecological preservation, and ultimately promoting the project's long-term sustainability and community support. While the UDA framework shows great promise, further research is needed to refine its precise implementation in the context of dredging projects.

Digital Transformation

Data is crucial for understanding the changing natural factors and economic activities over time. India should prioritise the Digital Ocean project due to its extensive, warm coastal waters. Digital transformation should be embedded at all levels of the current policy framework. Policies should mandate the use of digital tools such as Geographic Information Systems (GIS), remote sensing, and satellite monitoring to track sediment movement, erosion patterns, and deposition in coastal zones, ports, rivers, and reservoirs. Implementing real-time, automated data collection systems, particularly in high-sediment areas like river mouths, estuaries, and port basins, is crucial. Policies should also encourage using IoT-enabled sediment traps and water quality sensors to monitor and manage

221 Kaware, Romit Rajendra. Policy Interventions for Sediment Management in India. Research Note, Module 15, Maritime Research Center, Pune.

sediment in inland waterways and coastal watersheds.

The blue economy can be a practical framework for recognising the importance of developing such capacities in the region. Marine Spatial Planning (MSP) is a collaborative process that engages stakeholders from various sectors, including fisheries, commerce, tourism, and conservation[222]. MSP helps identify critical areas for data collection based on ecological, economic, and social factors. Once MSP plans are established, they must be implemented and continuously monitored to ensure they achieve the intended outcomes. This implementation phase can involve several activities, such as formulating regulations and guidelines, establishing monitoring systems, and providing incentives to ensure compliance.

Additionally, establishing a Centralized Sediment Data Repository is essential to integrate data from various regions, such as watersheds, ports, inland waterways, and coastal zones. This centralised hub would provide stakeholders access to real-time data, enabling improved decision-making and predictive modelling of sediment-related issues. Collaboration between private and public organisations is crucial for improving data quality, establishing standards, and creating protocols for transferring marine data. Earlier discussions have emphasised the significant role of private enterprises in enhancing data accessibility[223].

Training and Value Addition

As India seeks to leverage its demographic advantage until 2055, the younger generation must play a central role in the nation's transformation (Malin & Tyagi, 2023 [38])[224]. Indian authorities should prioritise enhancing the workforce's expertise in marine technology, underwater communications, acoustics, and cloud computing. This preparation will equip the workforce to oversee, operate, and maintain advanced sediment classification technologies. Additionally, efforts should focus on understanding the unique characteristics of data and

222 Maritime Research Center. "Marine Spatial Planning." Maritime Research Center, June 2024, https://maritimeresearchcenter.com/wp-content/uploads/2024/06/MSP-Position-Paper-1_compressed.pdf.

223 Kaware, Romit Rajendra. Digital Transformation for Sediment Management in India. Research Note, Module 17, Maritime Research Center, Pune.

224 Malin, Sophie, and Ashima Tyagi. "India's Demographic Dividend: The Key to Unlocking Its Global Ambitions." S&P Global, 3 Aug. 2023, https://www.spglobal.com/en/research-insights/special-reports/look-forward/india-s-demographic-dividend-the-key-to-unlocking-its-global-ambitions.

leveraging them to develop innovative solutions tailored to the Indian Ocean Region (IOR). These initiatives can be integrated into India's Skill India initiative.

Collaboration between the private sector, educational institutions, and training centres is crucial for skill development in the Blue Economy. The User-Academic-Industry partnership can be effectively implemented by establishing a Centre of Excellence focusing on the five key areas: research, academia, skilling, incubation, and policy. Research should be multidisciplinary and aimed at enhancing core capabilities, while considerations of socio-economic, socio-political, and socio-cultural factors should complement science and technology. Collaborative projects, such as India's deep-sea benthos program—which explores polymetallic nodules in the Central Indian Ocean Basin—and the development of Autonomous Underwater Vehicles (AUVs), provide excellent opportunities for the private sector to contribute its expertise and experience[225].

In contrast to traditional, time-consuming courses, flexible learning opportunities should be introduced to make research more appealing by offering job security and career growth prospects. The New Education Policy provides a foundation for further initiatives, but more concerted efforts are needed to foster seamless collaboration among users, academics, and businesses across diverse dimensions. Massive Open Online Courses (MOOCs) represent an effective solution to reach a broad audience. These platforms can offer learning modules covering various topics such as marine science research, advanced sediment management, acoustic fingerprinting, climate change, and achieving sustainable development goals.

CONCLUSION

The Security and Growth for All in the Region (SAGAR) initiative underscores India's maritime development. With its tenth year, we reflect on SAGAR's critical role, especially in sediment management in port operations, inland water transport and coastal protection. These are highly dependent on the unique characteristics of the tropical Indian Ocean, including the

225 Underwater Domain Awareness (UDA) Framework: A National Policy Initiative for Acoustic Capacity & Capability Building. Interim Project Report, Maritime Research Center, Pune, Nov. 2021, https://maritimeresearchcenter.com/wp-content/uploads/2023/01/Report-Final-V6.pdf.

high sediment flux, intense monsoon season, climate variability and complex acoustic environments. This demands nuanced approaches to understanding the role of sediment management in SAGAR.

The key challenges of sedimentation, dredging, and sediment flow monitoring impact the efficiency and accessibility of the ports and inland navigation channels. Unmanaged sediment flow could impact the marine infrastructure's structural stability, causing delays in vessel movement. Moreover, the dynamic sediment movement affects the aquatic ecosystem health, affecting the spawning and habitat of fisheries, coral reefs, and other marine species. Leveraging underwater domain awareness (UDA), Internet of Things (IoT), Artificial intelligence (AI) and digital transformation would enhance real-time monitoring, modelling capabilities and sustainable processes.

Integration of sediment management will lead to opportunities to improve navigability, restore marine ecosystems, and empower the local communities. The "to see, to understand, to share" model gives a structured approach to the monitoring, processing and interpretation of data. As India moves forward, capacity building, public-private partnerships, and multilateral cooperation will be pivotal in aligning SAGAR's objectives with sustainable sediment management processes, thus reinforcing India's geo-strategic influence and ensuring long-term prosperity and sustainable economic development in the Indian Ocean region.

National Policy Framework for Acoustic Fingerprinting in Maritime Governance

Pradnya Kumbhare

The Security and Growth for All in the Region (SAGAR) initiative marked a significant pivot in India's maritime policy under the leadership of Prime Minister Narendra Modi. Recognising the strategic and economic potential of India's 7,500 km coastline and 14,500 km of navigable inland waterways, SAGAR seeks to position India as a key player in the Indian Ocean Region (IOR). Over the past decade, SAGAR has evolved into a central pillar of India's maritime diplomacy and security architecture, providing an integrated framework to promote maritime trade, reduce logistics costs for domestic and international trade, modernise port infrastructure, strengthen inland waterway connectivity, and develop multimodal logistics hubs.[226]

Beyond economic objectives, SAGAR encapsulates India's broader vision of regional security, sustainable development, and capacity building among Indian Ocean littoral states. It reflects a commitment to cooperative maritime governance, environmental stewardship, and disaster response coordination, aligning with India's aspiration to be a "preferred security provider" in the region. Building upon this foundation, during his March 2025 visit to Mauritius, Prime Minister Modi, in his bilateral discussions with Mauritian Prime Minister Navinchandra Ramgoolam, unveiled a new initiative — MAHASAGAR (Mutual and Holistic Advancement for Security and Growth Across Regions).[227] MAHASAGAR extends India's maritime vision beyond the IOR, articulating a strategy that seeks enhanced bilateral cooperation, deepened economic integration, and strengthened strategic partnerships across the Global South.

As India seeks to strengthen its maritime capabilities under frameworks like SAGAR and MAHASAGAR, integrating acoustic fingerprinting technologies can offer strategic advantages, including real-time situational awareness, predictive environmental monitoring, and enhanced security surveillance.

226 Ministry of External Affairs. (2015, March 12). Prime Minister Shri Narendra Modi announced Vision SAGAR. Retrieved from https://www.mea.gov.in/newsdetail1.htm?13355%2F=

227 Ministry of External Affairs. (2025, March 12). Prime Minister Shri Narendra Modi announced Vision MAHASAGAR. Retrieved from https://www.mea.gov.in/newsdetail1.htm?13355%2F=

The initiative signals India's intent to foster a more equitable, rules-based maritime order, promoting shared prosperity and collective security.

In the context of sediment transport studies, acoustic fingerprinting facilitates non-invasive, high-resolution tracking of sediment movement, aiding coastal management, port operations, and habitat conservation efforts. It also holds promise for improving the design and monitoring of subsea infrastructure, such as pipelines and undersea cables, where precise environmental knowledge is essential. As India seeks to strengthen its maritime capabilities under frameworks like SAGAR and MAHASAGAR, integrating acoustic fingerprinting technologies can offer strategic advantages, including real-time situational awareness, predictive environmental monitoring, and enhanced security surveillance. Investment in indigenous development of acoustic sensing platforms, supported by artificial intelligence and autonomous underwater vehicles (AUVs), will be vital to fully harness the potential of acoustic fingerprinting, ensuring technological self-reliance and operational superiority in the increasingly contested underwater domain.

TROPICAL WATER CHALLENGES AND THE ROLE OF UDA

India's tropical river systems present unique challenges for sediment management due to their dynamic hydrology, high sediment loads, and seasonal variations in flow. The monsoon season significantly influences sediment transport, causing rapid erosion, siltation, and sediment deposition in riverbeds and coastal areas. This leads to navigation hazards, reduced reservoir capacities, and increased vulnerability to floods. Additionally, tropical rivers like the Ganga, Brahmaputra, and Godavari are prone to heavy sedimentation, affecting inland water transport, hydroelectric projects, and deltaic ecosystems.[228] The interaction of these sediments with marine environments—such as estuaries, coastal wetlands,

228 Kale, V. S. (2010). Recent trends in sediment load of the tropical (Peninsular) river basins of India. Global and Planetary Change, 75(3-4), 108–118. https://doi.org/10.1016/j.gloplacha.2010.01.004:contentReference[oaicite:11]{index=11}

and nearshore habitats—further complicates coastal zone management, impacting fisheries, ports, coral reefs, and estuarine biodiversity.

Underwater Domain Awareness (UDA) can play a crucial role in addressing both riverine and marine challenges by integrating acoustic fingerprinting into a broader, multi-domain monitoring framework.[229] A well-developed UDA strategy enhances real-time sediment tracking, enabling authorities to predict and mitigate excessive siltation in critical inland and coastal waterways. By deploying acoustic sensors in strategic locations—river mouths, deltas, harbours, and continental shelves—researchers can create high-resolution sediment maps that improve dredging operations, coastal planning, and flood management strategies.

Furthermore, UDA-driven data collection supports sustainable river basin and coastal management by monitoring anthropogenic impacts such as dam construction, coastal infrastructure development, and sand mining, which contribute to sediment imbalance. The integration of AI-enabled acoustic analytics with satellite-based remote sensing offers a powerful tool for visualizing and predicting sediment dynamics across both freshwater and marine systems. Leveraging acoustic fingerprinting within a UDA-centric policy framework can significantly strengthen India's capacity for holistic maritime governance, environmental protection, disaster preparedness, and national security in both its rivers and surrounding seas.

Acoustic fingerprinting, a critical tool in underwater surveillance and sediment management, is gaining prominence across multiple sectors, including defence, oceanography, and environmental monitoring. While India has made significant progress in sonar technology and underwater sensing, there is a need for further investment, research collaboration, and policy integration to maximize its potential.

229 Maritime Research Center. (n.d.). Underwater Domain Awareness Framework. Retrieved from https://maritimeresearchcenter.com/

Recognising the critical role of acoustic technologies in strengthening Maritime Domain Awareness (MDA), India has made significant investments in upgrading its hydrographic survey fleets, enhancing seabed mapping projects, and developing indigenous sonar and underwater sensing systems.

NATIONAL VIEW ON ACOUSTIC FINGERPRINTING

India, with its vast coastline and strategic maritime interests, has been steadily advancing its acoustic monitoring infrastructure to enhance security, environmental conservation, and scientific research. Acoustic fingerprinting, a critical tool in underwater surveillance and sediment management, is gaining prominence across multiple sectors, including defence, oceanography, and environmental monitoring. While India has made significant progress in sonar technology and underwater sensing, there is a need for further investment, research collaboration, and policy integration to maximize its potential.

