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Underwater radiated noise: A new perspective in the Indian Ocean region

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ABSTRACT

Underwater Radiated Noise (URN) is an interesting research area both for military as well as non-military applications. The proliferation of submarines particularly by new entrants in the developing world requires far better URN management to effectively achieve the desired acoustic stealth. The ever increasing merchant marine fleet is accompanied with high levels of low frequency ambient noise that interferes with the marine mammal perception of their environment leading to severe Acoustic Habitat Degradation. The Indian Ocean Region (IOR) has particularly become strategically relevant in the twenty-first century with larger presence of warships and merchant marines from across the globe. URN measurement and analysis requires deep understanding of the signal characteristics and fluctuations in the tropical littorals of the IOR. The entire URN management issue needs to be looked at from a comprehensive perspective including policy, technology & innovation and human resource development. URN management requires massive infrastructure and resource investment and given the socio-economic priorities in the region, such resources are hard to get for any long-term strategic vision. The paper attempts to present the fundamental aspects of URN and then discuss the challenges and opportunities in the IOR to ensure safe, secure, sustainable growth for all in the region.

KEYWORDS

Underwater radiated noise (URN); Indian Ocean region (IOR); Tropical Littoral Waters; Acoustic Habitat Degradation; Acoustic Stealth; Measurement and Analysis

Introduction

Science and technology will always remain major drivers of human growth and prosperity. An effective understanding of the issues involved, and, an appropriate deployment of science and technology, will ensure sustainable growth and holistic development. The Cold War period saw significant efforts towards development of science and technology for military purposes, which was later transformed into multiple non-military applications and served the larger economic growth of nations. Geopolitically, too, after the Cold War, military-driven leadership and decision-making has given way to more nuanced approaches wherein the political leadership is prioritising multiple sustainable-growth requirements. Military budgets now have to compete with socio-economic requirements and also satisfy environmental benchmarks.

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Underwater radiated noise (URN) Management to endow acoustic stealth to naval platforms is one such requirement. It originated as a purely military requirement and remained classified due to intense competition among the super powers to achieve cutting edge capabilities. However, in the twenty-first century, non-military requirements such as the containment of acoustic-habitat degradation due to increasing shipping traffic, has gained global recognition. The developed world in general, and Europe in particular, has formulated strategies and mechanisms to effectively manage the requirement. However, the developing nations of the Indian Ocean region (IOR) need to cover quite some distance in this context. Socio-economic status, differing levels of political maturity, and formidable technological challenges, limit the ability of these countries to fast-track the effective management of URN. The adoption of a fragmented approach, by stakeholders within these nations, as also at a regional level, has also contributed to the slow progress of URN analysis. Yet, the prominence of the IOR, specifically in the renewed Indo-Pacific strategic formulation, demands expeditious efforts to match global standards and the adoption of a far more nuanced approach than has been the case thus far.

This paper will first cover the basics of URN, and thereafter discuss the requirements of URN-management, both for military and non-military applications. It will also elaborate the challenges and opportunities in the IOR, and identify specific tropical littoral challenges, as also the socio-economic aspects that impact the effectiveness of URN-management. Finally, the paper will bring out the urgent need to arrest any further acoustic-habitat degradation so as to take forward URN management in the IOR. The paper uses the study of "noiseonomics" to justify the rise in low-frequency ambient noise due to URN, resulting in severe acoustic-habitat degradation in the IOR. The next section dwells upon acoustic capacity-building to ensure effective URN measurement and analysis, which will be able to overcome the challenges of the IOR. In conclusion, the paper presents a few early initiatives undertaken by India in the region and also the very unique spatio-temporal, low-frequency ambient-noise mapping-work undertaken by the author as part of the Underwater Domain Awareness (UDA) initiative to complement the acoustic capacity-building required for effective URN-management in the IOR. A way-ahead to comprehensively address the emergent URN management issues, is also presented.