Current State of Acoustic Monitoring Infrastructure

Over the past decade, under the strategic vision of the SAGAR (Security and Growth for All in the Region) initiative, India has steadily expanded its capabilities in underwater sensing and acoustic monitoring, laying a robust foundation for applications such as acoustic fingerprinting. Recognising the critical role of acoustic technologies in strengthening Maritime Domain Awareness (MDA), India has made significant investments in upgrading its hydrographic survey fleets, enhancing seabed mapping projects, and developing indigenous sonar and underwater sensing systems. The Indian Navy, in collaboration with premier research institutions like the National Institute of Ocean Technology (NIOT), the Defence Research and

SAGAR's emphasis on regional cooperation has also enabled India to extend technical assistance and capacity-building initiatives in acoustic surveying to several Indian Ocean littoral states, supporting joint hydrographic missions and promoting data-sharing practices.

Development Organisation (DRDO), and the Indian National Centre for Ocean Information Services (INCOIS), has advanced critical research in underwater acoustics, including seabed characterisation, ambient noise mapping, and object detection based on acoustic signatures.[230] These developments have contributed to the early-stage deployment of acoustic fingerprinting techniques for vessel identification, sediment transport monitoring, and tracking underwater threats in strategic maritime zones.

SAGAR's emphasis on regional cooperation has also enabled India to extend technical assistance and capacity-building initiatives in acoustic surveying to several Indian Ocean littoral states, supporting joint hydrographic missions and promoting data-sharing practices. Pilot projects integrating machine learning algorithms with acoustic data analysis have been initiated in key strategic areas such as the Andaman and Nicobar Islands and the Arabian Sea, aimed at enhancing situational awareness, early warning systems, and environmental monitoring. Acoustic fingerprinting methods are gradually being incorporated into India's coastal and marine conservation efforts, supporting habitat protection for coral reefs, mangroves, and vulnerable marine ecosystems.

In parallel, SAGAR's broader strategic vision has actively promoted research investments and initiatives targeted at indigenous technological advancement in maritime surveillance and environmental stewardship—areas where acoustic fingerprinting holds significant promise. By prioritising safe, secure, and sustainable seas, India has expanded the deployment of underwater acoustic sensors, echo-sounders, and sonar-based platforms aligned with SAGAR's

230 Defence Research and Development Organisation. (n.d.). Sonar & signal behavior. DRDO. https://www.drdo.gov.in/drdo/naval-research-board/sonar-signal-behavior

goals of maritime infrastructure development and technological self-reliance. Collaborative research initiatives, bilateral projects, and regional capacity-building programmes have further facilitated the adoption of acoustic fingerprinting as a non-invasive, real-time method for seabed and sediment characterisation—critical for addressing shared challenges such as sediment-induced port congestion, erosion of coastal infrastructure, and marine habitat degradation.[231]

Moreover, as SAGAR evolves through the recently announced MAHASAGAR (Mutual and Holistic Advancement for Security and Growth Across Regions) strategy, technologies like acoustic fingerprinting are expected to become even more integral to India's regional engagement and maritime governance frameworks. The integration of advanced acoustic techniques ensures that India not only enhances its maritime security architecture but also leads by example in applying science and innovation for sustainable ocean development, aligning with global efforts to advance the blue economy and preserve marine biodiversity.

Defence, Oceanographic, and Environmental Agencies' Perspectives

From a defence perspective, acoustic fingerprinting is crucial for strengthening India's naval operations in the Indian Ocean Region (IOR). With increasing maritime threats, including illegal fishing, smuggling, and potential submarine incursions, the Indian Navy and Coast Guard are prioritizing advanced sonar and acoustic surveillance systems. The integration of AI and machine learning in sonar data interpretation is also being explored to enhance real-time threat detection. Oceanographic and environmental agencies view acoustic fingerprinting as a valuable tool for ecosystem monitoring. Sediment transport studies play a vital role in understanding

Despite the growing recognition of acoustic finger printing's potential, India lacks a unified national policy that integrates this technology across security, environmental, and industrial domains.

231 Deb, S., & Dutta, A. (2023). India's Role in Capability Development Measures for Maritime Security in the Indian Ocean Under SAGAR. Journal of Territorial and Maritime Studies, 10(2), 47–59. https://doi.org/10.2307/JTMS.10.2.47:contentReference[oaicite:7]{index=7}

coastal erosion, river discharge impacts, and habitat degradation. Agencies like the National Centre for Sustainable Coastal Management (NCSCM) emphasize the need for more robust acoustic monitoring networks to address climate change-induced shoreline changes. Acoustic-based marine mammal tracking is also gaining traction as part of conservation efforts for endangered species in Indian waters.

Need for National Policy Integration

Despite the growing recognition of acoustic finger printing's potential, India lacks a unified national policy that integrates this technology across security, environmental, and industrial domains. A structured approach is necessary to establish standardized data collection protocols, enhance inter-agency collaboration, and ensure technological advancements are aligned with national interests.

A national policy framework should focus on expanding acoustic monitoring infrastructure, increasing funding for research and development, and fostering international collaborations. Strengthening partnerships between defence, scientific, and private-sector stakeholders will be crucial for 32advancing acoustic fingerprinting capabilities. Additionally, integrating acoustic data into India's environmental impact assessment processes can help policymakers make informed decisions regarding coastal development and resource management.

While India has made notable progress in acoustic monitoring, a comprehensive national policy and greater investment in research are essential to fully leverage acoustic fingerprinting. By prioritizing this technology, India can enhance maritime security, protect its marine ecosystems, and position itself as a leader in underwater acoustic research.

STRATEGIC IMPORTANCE: WHY INDIA SHOULD FOCUS ON ACOUSTIC FINGERPRINTING

Acoustic fingerprinting is an emerging technology with significant implications for India's national security, environmental conservation, economic interests, and scientific research. Given India's extensive coastline, maritime trade dependencies, and increasing underwater infrastructure, investing in acoustic monitoring and

Acoustic fingerprinting can enhance coastal surveillance by detecting and classifying vessels based on their unique underwater signatures.

fingerprinting can strengthen strategic capabilities and enhance sustainable ocean management.

Security: Coastal Surveillance and Submarine Detection

Maritime security is a critical priority for India, especially in the Indian Ocean Region (IOR), where geopolitical tensions and illicit activities such as smuggling, illegal fishing, and submarine intrusions pose security risks. Acoustic fingerprinting can enhance coastal surveillance by detecting and classifying vessels based on their unique underwater signatures. By integrating acoustic sensing with artificial intelligence, security agencies can improve submarine detection, making it harder for adversarial forces to operate undetected in India's territorial waters.

Additionally, maintaining maritime border integrity is essential for protecting India's Exclusive Economic Zone (EEZ). Underwater acoustic networks can serve as early warning systems, identifying threats in real time. Deploying advanced sonar arrays and underwater listening stations at strategic locations like the Andaman and Nicobar Islands can further bolster India's naval presence and maritime defence capabilities.

Environmental Supervision: Biodiversity Monitoring and Impact Assessments

India's coastal ecosystems, including coral reefs, mangroves, and deep-sea habitats, are vulnerable to climate change, pollution, and industrial activities. Acoustic fingerprinting enables real-time biodiversity monitoring by detecting marine species and assessing habitat conditions.

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Passive acoustic monitoring has already been used to study the movement patterns of whales and dolphins, helping conservation efforts in Indian waters.[232]

The impact of underwater noise pollution from shipping, offshore drilling, and construction can be assessed using acoustic fingerprinting. By analysing changes in soundscapes, scientists can measure how human activities disrupt marine ecosystems. This data can inform regulations on noise pollution and guide the sustainable expansion of India's maritime industries while ensuring marine species are protected.

Economic Interests: Fisheries Management and Infrastructure Protection

India's fishing industry is a vital economic sector, providing employment and contributing to food security. However, overfishing, illegal trawling, and climate-related changes in fish migration patterns threaten its sustainability. Acoustic fingerprinting can support fisheries management by tracking fish populations, identifying illegal fishing vessels, and monitoring ocean conditions that influence marine life distribution. Implementing acoustic-based monitoring can help enforce marine conservation laws and ensure long-term resource sustainability.

Additionally, protecting critical underwater infrastructure—such as undersea communication cables, offshore oil rigs, and wind farms—is essential for national security and economic stability. Acoustic fingerprinting can detect potential threats like anchor damage, sabotage, or natural seabed shifts that could compromise these installations. Strengthening surveillance of offshore energy platforms is particularly crucial as India expands its renewable energy projects in offshore wind and tidal power.

Acoustic fingerprinting can support fisheries management by tracking fish populations, identifying illegal fishing vessels, and monitoring ocean conditions that influence marine life distribution.

232 Indian National Centre for Ocean Information Services. (2020). Marine ecosystem studies and observations. INCOIS. https://incois.gov.in

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Scientific Advancement: Enhancing Oceanographic Research

India has been expanding its oceanographic research capabilities through institutions like the National Institute of Ocean Technology (NIOT) and the Indian National Centre for Ocean Information Services (INCOIS).[233] Acoustic fingerprinting can enhance research by providing high-resolution data on sediment transport, ocean currents, and underwater geological formations. By deploying autonomous underwater vehicles (AUVs) equipped with advanced acoustic sensors, Indian researchers can improve deep-sea exploration and better understand marine ecosystems. Enhanced acoustic sensing can also support climate change research by monitoring ocean acidification and rising sea temperatures, which affect global weather patterns.

Investing in acoustic fingerprinting is a strategic necessity for India. It strengthens maritime security, aids in environmental conservation, supports economic interests, and advances scientific research. As technology evolves, India must prioritize acoustic monitoring infrastructure, policy development, and research collaborations to maximize the benefits of this transformative technology. By doing so, the nation can safeguard its

Acoustic fingerprinting can enhance research by providing high-resolution data on sediment transport, ocean currents, and underwater geological formations.

233 National Institute of Ocean Technology. (2022). Annual report 2021–22. NIOT, Ministry of Earth Sciences. https://www.niot.res.in

While international maritime laws provide general guidelines for underwater acoustics, India's national policies on defence, environment, and fisheries do not fully address the integration of acoustic monitoring.

maritime resources, enhance security, and establish itself as a global leader in underwater acoustics.

EXISTING POLICY LANDSCAPE AND GAPS IN ACOUSTIC FINGERPRINTING

Acoustic fingerprinting, despite its growing strategic and environmental importance, lacks a well-defined policy framework in India. While international maritime laws provide general guidelines for underwater acoustics, India's national policies on defence, environment, and fisheries do not fully address the integration of acoustic monitoring. Several gaps exist in data sharing, jurisdiction, standardization, and policy implementation, limiting the widespread adoption of acoustic fingerprinting in maritime security, resource management, and conservation.

National Defence and Environmental Policies on Acoustic Monitoring

India has made significant strides in maritime security and environmental conservation, yet acoustic monitoring remains underrepresented in national policies. The Indian Navy and Coast Guard use sonar technology for surveillance and anti-submarine warfare, but there is no formal policy integrating acoustic fingerprinting into broader maritime security strategies. Similarly, environmental policies under agencies like the Ministry of Environment, Forest, and Climate Change (MoEFCC) emphasize marine biodiversity protection but lack specific guidelines on acoustic monitoring of ecosystems. The Blue Economy Policy and the National Fisheries Policy recognize the importance of sustainable ocean management but do not incorporate acoustic fingerprinting for monitoring fish stocks, illegal fishing, or seabed health.[234]

234 Ministry of Earth Sciences. (2021). Blue Economy Vision Document of India. Government of India. https://www.moes.gov.in/sites/default/files/MoES_17Feb2021_0.pdf

Unlike developed nations that follow standardized protocols for marine acoustics, India has yet to establish regulations that ensure uniform data collection and interoperability. Without standardization, integrating acoustic fingerprinting into national security, fisheries management, and environmental conservation becomes challenging.

Gaps in Data Sharing, Intellectual Property, and Jurisdiction

One of the critical challenges in acoustic fingerprinting adoption is the absence of a structured data-sharing framework between defence, scientific, and commercial sectors. Acoustic data collected by defence agencies often remains classified, limiting collaboration with oceanographic and environmental researchers. Intellectual property concerns further complicate data accessibility, as private entities involved in offshore exploration may restrict the use of acoustic datasets. Additionally, jurisdictional issues arise when multiple agencies oversee maritime operations, leading to fragmented efforts in integrating acoustic technologies across different sectors. A standardized policy on data accessibility, balancing security and research needs, is crucial to advance India's acoustic capabilities.

Lack of Standardization in Acoustic Data Acquisition and Processing

India lacks a unified standard for acquiring, processing, and storing acoustic data. Different organizations use varied methodologies for underwater acoustic studies, leading to inconsistencies in data interpretation. Unlike developed nations that follow standardized protocols for marine acoustics, India has yet to establish regulations that ensure uniform data collection and interoperability. Without standardization, integrating acoustic fingerprinting into national security, fisheries management, and environmental conservation becomes challenging.

Policy Lag in Acoustic Fingerprinting Integration

Despite its potential, acoustic fingerprinting is not fully embedded in India's maritime security, fisheries

management, and marine conservation policies. While defence agencies use sonar technology, there is little effort to expand its applications for detecting illegal fishing, protecting undersea infrastructure, and monitoring marine biodiversity. Similarly, fisheries policies focus on satellite-based tracking rather than acoustic surveillance to prevent illegal trawling and overfishing.

The absence of a dedicated policy framework hinders India's ability to leverage acoustic fingerprinting for holistic maritime governance.

India needs a comprehensive policy framework that integrates acoustic fingerprinting into national security, environmental conservation, and economic planning. Standardizing acoustic data collection, promoting inter-agency collaboration, and updating policies to reflect technological advancements will ensure India maximizes the potential of acoustic monitoring. By addressing these gaps, India can strengthen maritime security, enhance ecosystem management, and become a global leader in underwater acoustics research and policy implementation.

POLICY RECOMMENDATIONS TO PROMOTE NATIONAL FOCUS

Acoustic fingerprinting is an advanced underwater monitoring technique with vast applications in maritime security, environmental conservation, and oceanographic research. For India, with its extensive coastline and strategic maritime interests, integrating acoustic fingerprinting into national policy is essential for bolstering security, protecting marine biodiversity, and advancing scientific research. However, the absence of a centralized framework, standardized data-sharing mechanisms, and coordinated research efforts has limited its full-scale implementation. To address these challenges, India must adopt a comprehensive set of policy recommendations, including the establishment of a

For India, with its extensive coastline and strategic maritime interests, integrating acoustic fingerprinting into national policy is essential for bolstering security, protecting marine biodiversity, and advancing scientific research.

Public-Private Partnerships (PPPs) can play a key role in developing indigenous acoustic sensing equipment, AI-based signal processing tools, and sonar technologies tailored for India's maritime conditions. defence and technology firms such as Bharat Electronics Limited (BEL) and Hindustan Aeronautics Limited (HAL) can collaborate with premier research institutions like the Indian Institutes of Technology (IITs) and the Defence Research and Development Organisation (DRDO) to develop next-generation acoustic monitoring systems. Additionally, international collaborations should be encouraged to facilitate knowledge transfer and access to cutting-edge technology.

centralized government-led program, incentivization of public-private partnerships, and development of a legal and technical framework for data sharing and utilization.

Establishing a Centralized Government-Led Acoustic Monitoring Program

A dedicated national initiative for the systematic collection, analysis, and utilization of underwater acoustic data is crucial for enhancing India's maritime capabilities. This program should be spearheaded by a multi-agency collaboration involving the Indian Navy, National Institute of Ocean Technology (NIOT), Indian National Centre for Ocean Information Services (INCOIS), and the Ministry of Earth Sciences (MoES). The primary objective of this initiative would be to create a national acoustic database, which can serve multiple sectors, including defence, environmental monitoring, fisheries management, and offshore resource exploration.

The government should set up a network of underwater acoustic sensors in strategic maritime zones such as the Andaman and Nicobar Islands, the Lakshadweep region, and along the Indian coastline.[239] These sensors will enable real-time monitoring of underwater activities, sediment transport patterns, and marine ecosystem changes. Additionally, autonomous underwater vehicles (AUVs) equipped with acoustic sensors should be deployed for deep-sea exploration and sediment analysis.

Funding for this initiative can be sourced through a combination of government allocations, international research grants, and collaborations with global scientific institutions. A well-defined operational framework, including data security protocols and research objectives, should be established to ensure the efficient functioning of this program.

Encouraging Public-Private Partnerships for R&D in Acoustic Technologies

Research and development (R&D) in underwater acoustic technologies require significant investment and expertise. By fostering collaboration between government agencies, private enterprises, and academic institutions, India can accelerate advancements in acoustic fingerprinting. The government should introduce financial incentives such as tax benefits, research grants, and subsidies for startups and established technology firms working on acoustic monitoring solutions.

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Additionally, international collaborations should be encouraged to facilitate knowledge transfer and access to cutting-edge technology. India can engage with leading maritime research centres and defence organizations worldwide to build expertise in acoustic fingerprinting.

Developing a Legal and Technical Framework for Acoustic Data Sharing

A major challenge in leveraging acoustic fingerprinting technology is the lack of a clear legal and technical framework for data sharing. The restricted access to underwater acoustic data due to security concerns, jurisdictional disputes, and the absence of standardized protocols hinders collaborative research and technological advancements. To overcome these barriers, India must establish a structured policy that allows different national entities to share and access acoustic data securely and efficiently.

A tiered classification system for acoustic data should be introduced, categorizing information based on sensitivity levels. Highly classified military data should be restricted to defence agencies, whereas general environmental and scientific data should be made accessible to research institutions and environmental organizations. A central regulatory body, possibly under the Ministry of Earth Sciences, should oversee data-sharing agreements and ensure compliance with security and privacy standards.

To facilitate secure data transactions, cloud-based platforms with controlled access can be developed. Advanced encryption methods, blockchain technology, and artificial intelligence can be integrated into these platforms to ensure data integrity and prevent unauthorized access. Furthermore, the adoption of standardized data

formats and storage protocols will enable seamless interoperability across various research and defence platforms.

Standardizing Acoustic Data Acquisition, Processing, and Storage

Uniformity in data collection methodologies and processing techniques is crucial for ensuring consistency and reliability in acoustic fingerprinting applications. The Bureau of Indian Standards (BIS) should work alongside scientific and defence institutions to establish national standards for acoustic sensor calibration, data acquisition techniques, and storage infrastructure.

Standardized procedures should be implemented for collecting and analysing acoustic data from different marine environments. This includes setting guidelines for hydrophone placement, frequency range selection, and data filtering methods. Training programs should be introduced to equip personnel in relevant agencies with expertise in acoustic data interpretation and management.

Integrating Acoustic Fingerprinting into Maritime Security and Fisheries Management

Maritime security is a top priority for India, given its vast coastline and increasing geopolitical challenges in the Indian Ocean region. Acoustic fingerprinting can play a transformative role in coastal surveillance, submarine detection, and the protection of critical underwater infrastructure such as undersea communication cables and offshore energy installations.

The Indian Navy and Coast Guard should deploy passive acoustic monitoring systems along India's maritime borders to track unauthorized vessel movements and potential underwater threats. AI-driven acoustic analysis tools can be integrated into existing

Acoustic sensors can be deployed in ecologically sensitive areas such as the Sundarbans, the Gulf of Mannar, and coral reef ecosystems to study the impact of human activities on marine life. The data collected can guide policy decisions related to marine conservation, coastal development, and climate change mitigation.

surveillance networks to enable automated detection and classification of anomalies.

In the fisheries sector, acoustic fingerprinting can help monitor fish populations, detect illegal trawling activities, and assess changing ocean conditions. The Ministry of Fisheries should collaborate with marine research institutions to deploy acoustic sensors in key fishing zones, ensuring sustainable resource utilization and combating illegal, unreported, and unregulated (IUU) fishing practices.

Strengthening Environmental Conservation Efforts

Acoustic fingerprinting has significant applications in marine biodiversity conservation and environmental monitoring. The government should integrate acoustic sensing into national marine conservation strategies to track underwater noise pollution, assess ecosystem health, and monitor sediment transport patterns. Acoustic sensors can be deployed in ecologically sensitive areas such as the Sundarbans, the Gulf of Mannar, and coral reef ecosystems to study the impact of human activities on marine life. The data collected can guide policy decisions related to marine conservation, coastal development, and climate change mitigation. Additionally, community participation should be encouraged by involving local fishers and environmental groups in acoustic monitoring programs.

Investing in Human Resource Development and Capacity Building

To successfully implement a national focus on acoustic fingerprinting, India should invest in human resource development and capacity building. Specialized courses on underwater acoustics, AI-based acoustic analysis, and marine technology should be introduced in universities and research institutions. Skill development programs should be launched to train personnel from defence, environmental, and industrial sectors in acoustic data interpretation, equipment maintenance, and research methodologies. Establishing dedicated research centres focused on underwater acoustics will further drive innovation and technological advancements in this field.

Role of Artificial Intelligence (AI) in Acoustic Fingerprinting

Artificial intelligence (AI) plays a crucial role in automating the detection and classification of acoustic

signatures in real-time. Machine learning algorithms analyse vast datasets to identify distinct patterns associated with different underwater objects, sediment compositions, and biological activity. By leveraging AI-driven acoustic analysis, security agencies, marine researchers, and environmental organizations can enhance their monitoring capabilities and decision-making processes. AI-based models improve the accuracy of acoustic fingerprinting by filtering out noise and detecting subtle variations in sound waves, making it a valuable tool for underwater surveillance, marine biodiversity tracking, and sediment transport studies.

In conclusion, to position India as a global leader in acoustic fingerprinting, a comprehensive policy framework is required to integrate this technology into national security, environmental conservation, and economic development strategies. A centralized government-led acoustic monitoring program, supported by public-private partnerships and robust data-sharing mechanisms, will enhance India's maritime capabilities. Standardizing data acquisition methods, strengthening maritime security applications, and promoting research and human resource development will further ensure that India harnesses the full potential of acoustic fingerprinting. By addressing existing policy gaps and implementing these strategic recommendations, India can effectively safeguard its maritime interests, protect its marine ecosystems, and drive scientific innovation in the field of underwater acoustics.

POLICY FORMULATION

Integration with AI and Autonomous Systems

One of the most promising advancements in acoustic fingerprinting is the integration of artificial intelligence (AI) with autonomous underwater vehicles (AUVs) and unmanned undersea vehicles (UUVs).[235] These systems enable real-time acoustic data collection, processing, and anomaly detection at an unprecedented scale. AI-driven algorithms can rapidly analyse massive datasets, identifying patterns and anomalies that would

235 Jenifer, A. K., & George, J. (2024). Underwater acoustic sensor technology review. International Research Journal of Modern Engineering and Technology Science, 6(10), 1–10. https://www.irjmets.com/uploadedfiles/paper//issue_10_october_2024/62960/final/fin_irjmets1730210547.pdf

be difficult for human analysts to detect manually.

Machine learning models can classify acoustic signatures with greater accuracy, distinguishing between natural underwater noise and signals of interest, such as vessel movements, marine life activity, or sediment shifts. By deploying AI-powered AUVs and UUVs in India's strategic maritime zones, real-time monitoring of the seabed and water column can enhance national security, environmental protection, and resource management. These autonomous systems can continuously survey vast underwater regions without human intervention, significantly improving efficiency in maritime operations.[240]

Moreover, integrating AI with acoustic fingerprinting can enhance predictive modelling capabilities. Advanced algorithms can forecast changes in sediment transport, underwater infrastructure stability, and marine ecosystem dynamics based on historical and real-time data. This capability will be crucial in preventing underwater hazards, mitigating environmental damage, and optimizing resource extraction activities.

Development of Global Acoustic Monitoring Networks

To achieve comprehensive ocean monitoring, there is a growing need to develop global acoustic monitoring networks that facilitate cross-border collaboration. Establishing interoperable sensor networks can support initiatives in marine biodiversity protection, underwater noise pollution assessment, and security surveillance.

International data-sharing agreements and standard protocols are essential for enabling seamless cooperation between nations. India, with its strategic location in the Indian Ocean, can play a key role in fostering regional and global partnerships for acoustic monitoring. Collaborations with countries that have advanced underwater acoustic capabilities, such as the United States, Japan, and France, can help India access critical technological expertise while contributing its own research efforts.[236]

By joining global initiatives, India can also strengthen its Maritime Domain Awareness and bolster its capabilities in areas such as

236 Intergovernmental Oceanographic Commission (IOC) of UNESCO. (2021). UN Decade of Ocean Science for Sustainable Development (2021–2030): Implementation Plan. https://www.oceandecade.org/wp-content/uploads/Decade-Implementation-Plan-Version-2.0_web.pdf

illegal fishing detection, submarine tracking, and climate change impact studies. Establishing international acoustic data repositories will promote transparency and support global ocean governance initiatives, benefiting both scientific research and maritime security.

Adaptive Policies for Sustainable Innovation

As acoustic fingerprinting technologies continue to evolve, regulatory frameworks must adapt to ensure their responsible and effective use. Traditional policy structures often struggle to keep pace with rapid technological advancements, leading to gaps in oversight and application. India must adopt flexible regulatory policies that allow for continuous adaptation based on emerging use cases and technological developments.