Underwater radiated noise

URN comprises acoustic signals emitted by marine vessels due to their operations in oceans or in freshwater systems such as rivers, lakes, etc. Emissions from marine vessels, whether they are surface platforms or sub-surface ones, are made up of three components, namely, "machinery", "propellers" and "hydrodynamic". These emissions are typically low-frequency (below 500 Hz) signals, corresponding to narrowband and broadband characteristics of the individual noise-source. Narrowband signals pertain to machinery (both reciprocating and rotating) for speed-dependent propulsion machinery as well as constant-speed auxiliary machinery. Broadband signals, on the other hand, pertain mostly to cavitation-related noise, largely dominated by propeller-cavitation.[1]

URN has aspects pertaining to military as well as non-military applications. The principal military application translates to the stealth of surface or subsurface combatants and auxiliaries, and includes everything that minimises acoustic signatures, with the aim of preventing or delaying detection and identification by an adversary, while increasing the efficiency of the vessel's own countermeasures and sensors. Self-Noise and Radiate Noise are two terms typically used to describe the sound emitted from a vessel. However, though their origin is the same, these have significant differences in terms of their impact. ***Self-Noise*** pertains to the measurements in near field, whose impact is on one's own sensors, whereas ***Radiated Noise*** pertains to far field measurements that impact the vulnerability of the platform from sensors deployed by an adversary. Stealth is a very critical aspect for naval vessels, right from design to their operational deployment. The provision of "stealth" is a contractual obligation of the shipyard where a naval vessel is being built, and, during the vessel's subsequent operational cycle, regular stealth assessments are undertaken to ensure low levels of URN.[2]

The effective management of acoustic stealth requires a tight correlation between the noise and vibration studies undertaken on board the vessel. These studies are done by several processes, ranging from the use of accelerometers to the physical measurement of URN by underwater acoustic hydrophones in a proper underwater-noise measurement range. To be truly useful, an underwater-noise measurement range must, at the very least, incorporate a measurement facility with prevailing conditions of low ambient noise in order to achieve high Signal-to-Noise Ratio (SNR) during measurement, minimal underwater-medium impact so as to ensure least signal-distortion, and, high-end data recording-and-analysis capabilities so as to achieve diagnostic as well as operational effectiveness. Even so, the measurement and analysis of URN requires a deep understanding of underwater acoustics and noise and vibration studies inside the platform, with a closed loop approach being pervasive right from the behaviour of on-board systems to the actual radiated noise emitted in the underwater medium.[3]

An increasingly relevant but non-military application is low-frequency ambient noise caused by distant shipping. This aspect of URN, to which marine platforms of all types contribute while underway in any part of the global ocean, has very devastating impact on the marine eco-system. Low-frequency ambient noise interferes with the perception of the environment by marine mammals and other species, causing severe acoustic-habitat degradation. This URN, characterised by low to very low frequencies, is only minimally attenuated by the underwater medium and thus propagates over thousands of kilometres, impacting an enormous area.[4] Even though individual platforms that are contributing to this URN, there is a clear requirement to bring in force regulations to minimise URN across the entire spectrum of mercantile shipping if irreversible degradation of the marine eco-system is to be arrested. In this regard, the EU's efforts are praiseworthy. In its Marine Strategy Framework Directive (MSFD), the European Commission (EC) has set requirements to reduce the impact of the URN level caused by merchant shipping on marine life (Directive 2008/56/EC) and to achieve Good Environmental Status (GES) by 2020.[5]