A key aspect of adaptive policy making is balancing technological innovation with environmental conservation. Acoustic monitoring must adhere to guidelines that mitigate potential disturbances to marine life while maximizing its benefits for security and scientific research. Establishing national and regional acoustic monitoring guidelines will help regulate data collection activities, prevent unethical surveillance, and promote sustainable development in marine industries.

To fully capitalize on acoustic fingerprinting advancements, India must invest in infrastructure development and human resource capacity building. Establishing state-of-the-art acoustic monitoring facilities, cloud-based analytics platforms, and high-performance computing resources will be essential for processing and storing vast amounts of underwater acoustic data.

Additionally, regulatory frameworks should provide clear directives on intellectual property rights, ensuring that research institutions and private sector innovators can develop and commercialize acoustic technologies while maintaining national security interests. Incentivizing ethical AI

Collaborating with global regulatory bodies, such as the International Maritime Organization (IMO) and the Intergovernmental Oceanographic Commission (IOC), will help India align its acoustic monitoring strategies with international best practices.

By prioritizing UDA and leveraging acoustic fingerprinting, India can fortify its maritime security, protect marine biodiversity, and harness its blue economy for sustainable growth.

development in underwater acoustics will be crucial to maintaining transparency, accountability, and long-term sustainability.

Enhancing Data Security and Standardization

As India expands its acoustic monitoring capabilities, ensuring data security and standardization will be paramount. Acoustic data can be highly sensitive, especially in defence applications, necessitating robust encryption and cybersecurity measures to prevent unauthorized access or data breaches. A standardized framework for data acquisition, storage, and processing should be implemented to facilitate seamless interoperability between different agencies and research bodies. Establishing national acoustic data repositories with tiered access protocols will enable secure information sharing while maintaining confidentiality for classified datasets.

Additionally, India should actively participate in international efforts to develop standardized methodologies for acoustic fingerprinting. Collaborating with global regulatory bodies, such as the International Maritime Organization (IMO) and the Intergovernmental Oceanographic Commission (IOC), will help India align its acoustic monitoring strategies with international best practices.[237]

Future advancements in acoustic fingerprinting, driven by AI integration, global collaboration, adaptive policies, infrastructure development, and enhanced data security, will significantly enhance India's maritime capabilities. By strategically investing in these areas, India can establish itself as a global leader in underwater acoustic monitoring while safeguarding its security, economic, and environmental interests. Through sustained innovation and policy adaptation, acoustic fingerprinting can become a cornerstone of

237 International Maritime Organization. (2023). Revised guidelines for the reduction of underwater radiated noise from shipping to address adverse impacts on marine life. https://wwwcdn.imo.org/localresources/en/Documents/MEPC.1-Circ.906.pdf

India's maritime strategy, driving advancements in defence, research, and sustainable ocean management.

CONCLUSION

Acoustic fingerprinting is a crucial technology for strengthening Underwater Domain Awareness (UDA), a key aspect of maritime security, environmental conservation, and scientific research. By analysing underwater acoustic signatures, this technology provides critical insights into naval operations, ecosystem health, fisheries management, and offshore energy infrastructure. However, India's current acoustic monitoring capabilities remain fragmented, with gaps in policy integration, data-sharing frameworks, and technological standardization.

To address these challenges, a centralized, government-led UDA initiative is necessary, integrating acoustic fingerprinting into national security, marine conservation, and economic strategies. Public-private partnerships must be encouraged to drive indigenous research and development in acoustic technologies. Additionally, robust legal and technical frameworks should regulate data collection, processing, and sharing while ensuring national security and strategic interests. AI-driven acoustic analysis and autonomous underwater vehicles (AUVs) can enhance real-time monitoring, strengthening India's maritime situational awareness.

Future trends indicate a growing focus on global acoustic surveillance networks, adaptive regulatory policies, and infrastructure investments. By prioritizing UDA and leveraging acoustic fingerprinting, India can fortify its maritime security, protect marine biodiversity, and harness its blue economy for sustainable growth. A long-term strategic vision is essential to establish India as a global leader in underwater acoustic research and technology.

Maritime Heritage and Indigenous Knowledge

Radhika Seshan

BACKGROUND

The paper focusses on the twin aspects of heritage and knowledge, primarily through identifying areas where oral and community traditions can help us to understand forms of engagement with the maritime world in the past, and the ways in which this shaped the ways in which coastal communities dealt with aspects of the littoral world in particular.

What is heritage, and what is knowledge? And how are the two to be used to understand the maritime and the coastal worlds? It is, I believe, necessary to begin with defining the terms that are being used. There are three words that need to be explained – heritage, maritime, and indigenous. To begin with heritage, what do we mean by the term? It is a word that has become much more commonly used in recent times, to talk of many things. But for the common person, the word instantly conjures up an image of a building – of what is often termed a 'monumental heritage'. Thus, issues of conservation, restoration or preservation of monuments become a key concern, and much of the discussion has revolved around these issues. So then, the question arises, what is heritage? My answer would be that it has to be at least three things – the built heritage, the natural heritage, and the human heritage. By the last, I mean attitudes, eccentricities of a city or of its inhabitants that become its defining characteristic, or ways of living in certain parts of a country or a city, which are distinctly different from others, not too far away in terms of mileage, and worlds apart in culture. For example, if we look at ports and fishing villages, we have people who live in the larger ports (Mumbai included) for whom the sea seems to be just part of the background, rather than an intrinsic part of their daily life. The sea is thought about during the monsoon, not because of the rain or the season itself, but because of the flooding of parts of the city that happen every year during the rainy season. Then there are those who live

What is heritage? My answer would be that it has to be at least three things – the built heritage, the natural heritage, and the human heritage.

For most indigenous, coastal, and riverine communities, rivers and forests are simultaneously livelihood and environment.

nearer the sea who may walk along the sea, or sit on the bulwarks bordering the seafront and enjoy the breeze. But move towards the areas which are still occupied by the fisherfolk, or the areas of the Indian Navy, and there is a different city scape that emerges. Heritage, therefore, is a matter also of human perception of the areas that they occupy, and therefore of the world view that they have about their spaces. In other words, the spaces, mental and cultural, that they occupy, are crucial to their perception of the geographical spaces that they inhabit. Thus, for the city dweller, it is about infrastructure, about the buildings (Mumbai has a thriving urban heritage preservation community), but not so much the natural heritage.

Moving on to the domain of natural heritage, rivers and forests emerge as central, living entities within the cultural and ecological landscape. These are not just physical resources, but repositories of history, memory, and identity. However, the ways in which communities perceive and engage with rivers and forests vary greatly, shaped by local traditions, economic dependencies, and policy narratives. A crucial tension exists between viewing these spaces as sources of livelihood versus viewing them as environments to be protected. In truth, this dichotomy is artificial and often imposed through top-down governance mechanisms or conservation paradigms that overlook lived realities.

For most indigenous, coastal, and riverine communities, rivers and forests are simultaneously livelihood and environment. They offer tangible sustenance—fish, fuelwood, medicinal plants, agricultural irrigation, and forest produce—as well as intangible services—cultural continuity, spiritual rituals, and socio-ecological resilience. Attempting to separate economic use from environmental value can result in governance blind spots, where neither objective is truly achieved. Instead, integrated approaches are needed that recognize

A river, across time and space, is not merely a body of flowing water. It is life itself—hydrating the land, supporting biodiversity, and anchoring seasonal rhythms. It is livelihood—powering agriculture, enabling transport, and sustaining artisanal economies. And it is culture—sacred geography, the site of rituals, festivals, and the locus of intangible heritage.

the co-dependence of ecological health and human well-being.

A river, across time and space, is not merely a body of flowing water. It is life itself—hydrating the land, supporting biodiversity, and anchoring seasonal rhythms. It is livelihood—powering agriculture, enabling transport, and sustaining artisanal economies. And it is culture—sacred geography, the site of rituals, festivals, and the locus of intangible heritage. From ghats and temples to boat-making and storytelling traditions, rivers have been at the heart of civilizational imagination.

Similarly, forests are not just biodiversity hotspots but living landscapes of human-nature symbiosis. Communities dwelling in or around forests have evolved intricate systems of stewardship, often rooted in customary laws and spiritual beliefs. These systems balance extraction and regeneration, providing a valuable alternative to extractive models of natural resource management.

In the current context of climate change, biodiversity loss, and ecological displacement, rethinking rivers and forests through this integrative lens is not only timely but essential. Marine Spatial Planning (MSP), Blue Economy frameworks, and Underwater Domain Awareness (UDA) strategies must extend their

The need of the hour is a governance model that respects natural heritage as dynamic and multifunctional—where livelihood, environment, and culture are seen not as competing priorities, but as interwoven imperatives.

vision upstream—recognizing rivers and forests as part of a continuous socio-ecological system that feeds into coastal and marine ecosystems.

The need of the hour is a governance model that respects natural heritage as dynamic and multifunctional—where livelihood, environment, and culture are seen not as competing priorities, but as interwoven imperatives.

What I also pointing to is the intertwining of the three different aspects of heritage that I have talked of above, for the human is who identifies with, engages with, or destroys the heritage, both natural and built. And so, an understanding of the many aspects of heritage becomes crucial.

Moving on to the maritime, it has long been assumed that 'maritime' necessarily means oceanic spaces. As I have pointed out on many occasions, the word comes from the Latin *mare* or *mer*, which merely means water, and not saltwater. Therefore, 'maritime' includes salt and fresh water, swamps, lakes (fresh and salt), inland seas (like the Caspian or the Dead Sea), and of the many lives around these water bodies. Coasts are especially important, for they involve land, sea, and the worlds of both, and the people who occupy such areas – the littoral societies. It would perhaps be useful to quote a major maritime historian, M.N. Pearson, on littoral societies. He says:

"....there is such a thing as littoral society, that is, that we can go around the shores of an ocean, or a sea, or indeed the whole world, and identify societies that have more in common with other lit toral societies than they do with their inland neighbours. Location on the shore transcends differing influences from an inland that is very diverse, both in geographic and cultural terms, so that the shore folk have more in common with other shore folk thousands of kilometres away on some other shore of the ocean than they do with those in their immediate hinterland. Surat ocean than they do with those in their immediate hinterland. Surat and Mombasa have more in common with each other than they do with inland cities such as Nairobi or Ahmadabad."[238]

He went on to say that while studying littoral societies, "location on or near the shore" was important, both location and culture were important. Littoral societies are by definition those

238 M.N. Pearson, "Littoral Society: The Concept and the Problems", Journal of World History, Vol. 17, No. 4 (Dec. 2006), pp. 353-373.

For accumulating indigenous knowledge, the first and most important aspect is that of listening. Many communities have stories to tell, which are often dismissed as 'mere myth'. They may well be myth now; but we need to ask whether, embedded in these stories, there is a historical reality.

that occupy the spaces between land and sea and therefore belong to both. But some communities may, he said, belong to the land more than to the sea, despite living in close proximity to the sea, and the reverse would be equally true. How do we study the two? As coastal, as maritime, as pastoralists or agriculturalists, or a combination of all? And where in this do we locate the marauders – both those from land and those from sea? Historically, it has been argued that piracy in some parts of the world was a seasonal occupation of those who could not derive enough from land; and in the 17th century, the Dutch in Malabar complained that they could not get a monopoly of pepper, for they did not have access to the multiple routes across the peninsula, used by those who 'smuggled' the pepper across to the other coast and so to other markets. The British, too, used the terms smuggling and piracy almost interchangeably, and as labels, so that those who challenged them were cast as either smugglers or pirates or both.

What Pearson pointed to was the gaps in historical research. As Edward Alpers[239] said,

"A study of littoral society is much more holistic than that of port cities, and forces one to concentrate much more on the sea, thus avoiding the temptation to which many port city studies have succumbed, that is, the tendency to stray inland to distant markets and influences, and ignore the sea altogether."

It is from these questions and histories that I approach the idea of knowledge. It is to be remembered that knowledge is not and cannot be static. The aggregation of knowledge is undoubtedly important, but the point is that it is an aggregation. And so, what has been added and what has been lost are questions to which

239 Edward A. Alpers, "From Littoral to Ozone: On Mike Pearson's Contributions to Indian Ocean History", Journal of Indian Ocean World Studies, 2, No. 1 (2018), pp. 12-24.

we cannot find answers. Nevertheless, there are certain aspects that we can still trace, remembering always that with the passage of time, concerns and problems have changed.

For accumulating indigenous knowledge, the first and most important aspect is that of listening. Many communities have stories to tell, which are often dismissed as 'mere myth'. They may well be myth now; but we need to ask whether, embedded in these stories, there is a historical reality. To quote Pearson again, "When we look to the sea, we need to separate out the coastal zone from the deep water." What stories of the coast can we get? For example, on the west coast of India, there are certain small creeks which are avoided by the fisherfolk at certain times of the day. When asked, they merely say that it is not safe – but many are unable to say anything more than that. These are tidal creeks, and during ebb tide, there are strong currents that drag one out to sea, but this is never specifically stated. Knowledge of winds and currents is deeply ingrained in those who deal with water on a daily basis, and it is this knowledge that is of prime importance.

But we also need to remember that, as I said above, knowledge is aggregated. What have these communities learnt about the vagaries of the oceans in more recent years? Environmental changes have taken place, and with global warming, water levels have risen. How has this affected fishing? Fisherfolk have their traditional fishing grounds, but the impact of environmental change on these grounds needs to be studied. To this, we also need to add the effects of human intervention in the waters. One study on the impact of the establishment of a port on the east coast of India demonstrated that the fisherfolk of the region had moved further south to fish, but had 'infringed' on the area that traditionally belonged to the folk of a different part of the coast, resulting in clashes between the two groups. This was seen as a law-and-order problem, which, no doubt, it was; but there were other, deeper causes, which were never understood or addressed.

Another critical yet underexplored aspect in the Indian Ocean Region's interconnected maritime and riverine systems is sedimentation. The extensive construction of dams and barrages upstream in major rivers—

Reduced sediment supply undermines the natural expansion and resilience of mangrove forests, making them more vulnerable to storm surges and rising sea levels. In many regions, the lower stretches of rivers are now marked by saline intrusion, land loss, and declining fish stocks—all linked to sediment deprivation.

such as the Ganges, Brahmaputra, and Indus—has significantly altered the natural flow regimes and sediment load reaching the lower reaches and coastal deltas. Sedimentation is a fundamental process that shapes estuarine and deltaic ecosystems, supports mangrove proliferation, and replenishes coastal landforms. Its disruption has triggered a cascade of ecological consequences, including delta subsidence, erosion of riverbanks, and loss of biodiversity in estuarine zones.

While mangroves have received increasing attention in climate resilience and conservation dialogues, there remains a critical gap in understanding the impact of altered sediment dynamics on their regeneration and stability. Reduced sediment supply undermines the natural expansion and resilience of mangrove forests, making them more vulnerable to storm surges and rising sea levels. In many regions, the lower stretches of rivers are now marked by saline intrusion, land loss, and declining fish stocks—all linked to sediment deprivation.

Equally important is the socio-economic transformation occurring along these riverine corridors. Historically, ferries served as vital connectors between communities on either bank, particularly near river mouths where trade and daily life revolved around water-based mobility. These ferry system's not only facilitated transportation but also sustained local livelihoods, cultural exchange, and access to shared resources. However, the expansion of bridge infrastructure has gradually replaced ferry routes, especially in peri-urban and semi-rural areas. While bridges offer improved connectivity and year-round access, they have also transformed the spatial and cultural relationship between communities and their rivers.

In many fringe and deltaic regions, people now engage with the river less as a lived ecosystem and more as a background to infrastructural modernity. This shift has implications for environmental stewardship, disaster preparedness, and water governance. The reduction in direct, daily interaction with the river—once a source of identity, economy, and resilience—may weaken community-based monitoring, traditional ecological knowledge systems, and participatory management practices.

Understanding the interplay between sedimentation, infrastructural change, and community engagement is essential to designing holistic and inclusive approaches under initiatives like SAGAR and Marine Spatial Planning (MSP). It also underscores the need to integrate riverine and coastal processes within the broader Underwater Domain Awareness (UDA) framework, recognizing that sustainable ocean governance begins far upstream.

There has also been a great deal said on the knowledge of indigenous communities and their importance. This also needs to be addressed in more specific terms. Wind roses have been used over centuries; can we correlate this knowledge to present wind systems, and try to map the changes that have occurred? Every year, in India, the effects of El Nino and La Nina are tracked anxiously, but do indigenous communities have a knowledge that predates these names? In other words, do they have an inherited legacy of oral traditions about the monsoon and its force that predates these terms, but which are in many ways similar. It is, I would suggest, time that we approached this knowledge in a much more systematic fashion.

Finally, there is the question of health. All communities have health issues specific to their occupation. For the coastal communities, these would have earlier included things ranging from rope burns to tetanus to scurvy to malnutrition and tuberculosis, and much more. How did they deal with these earlier? Do they still have a vocabulary for these, and a possible local cure for at least some of them?

I am fully aware that this paper poses more questions than it answers. However, the deliberate act of raising questions is a necessary precursor to generating meaningful answers. Without first identifying the gaps in understanding and the ambiguities in current approaches, there can be

no systematic search for solutions. In this regard, the present work should be viewed more as an exercise in framing the contours of future inquiry rather than a culmination of primary research findings. The intent has been to outline emerging areas of concern and interest that merit deeper exploration by scholars, practitioners, and policymakers alike.

Indeed, asking the right questions is the first and most critical step in advancing knowledge. It is only by interrogating existing assumptions, highlighting underexplored dimensions, and surfacing latent tensions that we can move toward a more comprehensive and effective framework for regional maritime cooperation. In that spirit, I reiterate that we must not only seek answers but be prepared to ask even more nuanced and challenging questions as we progress.

The Way Ahead
100 Warriors Initiative

Nishtha Vishwakarma

By empowering a diverse group of coastal, river, and water warriors—activists, researchers, educators, and everyday citizens—the 100 warriors initiatives of MRC, Pune seeks to raise awareness, drive sustainable practices, and foster a deeper connection between people and their marine and water resources in line with the SAGAR vision.

BACKGROUND

The '100 Warriors' initiative, which has been crafted and developed by the Maritime Research Center (MRC), aligns with the *Security and Growth for All in the Region (SAGAR)* vision of the Government of India (GOI). The SAGAR vision recognises the security concerns in the Indian Ocean Region (IOR) and acknowledges the economic opportunities for building growth and prosperity for all. The alignment of these two initiatives ensures improved livelihoods of the coastal and riverine communities and offer sustainable use of ocean resources for economic development. By empowering a diverse group of coastal, river, and water warriors—activists, researchers, educators, and everyday citizens—the 100 warriors initiatives of MRC, Pune seeks to raise awareness, drive sustainable practices, and foster a deeper connection between people and their marine and water resources in line with the SAGAR vision. This research paper will highlight how the '100 Warriors' initiative brings benefit to the socio-economic, socio-political, and socio-cultural aspects of these fisherfolk communities. This project, which intends to introduce new employment avenues, specifically empowers the youth from the coastal and riverine communities, which will ultimately help them achieve economic empowerment and employment generation. Additionally, focusing on ecological conservation benefits both the fisherfolk and the wider community and ecosystem, safeguarding delicate marine ecosystems and supporting biodiversity.

INTRODUCTION

The '100 Warriors' initiative[240] focuses on strengthening the livelihoods of coastal and riverine communities by providing them with skills, training, and support to better handle challenges associated with climate change, unsustainable practices, coastal erosion, and economic pressures from overfishing or illegal fishing activities. This initiative aligns with the *Security and Growth for All in the Region (SAGAR)* vision

240 Maritime Research Center. 100 Coastal Warriors-Concept Note. https://maritimeresearchcenter.com/wp-content/uploads/2024/10/100-Coastal-Warriors-Concept-Note-1.pdf

of the Government of India (GOI)[241]. The SAGAR vision recognises the security concerns in the Indian Ocean Region (IOR) and acknowledges the economic opportunities for building growth and prosperity for all. The action plan with the deployed warriors revolves around revitalising coastal and riverine communities through practical solutions. The aim is to empower these communities to protect their own livelihoods and work towards more sustainable, long-term practices. This initiative promotes the sustainable use of ocean, river, and water resources for economic growth, improved livelihoods, and job creation while preserving the health of these ecosystems. By integrating blue economy principles, coastal and riverine communities, the initiative seeks to balance economic development and environmental stewardship, ensuring that the rich marine resources contribute to long-term prosperity and ecological sustainability.

In addition to catering to the coastal and riverine communities, the '100 Warriors' Initiative also covers prospects associated with water resource management in India. Besides its 8000 km[242] (approximately) coastline and major rivers like the Ganges and Brahmaputra, India has diverse water resources, including extensive groundwater reserves that are mainly contributed by substantial monsoon rainfall. Effective management of these water resources requires sustainable practices such as rainwater harvesting and efficient irrigation, technological innovations like remote sensing and desalination, and robust policy frameworks to ensure equitable distribution and use.[243] Community engagement and awareness campaigns are crucial for facilitating a culture of conservation of these resources, and that is where the '100 Warriors' initiative can be of great significance. The initiative's programs will focus on education, community engagement, and hands-on restoration efforts, encouraging participants to participate in water, river, and ocean conservation activities. From organising clean-up events and

241 Press Information Bureau (PIB) Release. Ministry of Defence. March 2022. https://pib.gov.in/PressReleasePage.aspx?PRID=1807607

242 Survey of India. https://surveyofindia.gov.in/webroot/UserFiles/files/Length%20of%20Coastline%20of%20India.pdf

243 Jal Shakti Abhiyan: Catch the Rain. Ministry of Jal Shakti. https://jsactr.mowr.gov.in/

By aligning with the UDA Framework, the Initiative aims to build innovation and inclusivity in sustaining traditional livelihoods whilst embracing modern practices.

habitat restoration projects to hosting workshops and educational outreach, the aim is to equip individuals with the knowledge and tools they need to make a lasting impact. The aspiration is to build resilient communities that cherish and protect their natural resources by aiding a sense of ownership and responsibility for our waterways.

The initiative has been progressing the Underwater Domain Awareness (UDA) framework[244] for safe, secure, and sustainable growth for all in the tropical waters of the Indian Ocean Region (IOR) and beyond. The UDA Framework addresses the policy, technology interventions, acoustic capacity & capability-building requirements[245]. By aligning with the UDA Framework, the Initiative aims to build innovation and inclusivity in sustaining traditional livelihoods whilst embracing modern practices. This initiative envisions building resilience, preserving ecosystems, and empowering the coastal and riverine communities for sustained progress. By collaborating with local stakeholders and leveraging targeted technology integrations, the aim is to create sustainable models that empower beneficiaries while preserving the fragile ecological balance.

By empowering a diverse group of coastal, river, and water warriors—activists, researchers, educators, and everyday citizens—the initiative seeks to raise awareness, drive sustainable practices, and foster a deeper connection between people and their marine and water resources. The '100 Warriors' initiative will benefit these indigenous communities in their socio-economic, socio-political, and socio-cultural areas. This project, which intends to introduce new employment avenues, will specifically empower the youth from the coastal and riverine communities, which will ultimately help them achieve economic empowerment and employment

244 Dr (Cdr) Arnab Das. Maritime Research Center. Underwater Domain Awareness (UDA) Framework. https://udafoundation.in/wp-content/uploads/2024/12/Underwater-Domain-Awareness-UDA-Framework.pdf

245 UDA Foundation website. https://udafoundation.in/

generation. Additionally, the focus on ecological conservation benefits the fisherfolk and the wider community and ecosystem, safeguarding delicate marine ecosystems and supporting biodiversity.

UNIQUENESS OF THE TROPICAL WATERS: MAJOR CHALLENGES FACED BY THESE COMMUNITIES

Given the challenges of climate change, overfishing, displacement, and territorial disputes, initiatives like 100 Warriors, which focus on empowering communities, promoting sustainable livelihoods, and enhancing disaster resilience, are essential to maintaining a balance between growth, security, and cultural preservation in these regions. The tropical waters exhibit unique characteristics, including rich biodiversity, abundant and diverse mineral resources, and underwater acoustic propagation, all of which significantly impact local communities. These waters are significant from an ecological and environmental perspective, and they are deeply intertwined with the livelihoods, governance, and cultures of the communities living along their coasts and within their water systems. In brief, tropical waters have unique socio-political, socio-economic and socio-cultural characteristics that are intricately tied to the ecosystems they support. These factors influence how coastal and riverine communities interact with their environment, govern their territories, and develop their economies.

Tropical waters are often situated in regions with complex socio-political dynamics. Although these waters are home to abundant marine resources, managing them frequently involves complex socio-political negotiations between government authorities, local communities, and international stakeholders. Countries or communities managing tropical waters often face challenges in balancing economic development with environmental sustainability. In some cases, regional agreements or international conventions may be aimed at preserving these ecosystems, such as the United Nations Convention on the Law of the Sea (UNCLOS)[246] or regional cooperative frameworks like SAGAR Vision (Security and Growth for

246 Sunil Kumar Agarwal and Kamlesh K. Agnihotri. UNCLOS and climate-induced maritime challenges: Strategic implications for the Indian Ocean Region. Maritime Affairs: Journal of National Maritime Foundation. Taylor and Francis. https://www.tandfonline.com/doi/abs/10.1080/09733159.2022.2097702

All in the Region) in the Indian Ocean. Socio-political issues can also arise due to climate-induced migration. Coastal communities in tropical regions are increasingly vulnerable to rising sea levels, storm surges and other climate-related disasters. The displacement of populations from low-lying coastal areas leads to tensions over migration, land rights and urbanisation.