Effective URN measurement and analysis infrastructure and protocols are required irrespective of whether discussion is to be centred upon military or non-military realms. Thus far, URN management remained limited to the military requirement alone and information and data were largely unavailable in the open domain for use by academic and research communities. The reluctance of the commercial shipping industry as a whole to even recognise this dimension of the marine ecosystem as one of grave concern, has also contributed significantly and adversely to delays in the formulation of requisite regulatory provisions. Slaves to the profit motive to the exclusion of all else, the shipping community has, by and large, deliberately avoided the issue altogether. Aiding and abetting this ostrich-like syndrome has been the political establishments of most countries. It was not until catastrophic manifestations of whale stranding became commonplace at multiple locations, due to increasing distant-shipping UNR, led to public outrage that there has been some firming up of political resolve. The harsh truth is the effective URN-management cannot be postponed any longer. There is, today, an inescapable necessity for serious scholarship to be encouraged at every level for identifying gaps in all the three domains, namely, those of "policy", "technology", and, "skilled human resource".[6]

Indian Ocean region

The IOR itself has emerged as a critical maritime space due to its political, strategic, and economic as well as security significance. It has the largest concentration of human population, natural resources, disparate developing economies, congested sea lanes, and, contested territorial spaces. These factors have led to extra-regional powers maintaining a strategic presence in the region in order to protect their economic and political interests, often leading to superpower rivalry unfolding at the cost of regional peace and progress.[7] India, as a "rising power", as also as a consequence of its unique geostrategic location within the region, has no option but to demonstrate leadership in this regional power play. There is a widely recognised need to establish a rules-based maritime order, backed by safe, secure and sustainable growth for all in the region.[8]

The twenty-first century is seeing a massive proliferation of submarines amongst developing nations. This is all the more striking because the developed world seems to be moving away from an engagement in any similar sort of "submarine race". The Indo-Pacific has become the centre stage for such submarine programmes led by China and India. The submarine programmes of both countries now incorporate nuclear-powered boats, with several types and classes being capable of carrying Weapons of Mass Destruction (WMD).[9] This proliferation of submarines has brought underwater warfare and submarine countermeasures to centre stage within the Indo-Pacific. However, developing nations will always have to balance competing socio-economic requirements against military capacities and capabilities. This often forces them to compromise on budget allocations for safety standards and other critical requirements, other than the most immediate operational deployments. "Underwater signature management" is one such requirement that continues to remain poorly developed in several developing nations of the IOR.[10] The IOR also has multiple nation states that are wracked by political instability, giving rise to malevolent non-State actors (and, sometimes, State-sponsored malevolent non-State actors, too) who play a significant role, albeit a severely destabilising one, in the region. In the absence of adequate rules-based restrictions, these non-State actors enjoy significant asymmetry in their operations and manage to gain access to disruptive technologies, particularly in the underwater domain. These disruptive means include acoustic mines, underwater unmanned vehicles that could home on to the platforms based on the unique URN and many more.[11] Thus, there are significant security concerns originating in the underwater domain that need to be addressed through improved URN management.

The economic impact of energy and seaborne commerce has been very significant over the last two decades. Forty per cent of global energy flows from the Persian Gulf to the East (India, China, South Korea and Japan). In addition, raw materials from the African coast are what drive economic engines of littoral States of East Asia, including China, South Korea and Japan. Westbound maritime traffic, too, is dense. Finished goods from Asia in general, and East Asia in particular, are regularly carried in very large cellular vessels, of upwards of 20,000 TEU, bound for West Asia and Europe. From 2003 to 2012 the volume of maritime trade has tripled.[12] Increased shipping traffic adds significantly to low-frequency ambient noise throughout the maritime stretches of the region. This rise in ambient noise has a twofold implication on sonar performance – first, due to deteriorating Signal-to-Noise Ratios (SNR), and second, due to the changing migration pattern of the marine mammals, which affects established patterns of underwater biological noise. With increasing submarine fleets and the concomitant requirement to deploy them effectively, the SNR and accurate assessments of biological noise are major factors that demand serious attention. Ambient noise assessment is a critical requirement. This is not something that can be acquired from abroad. It will require indigenous effort, involving very substantive and substantial "field work".