It is worth noting that tropical waters have a significant influence on the socio-economic conditions of communities that rely on them, often forming the backbone of local economies. The 100 Warriors initiative aims to enhance the resilience of these communities by promoting sustainable fishing practices and providing training in resource management, which is directly linked to the socio-economic stability of these regions. Communities in these regions often lack the financial resources to adapt to or mitigate the impacts of climate change, further deepening the socio-economic divide. Efforts like the 100 Warriors initiative, which focus on resilience building and sustainable livelihoods, are vital to addressing this issue. Coastal populations rely on the sea for fishing, salt production, aquaculture, and various marine-based industries, including seaweed farming. As these industries face challenges of environmental degradation and overexploitation, communities' access to income and food security becomes precarious.

Indigenous communities in tropical regions often possess sophisticated knowledge systems regarding marine ecosystems, fishing practices, and the sustainable management of resources. These communities are custodians of traditional knowledge that has been passed down for generations, often including practices that promote biodiversity conservation and sustainable livelihoods. However, these Indigenous communities can face challenges from external economic forces, government policies, and modernisation, which often undermine traditional practices. Initiatives like 100 Warriors, which incorporate traditional ecological knowledge into modern conservation efforts, will help preserve these cultural practices while ensuring economic stability. By addressing the human and environmental dimensions of tropical waters, these communities can thrive while contributing to the broader objectives of regional stability and inclusive development.

ALIGNMENT OF THE '100 WARRIORS' WITH SAGAR VISION

While SAGAR Vision broadly focuses on regional security, maritime trade, and growth, it also underscores the importance of inclusive development in the Indian Ocean Region (IOR)[247]. It aims to promote regional cooperation and security, but also recognises that the well-being of local communities is central to long-term prosperity. The 100 Warriors initiative seeks to empower coastal, riverine, and water resource-dependent communities, equipping them with the skills and knowledge to address environmental challenges and improve their socio-economic conditions. It focuses on building the capacity of these communities to be self-reliant, helping them improve their livelihoods, protect their resources, and respond to challenges such as climate change, resource depletion, illegal fishing, water scarcity, and other environmental issues. This aligns directly with the SAGAR Vision's goal of inclusive growth. By improving the livelihoods and resilience of vulnerable communities, 100 Warriors will contribute to a more stable and prosperous region.

Sustainable Resource Management: One of the core goals of the SAGAR Vision is sustainability, especially in the context of maritime and coastal resources. By promoting the responsible and sustainable management of both marine and freshwater water resources, the SAGAR Vision envisions long-term economic stability and environmental preservation. The '100 Warriors' initiative directly contributes to this by supporting communities involved in coastal, riverine, and water resource management. Through training in sustainable practices, such as responsible fishing, eco-friendly agriculture, water conservation, and flood management, the initiative helps these communities protect their ecosystems and manage water resources more efficiently. This enhances environmental resilience and supports sustainable growth, aligning with the SAGAR Vision's focus on maintaining ecological balance for long-term regional prosperity. For

247 Deepak Tongli. May 2024. SAGAR POLICY India's Doctrine of Maritime Cooperation in the Indian Ocean Region. https://www.researchgate.net/publication/380971035_SAGAR_POLICY_India's_Doctrine_of_Maritime_Cooperation_in_the_Indian_Ocean_Region

example, communities dependent on coastal fisheries are trained in sustainable fishing techniques that protect fish stocks, prevent overfishing, and ensure the marine ecosystem remains intact. Similarly, riverine communities are educated on water management techniques to avoid over-extraction, reduce pollution, and prevent soil erosion, which protects their livelihoods and the broader ecosystem. By offering tailored skill development programs and promoting sustainable fishing practices, this initiative empowers the coastal and riverine communities to adapt to climate change challenges while securing their livelihoods. Additionally, focusing on ecological conservation benefits both the fisherfolk and the wider community and ecosystem, safeguarding delicate marine ecosystems and supporting biodiversity. It will specifically empower the youth from the coastal community, which will ultimately help them with economic empowerment and employment generation.

Resilience to climate change and natural disasters: Another area where the '100 Warriors' initiative aligns with the SAGAR Vision is its focus on building resilience to climate change and natural disasters. The SAGAR Vision acknowledges the vulnerability of countries in the IOR to climate change, natural disasters, and environmental degradation. Coastal areas are particularly susceptible to sea-level rise, cyclones, and flooding, while riverine communities face threats from changing water levels, droughts, and floods. The 100 Warriors initiative focuses on enhancing the disaster resilience of these communities by training them in disaster preparedness, early warning systems, and climate adaptation strategies. These trainings will enable these communities to respond more effectively to natural disasters and climate change events, which directly aligns with SAGAR Vision's objective of fostering a resilient region capable of handling environmental and climate-related challenges. For instance, coastal communities might be trained to build storm-resistant infrastructure or adopt flood-prevention techniques, while riverine communities could be equipped to handle sudden changes in river flow, such as floods or droughts. By ensuring that these communities can effectively cope with environmental challenges, the 100 Warrior initiative strengthens the

security and sustainability aspects of the SAGAR Vision.

Regional security and cooperation: The SAGAR Vision advocates for regional cooperation in managing the common resources of the IOR, including maritime routes, fisheries, and water bodies. By fostering collaboration among regional stakeholders, SAGAR aims to create a secure and stable environment that facilitates growth and cooperation. The 100 Warriors initiative enhances community-level security by promoting collaboration between coastal and riverine communities at the local level. These communities often share common water resources, such as rivers or seas, and may face challenges related to conflicts over resource use, illegal activities, or climate-induced displacement. Through training and capacity-building initiatives, 100 Warriors can help establish cooperative frameworks that enable these communities to share resources, promote peaceful coexistence, and work together on joint disaster response efforts. This strengthens local security and contributes to regional stability, a key goal of the SAGAR Vision.

SAGAR Vision promotes the idea that the security and prosperity of one community or nation are intertwined with others in the region, and the 100 Warriors initiative helps create this interconnected security at the grassroots level.

Supporting economic and social development: SAGAR Vision aims to create an environment conducive to economic growth, particularly in regions heavily reliant on maritime trade and fisheries. By ensuring that coastal and riverine communities are secure, self-sufficient, and resilient, the SAGAR Vision lays the foundation for sustainable regional development. [248]The 100 Warriors initiative focuses on contributing to economic growth by providing skills training, given opportunities for entrepreneurship, and improving the lives of communities. This training may cover areas such as eco-tourism, aquaculture, water management, and sustainable agriculture, enabling these communities to diversify their income sources and reduce their vulnerability to market shocks

248 SAGAR – India's Vision for the Indian Ocean Region. India Foundation. November 1, 2017. https://indiafoundation.in/articles-and-commentaries/sagar-indias-vision-for-the-indian-ocean-region/

or environmental changes. By fostering economic independence and promoting sustainable practices, the 100 Warriors initiative ensures that these communities continue to thrive, thereby supporting the broader economic growth goals of SAGAR Vision.

Hence, it can be well established that the '100 Warriors' initiative aligns with the SAGAR Vision in several significant ways, especially it helps in promoting inclusive development, sustainability, regional cooperation, and climate resilience. Therefore, by empowering coastal, riverine, and water resource-dependent communities, the initiative helps strengthen local economies, protect natural resources, and improve the security of communities in the IOR. Through training, capacity-building initiatives, and community engagement initiatives, 100 Warriors can directly contribute to the overarching goals of the SAGAR Vision, ensuring that growth and security are shared across all communities in the region, with a focus on sustainable and resilient development. This partnership between local empowerment and regional cooperation is essential for achieving the broader objectives of Security and Growth for All in the Region.

WATER, RIVER AND COASTAL MANAGEMENT STRATEGIES OF THE '100 WARRIORS' INITIATIVE

The 100 Warriors Initiative stands as a robust grassroots response to some of the most pressing environmental and social challenges facing India's coastal, riverine, and water-dependent communities. This initiative supports traditional knowledge systems, local participation, and long-standing practices that have historically supported the delicate balance between communities and their surrounding ecosystems. As climate change continues to accelerate, with rising sea levels, erratic rainfall patterns, and worsening droughts, the 100 Warriors will play a critical role in building resilience, promoting sustainability, and reestablishing harmony with nature.

A central pillar of the initiative is the restoration of rivers and coasts, particularly in vulnerable areas. Drawing inspiration from successful models like those seen along Odisha's

One of the most distinctive and culturally rich elements of the 100 Warriors Initiative is its emphasis on reviving traditional water management techniques. In Rajasthan, for example, ancient systems like the 'kundi' —a simple, yet ingenious rainwater harvesting method—are being reintroduced. These systems, designed to collect and store scarce rainfall in arid zones, have offered water security for generations.

Devi River mouth[249], the 100 Warriors can be actively engaged in restoring mangrove forests and other coastal vegetation. These natural ecosystems play an essential role in buffering coastal communities from storm surges, tidal flooding, and erosion—all of which have become more frequent and intense due to global warming. By reviving these habitats, the initiative not only strengthens natural defences but also revitalises biodiversity, which in turn supports local fisheries and livelihoods. On the livelihoods front, the initiative supports a transition to sustainable income sources that align with environmental goals. In several coastal regions, community members—especially women and young people—will be trained in practices such as seaweed farming, constructing artificial reefs, and using green fuels. These ventures provide both economic security and ecological benefits. Seaweed farming, for instance, helps sequester carbon and improve water quality, while artificial reefs encourage marine life to flourish, restoring fish populations that many families depend on for food and income.

Crucially, the 100 Warriors initiative will not work in isolation—it will complement government schemes, such as the Pradhan Mantri Matsya Sampada Yojana[250]. Through this collaboration, infrastructure such as fish drying yards, cold storage units, fish processing centres, and even emergency rescue shelters can

249 Deccan Chronical. Odisha Imposes 7 Month Fishing Ban at River Mouths to Safeguard Olive Ridley Turtles. 1 November 2023. https://www.deccanchronicle.com/nation/current-affairs/011123/odisha-fishing-ban-olive-ridley-turtles.html

250 India Brand Equity Foundation. Pradhan Mantri Matsya Sampada Yojana. https://www.ibef.org/government-schemes/pradhan-mantri-matsya-sampada-yojana

Empowerment plays a central role in the initiative, and nowhere is this more evident than in the story of the 'Jal Sahelis'—women water stewards from Bundelkhand. These women have been trained in the technical and practical aspects of water conservation, from repairing broken hand pumps to constructing check dams and spreading awareness about water literacy.

be developed in vulnerable coastal belts. This integrated approach boosts the long-term resilience of coastal populations by not only improving day-to-day livelihoods but also strengthening communities' capacity to respond to climate disasters.

In the realm of river management, the initiative draws inspiration from global best practices, such as Durban's 'Take Back Our River' projects[251]. These models place the power of conservation and stewardship back in the hands of local people. Similarly, the 100 Warriors aims to mobilise youth and local leaders to monitor river health, manage waste, and restore degraded habitats. This sense of ownership is critical, not just for maintaining cleaner, healthier rivers, but for ensuring that communities remain engaged and proactive stewards of their environment for generations to come.

In addition to conservation efforts, the initiative promotes watershed-level strategies to tackle sedimentation and pollution. These include afforestation drives, soil conservation practices, and promoting sustainable agriculture in catchment areas. Together, these actions prevent erosion, protect aquatic ecosystems, and help maintain clean water sources for both humans and animals.

One of the most distinctive and culturally rich elements of the 100 Warriors Initiative is its emphasis on reviving traditional water management techniques. In Rajasthan, for example, ancient systems like the 'kundi'[252]—a simple, yet ingenious rainwater

251 C40 Cities. 100 Resilient Cities Pilot Project: Community Based Interventions to Improve River Health (Aller River). https://www.c40.org/case-studies/community-based-interventions-to-improve-river-health/?utm_source=chatgpt.com

252 Down To Earth. https://www.downtoearth.org.in/environment/oasis-underneath-28759

harvesting method—are being reintroduced. These systems, designed to collect and store scarce rainfall in arid zones, have offered water security for generations. Similarly, the 'Johad Pattern'[253], also from Rajasthan, encourages communities to collectively build ponds and check dams, which help recharge groundwater and provide a buffer during dry months.

States like Maharashtra have taken this further with programs like the 'Mission 500 Crore Litre Water Storage'[254], which aims to create decentralised water reservoirs through community action. This has not only improved local water tables but also had a visible impact on agricultural productivity and household water access during drought years.

Empowerment plays a central role in the initiative, and nowhere is this more evident than in the story of the 'Jal Sahelis'—women water stewards from Bundelkhand. These women have been trained in the technical and practical aspects of water conservation, from repairing broken hand pumps to constructing check dams and spreading awareness about water literacy. Their leadership has transformed water governance at the village level, creating lasting change in traditionally underserved and patriarchal regions.

In Tamil Nadu, the initiative showcases what's possible when modern water management is thoughtfully combined with traditional wisdom. Community-led efforts have restored hundreds of neglected water bodies, reintroduced mangroves, and implemented large-scale rainwater harvesting systems[255]. Over 4 million people have already benefited from these efforts, thanks to better access to clean water, increased flood protection, and improved local climates.

Overall, the 100 Warriors Initiative represents a significant shift in how environmental issues are tackled, from the top down to the grassroots. It's about trusting local communities to be the drivers of change, giving them the tools, knowledge, and confidence to restore what's been lost and protect what remains. By reconnecting

253 Shivani Gupta. This Ex-IRS Officer's Water Solution Transformed 204 Drought-Hit Maharashtra Villages. The better India. March 2025. https://thebetterindia.com/414333/irs-officer-ujjwal-kumar-chavan-water-conservation-project-for-drought-prone-villages-maharashtra/

254 Water Warriors of Maharashtra. The New Indian Express. April 2025. https://www.newindianexpress.com/good-news/2023/Apr/16/water-warriors-of-maharashtra-2566277.html

255 TN to restore 5,000 waterbodies through community participation. The Print. February 2024. https://theprint.in/india/tn-to-restore-5000-waterbodies-through-community-participation/1971547/

The UDA Framework provides the scientific and strategic backbone of the 100 warriors initiative. It leverages advanced technologies—particularly acoustic systems, data analytics, and geographic mapping tools—to gather critical information about underwater and aquatic environments.

people with their land, rivers, and oceans, the initiative offers not just a model for environmental restoration but a movement of hope, resilience, and renewal.

IMPLEMENTING THE '100 WARRIORS' INITIATIVE

The successful implementation of the 100 Warriors Initiative hinges on a well-structured, multilayered approach that bridges grassroots engagement with strategic policy and technological frameworks. To translate this initiative from vision to reality, a select group of 100 Warriors are to deployed across India's coastal, riverine, and water-resource dependent regions. These individuals will serve as both field-level agents of change and as key informants for decision-makers at multiple levels. Their role is not only to understand the realities on the ground but also to connect those insights with national strategies on sustainability, water security, and environmental governance.

At the heart of this deployment strategy lies the UDA Framework, a sophisticated and holistic approach to understanding and managing India's vast and complex water resources. The UDA Framework provides the scientific and strategic backbone of the 100 warriors initiative. It leverages advanced technologies—particularly acoustic systems, data analytics, and geographic mapping tools—to gather critical information about underwater and aquatic environments. These tools will enable the 100 Warriors to engage in ground-truthing, data collection, and real-time environmental monitoring, ensuring that any interventions are both data-driven and contextually relevant.

In practice, this will involve warriors using acoustic sensors to monitor coastal erosion, salinity intrusion, water contamination, fish stock levels, sedimentation, and other

critical variables. The data collected will feed into a central system where it can be analysed, interpreted, and shared with relevant stakeholders, ranging from local governments and ministries to non-governmental organisations, private sector players, and international partners. This shared and transparent data ecosystem will foster an integrated response to challenges and promote trust between stakeholders.

To ensure the effectiveness of these operations, the initiative plans to establish Centres of Excellence and Skilling Centres, as proposed in the UDA Framework. These centres will play a crucial role in building the Warriors' capacity and capability. Training programs will focus not only on technical skills, such as the use of underwater drones, GIS mapping, or data interpretation, but also on policy literacy, community engagement, conflict resolution, and interagency coordination. These centres will thus serve as the backbone of the human capital driving the initiative, equipping Warriors with the necessary tools to serve as environmental monitors, policy advocates, and community leaders.

The entire project is based on a three-pronged approach, centred around *Policy Intervention, Technology Intervention, and capacity* and *capability building.*

POLICY INTERVENTION

A select subset of the 100 Warriors are to be trained to become policy liaisons, tasked with understanding the complex legal and institutional landscape surrounding water governance in India. Their training will focus on identifying policy gaps, overlaps, contradictions, and enforcement challenges.

These individuals will act as intermediaries between field realities and the policymaking ecosystem, engaging with decision-makers across ministries, state departments, and local governance bodies. Their interactions with stakeholders from the government, social sector, and corporate domains will form the basis for a set of policy briefs and white papers. These documents will not only highlight existing limitations in the current regulatory framework but also offer evidence-backed recommendations for reform.

Key concerns that the Warriors will likely address include:

- The fragmentation of jurisdiction over water bodies between the state and central governments.
- Conflicting mandates between environmental, industrial, and agricultural water use policies.
- Gaps in cross-border water-sharing agreements exist, particularly in regions were rivers flow through multiple states or neighbouring countries.
- Weak monitoring and enforcement mechanisms often lead to unchecked pollution or overexploitation of resources.
- The lack of a community voice in water management, especially among marginalised coastal and riverine populations.

These Warriors will be expected to work closely with policymakers to curate documentation, recommend legislative and administrative changes, and participate in consultations that shape new and evolving frameworks. By operating at this intersection of governance, grassroots insight, and evidence-based advocacy, they will catalyse a new wave of policy responsiveness tailored to the real-world complexities of India's water systems.

TECHNOLOGY INTERVENTION

The 'Technology Intervention' phase of the 100 Warriors Initiative marks a critical turning point in how India's coastal, riverine, and water-resource-dependent regions could be managed and transformed in the face of climate, ecological, and socio-economic challenges. At this stage, the focus shifts from traditional, manual, and often fragmented approaches to a data-driven, technologically integrated system—one that is dynamic, predictive, and responsive to the evolving needs of these vulnerable ecosystems.

The first significant step in this phase is to identify technology gaps through an extensive global literature review, drawing from diverse case studies, academic research, government reports, and field practices from around the world. Warriors will conduct a detailed survey of digital transformation efforts in regions with similar environmental conditions, such as tropical and subtropical coastal zones across Southeast Asia, the Pacific Islands, parts of Africa, and Latin America. The goal is to examine

how technology has been used in those regions to manage fisheries, monitor ecosystems, track erosion, and support community resilience. By benchmarking global successes and failures, the Warriors can then adapt and customise digital tools and technologies to suit the specific needs of India's tropical waters, which present unique challenges such as high biodiversity, monsoonal fluctuations, and densely populated coastlines.

Following this research, selected Warriors—those with backgrounds in engineering, environmental science, or digital innovation—will engage in a scoping exercise. This involves mapping real-world problems observed in the field and identifying where technological interventions can provide viable and scalable solutions. For instance, they may discover that outdated manual logging of fish catch data is contributing to poor fisheries management. A tech-driven solution, such as mobile-based data entry systems or blockchain for supply chain transparency, could be proposed. Similarly, they may find gaps in flood early-warning systems in riverine communities, which could be addressed with IoT sensors and AI-based predictive models.

These individuals will immerse themselves in local conditions, gaining first-hand insights into the economic, cultural, and logistical constraints that shape day-to-day life in coastal and riverine areas. By doing so, they will ensure that proposed technological solutions are not only innovative but also realistic, culturally appropriate, and adaptable. Warriors will work to bridge the digital divide by focusing on interoperability between new and existing systems. Warriors will also lead efforts to train local personnel in the use of new tools and basic digital literacy, so that communities are not left behind in the digital transition. Whether it's teaching fishers how to use a mobile app to check ocean conditions or training panchayat members on how to interpret sensor data, the emphasis is on making technology accessible and empowering at the grassroots level.

One of the most strategic components of this phase is promoting and implementing Marine Spatial Planning (MSP)[256]. MSP is a science-based, data-intensive approach to managing ocean and coastal spaces. It involves mapping and analysing all the human

256 Sanskar Soni. 'Marine Spatial Planning: A holistic approach to manage marine environment'. UDA Digest. Feb 19, 2023. Marine Spatial Planning: A holistic approach to manage marine environment - UDA Digest

and ecological activities that occur in a marine area, such as shipping, fishing, tourism, conservation zones, and oil exploration, to design a more efficient and conflict-free use of marine resources. Warriors engaged in this aspect of the initiative will be trained in data analytics, remote sensing, GIS mapping, and high-end modelling techniques.

Importantly, Warriors will also advocate for open-data practices, so that community members, NGOs, local institutions, and even other countries sharing regional waters can collaborate more effectively. The digital backbone they help build will not be an isolated silo but part of a larger, interconnected system of environmental governance. By identifying the right technologies, adapting them to local realities, and embedding them into everyday practices, the Warriors will play a foundational role in making India's water-resource governance more innovative, more inclusive, and more future-ready.

CAPACITY AND CAPABILITY BUILDING

This phase of the 100 Warriors Initiative focuses on the long-term sustainability and scalability of the mission, laying the foundation for a transformative, institutionalised model of skill training, knowledge transfer, and capacity building. The goal is to ensure that the momentum built during the initial deployment not only continues but grows into a national and even international standard for coastal, riverine, and water-resource stewardship. To that end, a select cohort of warriors will be identified and trained to lead the design, implementation, and dissemination of structured training programs targeting farmers, fishers, local youth, and policymakers alike.

At the core of this effort is the groundwork and curation of action-oriented training modules. These warriors will act as change agents, taking on the responsibility of translating high-level concepts, such as the blue economy, sustainable coastal development, underwater domain awareness (UDA), and climate adaptation, into digestible, localised formats for community-level dissemination. They will facilitate workshops, hands-on demonstrations, and digital literacy drives to train farmers and water-dependent community members in practical

The UDA Capability Building Framework will be highly structured and institutionalised, with formal certification processes, levels of expertise, and pathways for professional growth. It will also include customised curricula for different target groups—from coastal youth to scientists, from government officials to international partners. In addition, through regional cooperation and knowledge sharing, India can lead the way in developing a South-South model for blue economy growth, supporting African, Southeast Asian, and Pacific nations with a proven and scalable methodology.

applications of policy, technology, and resource management. These sessions will cover topics such as sustainable aquaculture, precision agriculture near coastal belts, waste management, and early warning systems for flooding and tidal surges.

Furthermore, these warriors will take a proactive role in promoting awareness of government schemes and blue economy policies, ensuring that communities not only understand but also access the financial and developmental support available to them. By demystifying policy frameworks and connecting them to grassroots realities, the warriors will help close the gap between policy formulation and policy implementation. This also encourages communities to become active participants in governance, thereby fostering a sense of ownership and responsibility in the sustainable use of technology and resources.

However, this transformation cannot be limited to the grassroots level alone. For the initiative to truly take root, sensitisation must happen across all strata of influence, from local village heads and gram panchayats to bureaucrats, CEOs, CSR strategists, and civil society organisations. The initiative recognises the importance of developing a multi-tiered ecosystem of leadership and awareness. Warriors will be trained to communicate complex issues in accessible ways to various audiences, using data, real-life stories, and visual tools to engage different stakeholders in the cause.

To ensure consistency and replicability, a complete acoustic capacity and capability-building framework will be developed. This framework will serve as the technical and pedagogical blueprint for all training efforts related to the UDA domain. It will combine theoretical modules on marine acoustics, underwater data systems, marine biodiversity, and climate modelling, with field-based experiential learning, including the use of underwater drones, acoustic sensors, and real-time data platforms.

This framework will be highly structured and institutionalised, with formal certification processes, levels of expertise, and pathways for professional growth. It will also include customised curricula for different target groups—from coastal youth to scientists, from government officials to international partners. In addition, through regional cooperation and knowledge sharing, India can lead the way in developing a South-South

model for blue economy growth, supporting African, Southeast Asian, and Pacific nations with a proven and scalable methodology.

In short, this phase of the 100 Warriors Initiative is not just about education or training—it's about creating a national and global knowledge ecosystem. An ecosystem that is multidisciplinary, inclusive, technology-driven, and rooted in local realities, yet aligned with international sustainability standards. The select warriors tasked with leading this transformation will play a crucial role in shaping the next generation of environmental stewards, ensuring that the mission lives on through skilled hands and informed minds across the nation and the tropical world.