The very nature of the tropical littoral waters of the IOR results in suboptimal sonar performance and hampers meaningful URN management. The acoustic meaning of "deep" and "shallow" water needs to be understood if one is to correctly appreciate the physical challenges of the IOR. The hypsometric definition of "deep" waters has two elements, viz., "depth" and "distance from the shore". Thus, waters found at the outer edge of the continental shelf or Exclusive Economic Zone (EEZ), ***and*** which have depths in excess of 200 metres are hypsometrically "deep". By contrast, water depths lesser than 200 metres are hypsometrically defined as "shallow". Acoustically, however, these terms are referenced to the surface and bottom acoustic boundaries. Acoustically shallow waters are those that result in a large number of interactions between a propagated sound beam with the surface and bottom boundaries (which translates to higher distortions due to multipath fading). Multipath propagation itself is governed by the depth of the sound axis that provides the SOFAR Channel to minimise the surface and bottom interaction due to refraction towards the sound axis. The depth of sound axis varies, from a low of 50 metres near the poles to a high of 2,000 metres near the Equator. Thus, considered from an acoustic perspective, the IOR has hardly any "deep" waters. This, then, partially accounts for the poor sonar performances experienced in the IOR. To compound matters, the tropical weather adds to surface fluctuations and also variations in the site-specific bottom variations, thereby increasing multipath distortions. If this was not complication enough, the rich biodiversity found in tropical waters also contributes to volume-distortions in respect of sonar signal propagation, resulting in a veritable cocktail of complex signal modifications due to local conditions affecting the underwater medium.[13]

Acoustic habitat degradation

Marine mammals and some other underwater species, too, are known to use sound waves for multiple biologically critical functions, such as foraging, navigation, communication, survival (through the avoidance of predators), to name only a few. Their perception of the underwater environment is through acoustic signals and this is termed "acoustic vision". The increasing ambient noise in the same frequency band as their habitat-perception seriously degrades their acoustic vision and their ability to effectively interact with their surroundings. This is what is known as "Acoustic Habitat Degradation". Alarmingly, low frequency ambient noise caused by distant shipping has increased at a rate of 3 dB per decade since the pre-Industrial era (data available since 1951).[14]

The world's merchandise trade, which is conducted via the global mercantile marine, is a major driver of the economic growth of individual nations. Consequently, enhanced trade has been pursued as a means of enhanced economic growth. This pursuit has led to a very sharp rise in shipping traffic. The term "*Noiseonomics*" has been coined by GV Frisk to describe the relationship between ambient noise levels in the sea and global economic trends. His work is based on the assumption that distant shipping is the single most ubiquitous source of ambient noise in the ocean and this assumption has led to the following two hypotheses:

- *Hypothesis 1*: Gross-tonnage of the world fleet is directly correlated with low-frequency ambient noise.
- *Hypothesis 2*: The world GDP is directly proportional to the gross tonnage of the commercial shipping fleet.
- *Corollary*: Ambient noise in the oceans is directly correlated with the world GDP.

Figure 1, used by Frisk in his work, confirms that the rate of growth in all the three parameters, namely the World GDP, World Fleet Gross Tonnage and the Low-frequency Ambient Noise in the oceans is approximately 3.3 dB per decade. This closely matches with actual underwater recordings.

The frequent stranding of marine mammals along the Indian coast is a grim manifestation of catastrophic acoustic habitat degradation. Figure 2 presents recent incidents of stranding that are manifestations of severe acoustic habitat degradation. Such strandings are attributable to the navigation failure due to high ambient noise, leading to disorientation.[15]