BIO-PROFILE

Dr. (Cdr.) Arnab Das

Arnab is a researcher, maritime strategist, and entrepreneur. He is the Founder & Director of the Maritime Research Centre (MRC) under the Foundation for Underwater Domain Awareness (FUDA), Pune, which is working on a unique concept of Underwater Domain Awareness (UDA) as its main focus. He also runs his Start-up, M/S NirDhwani Technology Pvt Ltd which provides consultancies and services for high-end maritime security solutions and marine conservation support. He advises start-ups on underwater technology solutions and defence strategies. He has over 100 publications, a book, and two book chapters to his credit.

Arnab was commissioned as an electrical officer in 1994. He was deputed to IIT Delhi in 2001 for his Master's in Underwater Electronics and subsequently appointed as the Project Officer at IIT Delhi to manage the Navy's Underwater R&D. He delivered multiple technology transfers, including for the strategic submarine project related to underwater systems and algorithms. He also completed his PhD from IIT Delhi in 2007 in underwater signal processing. He was invited to Tokyo University in 2014 as a visiting researcher to participate in the design and development of passive acoustic monitoring systems for freshwater dolphins. He was also at the Acoustic Research Laboratory of the Tropical Marine Science Institute at the National University of Singapore in 2015 for a year, post his retirement from the Navy to understand underwater technology development from a global perspective.

Amb. Anup K. Mudgal

As India's High Commissioner to Mauritius, Ambassador Anup K. Mudgal, a member of the Indian Foreign Service (IFS), retired in May 2016. His thirty-two-year diplomatic career included three stints at the Ministry of External Affairs' headquarters, where he oversaw matters relating to human resource development as well as relations with countries in India's neighbourhood, the ASEAN region, the Russian Federation, and some countries in Central and Eastern Europe. Amb. Mudgal served in a variety of roles in the Indian Missions in Mexico (including NAFTA matters), Peru, the former Yugoslavia, Belgium (EU matters), Germany, Austria (work relating to: IAEA, UNIDO, UNODC, UNOOSA, UNCITRAL), and Mauritius as part of his eight assignments overseas (including IORA).

Among Amb. Mudgal's areas of expertise are maritime security and defence, the ocean economy, particularly the blue economy within the broader sustainability agenda, trade policy and market access, technology transfer, adaptation, and application, and human resource management, including skill development and development assistance. Amb. Mudgal has participated in a number of voluntary activities, with the most significant ones being: member of the FICCI Task Force on Blue Economy; member of the Steering Committee on Blue Economy under the PMEAC; and guest lecturer at several schools of higher learning.

Prof. P.V. Rao

Prof. P.V. Rao is a distinguished academic and researcher with over 45 years of teaching and research experience in political science and international relations. He served as the Director of the Indian Ocean Centre at Osmania University and is currently an Emeritus Professor at Osmania University. He is also a National Fellow at the Indian Council of Social Science Research (ICSSR). Throughout his career, Prof. Rao has contributed extensively to maritime and regional studies, with a strong focus on Indian Ocean geopolitics, naval diplomacy, and regional cooperation. He has been a guest faculty at the College of Defence Management (CDM) and the College of Air Warfare, Secunderabad, where he has shared his expertise on strategic affairs and security studies. Prof. Rao has authored and edited several seminal books, including *India's Naval Diplomacy: Contours and Constraints* (2022) and *India and ASEAN: Partners at Summit* (2011). His scholarly contributions extend to over 35 journal articles, and he is the founding editor of the *Journal of Indian Ocean Region*, published by Routledge, UK. His academic legacy continues to shape discourse on Indian Ocean studies, influencing policy and research on maritime security, regional integration, and strategic affairs.

Ms. Jayseelan Cathrine

J. Cathrine has a strong interdisciplinary background with a Master's in Water Science and Policy from Shiv Nadar University. Her thesis explored socioeconomic challenges in drought management and climate change. She also completed the Young India Fellowship at Ashoka University (PGD in Liberal Studies) and holds a B.Sc. (Hons) in Physics from St. Stephen's College, Delhi.

Professionally, she co-chaired the Underwater Domain Awareness (UDA) session at the World Ocean Summit Conference (WOSC) 2024, authored a position paper on Marine Spatial Planning (MSP), and led the development of a UDA skilling handbook. Currently, she is producing an MSP handbook, designing e-learning modules on the blue economy, and contributing to a monograph on the Indus and Brahmaputra transboundary basins. As Head of Research & Publication at the Maritime Research Center (MRC), she oversees key projects. She is also Co-Editor of the UDA Knowledge Center, demonstrating her commitment to knowledge dissemination, capacity building, and sustainable development research.

Mr. Akash Prasad

Akash Prasad is an AI researcher with a strong focus on climate technology and sustainability. Currently a research fellow at Maritime Research Center and an engineer in Metallurgical Engineering and Materials Science from IIT Bombay, he is passionate about integrating artificial intelligence with environmental sustainability to develop impactful solutions. During his time at the Maritime Research Centre (MRC), Pune, he worked on climate change mitigation strategies, analyzing the economic impact of rising sea temperatures using machine learning techniques. His research was presented at multiple webinars and resulted in a published article on climate risk assessment in the Indian Ocean Region. Additionally, he has worked on LSTM-based forecasting models, face recognition systems using YOLO-SNN, and drone navigation using optical flow estimation.

Beyond technical expertise, Akash has strong leadership skills, having served for two years in NSS IIT Bombay, where he led large-scale sustainability initiatives, including a 2,000+ sapling plantation drive. Under his leadership, NSS played a key role in environmental conservation and social impact projects, inspiring students to engage in meaningful change. With expertise in machine learning, deep learning, and AI-driven forecasting, Akash aims to advance research in climate technology, focusing on AI-powered solutions for environmental resilience and sustainability. His long-term goal is to drive innovations at the intersection of AI and climate science, contributing to a more sustainable future.

Mr. Shridhar Prabhuraman

Shridhar Prabhuraman brings over six years of experience in underwater acoustics at Maritime Research Center, Pune. He holds a Bachelor's degree in Computer Science and a Master's degree in Artificial Intelligence from the University of New South Wales (UNSW), where he was awarded the prestigious International Scientia Scholarship. His academic prowess and deep understanding of AI have been pivotal in advancing MRC's technological capabilities and research outputs.

In his current role, Shridhar leads pioneering projects such as the 3D Ambient Noise Mapping in the Indian Ocean Region (IOR) and the Marine Spatial Planning Tool for IOR. These projects aim to bolster maritime situational awareness and support sustainable marine resource management.

His research work at Maritime Research Centre, reflected in multiple notable publications, focuses on leveraging AI to enhance Underwater Domain Awareness (UDA) and drive innovation in the field.

Mr. Shlok Nemani

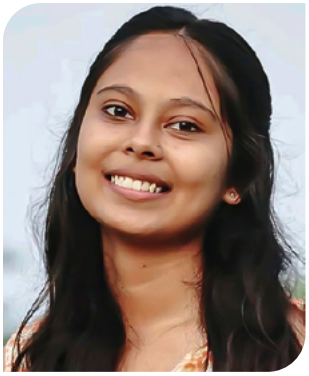
Shlok is an engineer, researcher and maritime enthusiast. He has done majors in the field of Integrated B.Tech + M.Tech, Electrical Engineering with specialization in Integrated Circuits and Systems and minors in Computer Science and Engineering, from Indian Institute of Technology Bombay. Throughout his education, he has been keen to work in the domains of Computer architecture and Signal processing. He has worked under his guide on a project, in collaboration with Indian Army to deliver an android application for their purposes. He has been associated with Maritime Research Centre as a research intern, followed by 2 years of association as a research fellow to take upon the work of Area, Productivity and Yield (APY) analysis.

As a research fellow at the Maritime Research Center, his work on APY analysis has been accepted and presented in World Aquaculture and Fisheries Conference 2023, hosted by Magnus group, followed by abstract acceptance in the Oceans 2023, organised by Gulf Coast. The work is also accepted to be published in the Indian Journal of Geo-marine Sciences (IJMS) 2025 post oral presentation in World Ocean Science Congress (WOSC) 2024. With MRC he is actively working on the development of APY Tool as an android application to be delivered for the farmers.

Mr. Romit Kaware

Romit Rajendra Kaware is a graduate of the Indian Institute of Technology (IIT) Delhi, holding a Bachelor's degree in Civil Engineering. Currently, he is pursuing his PhD in geotechnical engineering from IIT Delhi. He is a research fellow at the Maritime Research Center and his primary focus is on sediment management in the tropical waters of the Pacific. His work highlights the importance of sediment management in different domains like coastal zones, freshwater systems and watershed management while discussing the impacts of sedimentation in the context of people-economy-nature. It gives the context of the unique tropical conditions and the socio-economic challenges faced by the different stakeholders in sediment management.

His work also underlines how digital transformation and integration of AI in the current systems can lead to capacity and capability building in sediment monitoring. Romit is also deeply enthusiastic about applying his expertise in civil engineering, especially in the maritime sector to foster sustainable development.



Ms. Pradnya Kumbhare

Pradnya Kumbhare is a graduate from the Indian Institute of Technology (IIT) Bombay, where she specialized in Electrical Engineering. She is currently serving as a Research Fellow at the Maritime Research Center (MRC), Pune. In this role, she is engaged in interdisciplinary research that integrates engineering principles with marine science to address critical challenges in the underwater domain. Her work spans advanced applications such as acoustic fingerprinting and sediment management studies, both of which contribute to enhancing Underwater Domain Awareness (UDA). These efforts are aimed at enabling data-driven decision-making for sustainable marine resource management. With a strong commitment to ocean conservation and sustainability, she seeks to leverage her technical expertise to develop innovative solutions that support responsible maritime practices and strengthen the scientific foundation for effective governance of the marine ecosystem.

Dr. Radhika Seshan

Dr. Radhika Seshan retired as Professor and Head, Department of History, Savitribai Phule Pune University in 2019, and is now Visiting Faculty at the Symbiosis School for Liberal Arts, Pune. Within the broad area of medieval Indian history, her research focuses on trade, especially in textiles, and maritime networks.

Her most recent publications include Empires of the Sea: A Brief Human History of the Indian Ocean World (PanMacmillan India, 2024), The Constructions of the East in Western Travel Narratives, 1300-1800 (Routledge, 2020), Archives and Archiving in the 21st century (edited, Routledge 2024-25), Connecting the Indian Ocean World – Across Sea and Land, and Merchants and Ports in the Indian Ocean World: Across Sea and Land, jointly edited with Ryuto Shimada (Routledge, 2023) and Wage Earners in India 1500-1900: Regional Approaches in an International Context, jointly edited with Jan Lucassen (Sage, 2021). She has numerous research papers to her credit in national and international journals.

Ms. Nishtha Vishwakarma

Nishtha Vishwakarma is the Head of Communications and Outreach at the Maritime Research Center, where she leads the organisation's strategic outreach initiatives. In her role, she oversees all communication channels, ensuring that the messaging aligns with industry standards and the center's objectives. Nishtha also manages the UDA Digest e-magazine, contributing to its content strategy and production, further enhancing the center's digital presence. Before joining the Maritime Research Center, Nishtha worked as a Broadcast Media Researcher at Doordarshan India (DD India), the international media channel of the Government of India. There, she played a pivotal role in conceptualising and executing impactful show ideas that resonated with diverse audiences.

She holds a post-graduation degree in Public Relations and Corporate Communications from Xavier Institute of Communications, St. Xavier's College (Autonomous), Mumbai, where she developed a strong foundation in media management and communications strategy. Her diverse experience across media and communications sectors has equipped her with a unique ability to drive outreach efforts and deliver quality messaging in fast-paced environments. With a keen eye for detail and a passion for effective storytelling, Nishtha is committed to ensuring that every outreach initiative amplifies the Maritime Research Center's mission of promoting Underwater Domain Awareness (UDA), security, and sustainability. Her work bridges the gap between research and the broader public, making complex maritime issues accessible and engaging.

About ICWA

The Indian Council of World Affairs (ICWA) was established in 1943 by a group of eminent intellectuals led by Sir Tej Bahadur Sapru and Dr. H. N. Kunzru. Its principal objective was to create an Indian perspective on international relations and act as a repository of knowledge and thinking on foreign policy issues.

The Council today conducts policy research through an in-house faculty as well as through external experts. It regularly organizes an array of intellectual activities including conference, seminars, roundtable discussions, lectures and brings out a range of publications. It has a well-stocked library, publishes the journal 'India Quarterly', and is active on social media.

ICWA has over 100 MoUs with leading international and national think tanks, research and academic institutions to promote better understanding on international issues and develop areas of mutual cooperation. The Council's international partnerships are focused on dialogue and joint activities like research publications, while its national outreach is focused on creating awareness of and scholarship on issues pertaining to foreign policy and international relations.

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