Acoustic habitat degradation is a major fallout of the rise of maritime activities without a comprehensive regulatory framework. The Marine Mammal Protection Act (MMPA) was probably the first regulation to recognise and implement the precautionary principle for the marine environment. In 1972, the MMPA in the United States recognised the harm caused to marine mammals by unregulated noise and mandated that activities in the oceans would have to contain both, the quantum and intensity, of their acoustic energy emissions into the water. Way back in 1982, the United Nations Convention on the Law of the Sea (UNCLOS) did enunciate the deleterious and hazardous impact of noise upon marine mammals. However, it failed to announce a regulatory framework to tackle the increasing noise being pumped the ocean. This failure continues to date. The International Maritime Organisation (IMO), too, through its protocol of 1978 (MARPOL), addresses the aspect of marine pollution from ships through its six annexures. However, MARPOL fails to recognise "noise" – which is in the form of energy – as a pollutant. It only defines substance pollution (oil, noxious liquid substances, harmful packaged substances, sewage, garbage, and, air pollution). More recently, it has declared certain vulnerable areas as "Particularly Sensitive Sea Areas" (PSSA), where noise from

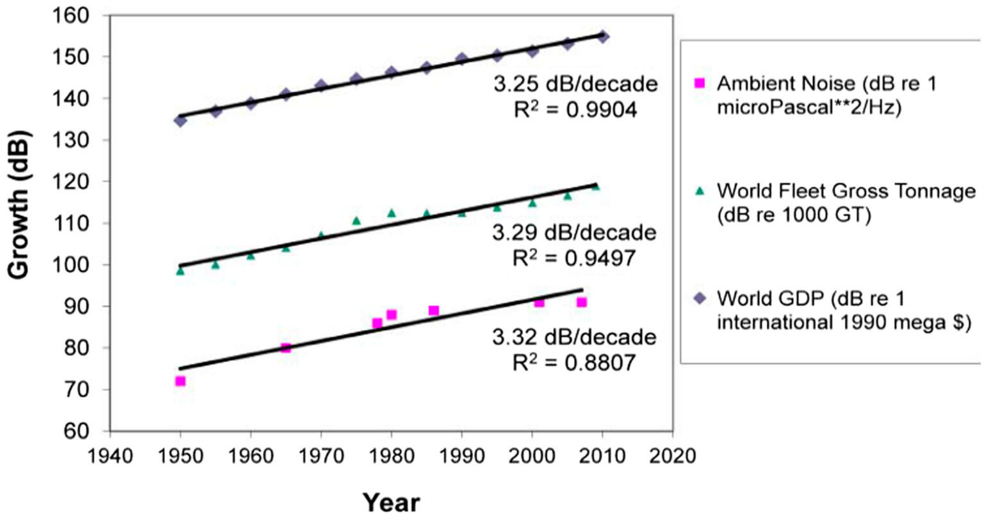

Figure 1. Long-term trends in Ambient Noise Levels, Gross Tonnage of the World Fleet, and World Gross Domestic Product.

Source: George V. Frisk, "Noiseonomics: The Relationship Between Ambient Noise Levels in the Sea and Global Economic Trends," *Scientific Reports* 2 (2012): 437. 10.1038/srep00437. https://www.researchgate.net/publication/225184829_Noiseonomics_The_relationship_between_ambient_noise_levels_in_the_sea_and_global_economic_trends. Notes: Measurements of ambient noise levels, world fleet gross tonnage, and world gross domestic product are plotted as decibel (dB) quantities for the period 1950–2007. Linear fits to the data for all three quantities show similar slopes of 3.3 dB per decade with high goodness of fit (R^2) factors.

Figure 2. Recent marine mammal stranding along the Indian coast. Left: 42 ft blue whale stranding off the Alibaug coast in June 2015. Centre: 50 ft Bryde whale stranding off the Mumbai coast in January 2016. Right: Over 90 short-finned pilot whales stranding off Tuticorin beach in January 2016.

the ships is, indeed, recognised as a hazard, and in order to protect the acoustic habitat, the IMO bars the ships from plying in these areas. However, the IMO fails to regulate the noise from the growing shipping traffic in the open ocean. The International Whaling

Commission (IWC) does recognise the adverse impact of noise on the whales from whale-watching vessels and others. Sadly, the IWC, once again like the other international organisations mentioned earlier, fails to formulate an effective policy for protecting whales from noise pollution in the oceans. Amongst all these failures, the European Union (EU) offers a shining example of what can and should be done. The Maritime Strategic Framework Directive (MSFD) of the EU lists noise as a descriptor for "good environmental status" by 2020, and does have a very detailed policy framework on the subject. Fortunately, there also other European regional initiatives, such as the "Helsinki Commission" (HELCOM), the "Convention for the Protection of the Marine Environment of the North-East Atlantic" (the "OSPAR Convention"), the "Agreement on the protection of Small Cetaceans of the Baltic and North Seas" (ASCOBANS), the "Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area" (ACCOBAMS), etc., that do, indeed, address the issue of noise in the oceans. However, it is important to recognise the trans-boundary nature of noise and the limited effect of national or sub-regional measures in the absence of larger regional and global initiatives.[16]

Within the IOR in particular, the massive push for maritime infrastructure is promoting and encouraging largely-unregulated activities at sea and on the coast, at both national and regional levels, thereby causing serious concerns in respect of sustainability. On the other hand, the growing global consciousness on environmental degradation is bringing uniform regulatory frameworks across regions and India, being a signatory to global norms, is likely to be constrained by these regulations.

Acoustic capacity building and capability enhancement

As mentioned earlier, URN-management requires very specialised infrastructure dedicated to data-collection and -analysis from all possible types of vessels and has multiple applications that are not limited to the military alone. Contemporary geopolitics dictate that capacity-building and capability-enhancement is undertaken at a national level, with the pooling of resources and the synergising of efforts across all stakeholders. Competing funding requirements will never allow political viability of a massive allocation of resources solely for military requirements of stealth. Therefore, military and civilian requirements must be clubbed if URN-management is to obtain requisite funding-support. It is only thus that the local developmental challenges of the IOR can be sensibly met. In spatial terms, too, URN-management has to cover the entire Exclusive Economic Zone (EEZ) right from near-shore areas to the outer edge of the continental shelf, and must also encompass freshwater bodies, including the national waterways and other forms of riverine/inland-water transportation. What is needed and what is proposed is a comprehensive end-to-end infrastructure and implementation strategy, for effective URN-management across all activities, along with a robust policy-framework and an effective regulatory and monitoring mechanism. This broad framework needs to have three major components:

- A ***Policy framework*** to seamlessly manoeuvre existing instruments, for stakeholder interaction towards security and conservation mandates.
- An ***Infrastructure framework*** to build the entire URN-management framework at the apex level.

- A ***Human-resource framework*** to motivate, train and deploy human resources that would then be in a position to manage the aforementioned "policy" and "infrastructure" frameworks. These systems will need to evolve over a long period, so the HR framework will be a very critical one, and needs to comprise a mix of young minds and experienced individuals, all with the right training and exposure.

Policy framework

The Policy Framework is an important start point as it requires massive data-collection and seamless interaction and data-exchange amongst multiple agencies under a variety of authorities. Almost all existing policies and instruments will need to be reviewed and a fresh proposal will need to be evolved. The organisational structure will need to receive an appropriate mandate before it is put in place. National-level "URN-management" standards need to be evolved, so as to provide thresholds for compliance by shipyards and port authorities. Even though standards for "stealth" might well remain exclusively with the Navy, these will need to draw both context and content from the national URN-management standards.

Infrastructure framework

The infrastructure framework needs to be one that takes the fullest advantage of the well-established trilateral principles of "to see", "to understand", and, "to share". Obviously, the connotations may vary from other framework-systems that also use these principles.[17]

- The "**To See**" component would include acoustic ranging equipment that would record the URN. Clearly, underwater sensors and their capabilities to record error-free URN will be a major challenge. Given their requirement of very substantial and capital-intensive infrastructure, as also the problems associated with siting a range within the Territorial Sea, in suitably conducive environmental conditions, fixed acoustic ranges are no longer the option of choice. For all these reasons, portable acoustic ranges have become very popular. However, they do not offer an unmixed blessing, as they require significant effort to identify suitable sites for their deployment, and, in addition, need regular and accurate assessments of the acoustic parameters at the potential site. This assessment goes by the generic term, "Ground-Truthing". Further, proper protocols of measurement and data collection need to be established, which are aligned to the analysis requirements.
- "**To understand**" implies analysis. This is a critical component that may be able to overcome some of the challenges of data-collection. Based upon the availability of resources and the strategy deployed for the acquisition of data, the ensuing analysis could either be centralised or distributed. The first concern would be to minimise distortions of the medium from the received data and also to ensure data-integrity by identifying and verifying data-corruption and errors. Deep Learning methods are available today that can manage multiple data-sets and provide the big picture. High Performance Computing (HPC) infrastructure will be required to manage the Big Data in "real time". Advanced underwater acoustics and signal processing techniques will

need to be deployed, whether at a centralised facility or at its distributed nodes. Predictive models for spatio-temporal low-frequency ambient noise mapping will be critical for multiple applications.

- "**To Share**" implies networking the concerned systems, for seamless data and information flow from offshore sites to the central system and this is, once again, a critical component. Indeed, real-time processing and networking are the keys to the attainment of any meaningful impact. Networking in the RF domain has progressed sufficiently to meet the requirement. Consequently, the need is to so configure sensor-networks as to bring the underwater signals above water, where advantage can be taken of the advances made in RF networking. Sound Surveillance System (SOSUS) systems are thing of the past and need to evolve into more contemporary forms such as the Deep Reliable Acoustic Path Exploitation System (DRAPES). India will have to work on a very innovative model that is a mix of DRAPES and others, keeping in mind the tropical littoral issues mentioned earlier, as also the high traffic-density in the IOR.[18]

Human resource development

The HR requirement will be complex as well as very substantial. For one thing, policy experts, technologists, and management cadres, all have to work seamlessly together to manage the massive programme that will need to be created. For another, a mix of young and experienced individuals has to be engaged with formal training and state-of-the-art exposure to field work and analysis tools. The experienced lot could come from various stakeholders as a second career option, while young and fresh graduates will add a new dimension to the programme with their quick learning abilities and agile attitude. Both sets will, however, need to go through a formal training programme run by global experts.

Conclusion

India is one of the pioneers in URN measurement and analysis in the IOR, having established an Underwater Range (UWR) at Goa, way back in the early 1990s. The UWR facility is an exclusive naval one and optimised for the assessment of the acoustic-stealth characteristics Indian warships. The facility has matured over the years and overcome multiple challenges in terms of deploying and maintaining fixed assets in the open ocean.[19] URN ranges for non-naval vessels will have their own challenges. When we look at the IOR, fixed ranges will have significant signal processing limitations due to shallow water acoustics and would require substantial efforts to maintain and restore data integrity. In physical terms the draughts of merchantmen are much higher than those of naval warships, and, the gradient of the continental shelf on India's western seaboard is gradual. One has, therefore, to move considerably to seaward in order to obtain suitable depths within the Exclusive Economic Zone (EEZ). Thus, portable acoustic ranges available from Commercially-Off-The-Shelf (COTS) offer an attractive option. However, these come with their own challenges of site-selection, decoupling of medium-fluctuations, SNR-enhancement, Ground-truthing, and so on.

The selection of the deployment site for a portable underwater range is a very critical aspect and could be a good example of acoustic capacity-building and capability-enhancement for Underwater Domain Awareness.[20] A brief on one such predictive model for low frequency ambient noise, based on shipping traffic data in the IOR, is presented in the succeeding paragraphs.

Low frequency ambient noise below 500 Hz is known to be dominated by distant shipping and the shipping traffic has a unique and evolving temporal and spatial pattern. The Automatic Identification System (AIS), used by Vessel Traffic Services (VTS), is a unique system that monitors the movement of all ships above 300 Gross Tonnage (GT) and all passenger ships regardless of their size. This AIS data provides a complete description of the ship and its voyage details. Radiated noise from a marine platform is a function of its type and the underwater noise propagation properties at any given location.

This work presents a spatiotemporal mapping of the low frequency ambient noise in a band of 20 Hz to 500 Hz, due to shipping. The spatial mapping presented in Figure 3 covers the entire IOR and the temporal transition of noise derived from the average AIS data from 2014 to 2016, on an annual basis. The acoustic signal-modification of the tropical shallow-water behaviour has been depicted using a channel model for varying Sound Velocity Profile (SVP), bathymetry and sediment characteristics. The Source Level (SL) computation has been undertaken using a modified Ross model with Automatic Identification System (AIS) inputs on the type and position of the ships. One can observe drastic acoustic degradation. The recent spike in the stranding incidents of big whales is attributable to the acoustic degradation resulting from distant shipping. This map can be used for several applications such as:

- Site selection for the deployment of portable acoustic range systems for effective URN measurement and analysis.
- An assessment of actual Acoustic Habitat Degradation for specific big whale species and quantification of the ecological degradation.
- The evolution of a policy framework for the management of marine eco crises.
- The deployment of subsurface military platforms, with a view to achieving the optimal performance of their sensors and identifying their own vulnerability to their adversaries.

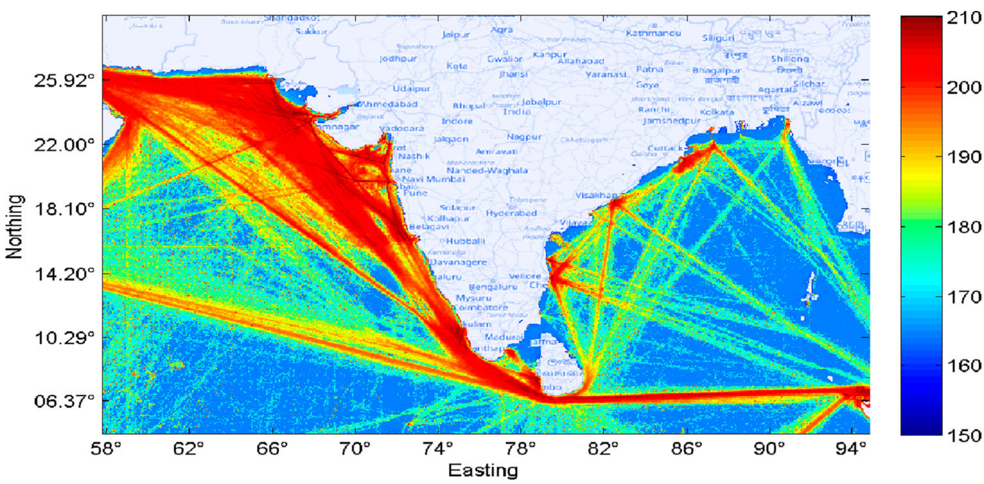

Figure 3. Spatial noise mapping for IOR (noise in dB re 1 μPa^2).

Effective URN management in the IOR will require a nuanced approach. The following way ahead is recommended:

- The evolution of a UDA framework to address competing resource-requirements and also be able to ascertain the political viability of the requirement to get a go ahead.
- The undertaking of a detailed study-project that would identify gaps in terms of policy structure, technology and innovation, and, human-resource development.
- Bearing in mind that Acoustic Habitat Degradation is a real issue and requires focussed approach from all levels, the precise assessment of the extent of degradation, identification of trends, and global regulatory provisions, all need to be examined.
- Massive and aggressive awareness-enhancing initiatives – through workshops and seminars that are pitched at policy-makers, practitioners, academia, industry, the scientific community, and other stakeholders – need to be undertaken very large scale.
- The institution of "fellowships" for Acoustic Capability and Capacity Development across multi-disciplinary, project-based research and development projects, with significant components of field experimentation, are needed for real-world problem solving.

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