Propelling India's blue economy: technological and governance perspectives in fisheries and aquaculture

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The blue economy, encompassing sustainable utilization of coastal and oceanic resources, has gained global significance in the context of the developing discourse on economic growth and environmental conservation in ocean-based economies. This article delves into the multifaceted realm of India's fisheries and coastal aquaculture sectors, exploring their status, challenges and prospects through the lens of the 'blue growth' narrative. Various enabling factors, such as technological advancements, governance improvements, market and policy incentives, and investment strategies are discussed that can catalyse a smooth transition of India's marine capture fisheries and aquaculture to align with the blue developmental agenda.

Keywords: Blue economy, coastal aquaculture, fisheries, governance perspective, sustainable development, technological advancements.

Introduction

THE concept of 'blue economy' is inspired by the realization that ocean-based activities and livelihoods are integral to human well-being. The United Nations Development Programme (UNDP) defines blue economy as 'the sustainable use of ocean resources for economic growth, jobs, and social and financial inclusion, with a focus on the preservation as well as restoration of the health of ocean ecosystems'[1]. It is conceived as an economic model for sustainable development with the world's oceans as its fulcrum. Mooted as an alternative to the 'green economy' during the Rio +20 UN Conference on Sustainable Development held in 2012 at Rio de Janeiro, Brazil, the concept has now grown into its own with several developing countries, particularly Small Island Developing States (SIDS) adopting blue economy in their development plans[2]. The main priorities of this concept include enhancing economic development (both tangible and intangible), improving social inclusion, and ensuring livelihoods while safeguarding the sustainability of the oceans. The blue economy concept is underpinned by the UN Sustainable Development Goal (SDG)-14 on 'sustaining life below water'. Presently, the global blue economy is valued at US$ 1.5 trillion annually, which is expected to grow to US$ 3 trillion by 2030 (ref. 3). India is a member of the Indian Ocean Rim Association (IORA), which focuses on the blue economy in the Indian Ocean region through its two programmes – The Security and Growth for All in the Region (SAGAR), and the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC). The Government of India (GoI) included blue economy as one of the ten core dimensions of growth in its Vision of New India by 2030 (ref. 4). A National Blue Economy Advisory Council (NBEAC) is also proposed to be set up under this policy framework.

Relevance of marine fisheries and aquaculture in India's blue economy

India is the second largest and fourth largest producer of aquaculture and capture fisheries respectively, in the world. Of the total production of 16.25 million metric tonnes (MT), 4.13 MT came from the marine sector, contributing a gross value of Rs 2326 billion in 2020–21, amounting to 1.1% of the Indian economy and 6.72% to the agricultural economy of the country. The fisheries sector in India has grown by over 8.0% during the last decade[5]. In 2022, the country's total marine fish production was estimated at 3.49 MT, valued at Rs 58,247 crores[6], catering to the demand from its fish-eating population. India is one of the leading nations in terms of seafood exports, trading nearly 1.36 MT of seafood worth US$ 7.76 billion in 2020–21 (ref. 5).

Coastal India has a population of 3.77 million marine fishermen (including one million active fishermen) residing in 3477 marine fishing villages[7]. They are engaged in a diverse spectrum of livelihood activities that include marine fishing, coastal aquaculture and beach tourism. Sea food is rich in protein, vitamins, minerals and healthy lipids, including omega-3 polyunsaturated fatty acids, making an important source of nutrition. In addition to direct consumption,

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Table 1. Probable percentage of biodiversity of marine harvest fisheries in India (compiled from Indian Council of Agricultural Research[8])

Major groups	No. of species		Total species diversity (%)
	Total	Commercially exploited	
Finfish	1,936	1,211	62.55
Crustaceans	2,439	94	3.85
Molluscs	3,827	95	2.49
Echinoderms*	765	32	3.10
Sponges*	486	41	8.44
Seaweeds	844	60	7.11

*Many species are under the Indian Wildlife Protection Act of 1972.

Table 2. Major identified deep-sea resources that can contribute to Indian marine fisheries (compiled from DAHDF)[63]

Resources groups	Estimated potential	Estimated value (Rs million)
Oceanic squid (*Sthenoteuthis oualaniensis*)	0.63 MT	8,000
Oceanic tuna	0.213 MT	35,000
Tuna-like fishes	33,000 T	6,000
Mesopelagic fishes	1.7 MT	NA
Ribbonfish (*Trichiurus auriga*)	0.3 MT	NA

seaweeds, mussels and other marine fauna have been a source of biomolecules, which have led to the development of several nutraceutical products used for treating common lifestyle diseases.

Indian seas are home to over 1936 species of finfishes[8], 3827 molluscs, 2439 crustaceans, 844 seaweeds and 13 seagrass species[9], a direct reflection of the potential of the blue economy for the country. Table 1 presents an overview of the aquatic biodiversity in Indian waters and their probable contribution to marine harvest fisheries.

Technological and governance perspectives for blue growth

Marine capture fisheries

Sustainability is enshrined in the concept of the blue economy, which when dealing with marine capture fisheries is quite challenging, as these are natural resources being harvested from an open-access and/or semi-regulated pool. In a recent assessment of marine fish stocks by ICAR-Central Marine Fisheries Research Institute (CMFRI), Kochi, 135 stocks were assessed using biology-based (micro) methods and 91.1% of the fish stocks were found to be healthy[10]. A similar result was noted earlier when 68 marine fish stocks were assessed using catch and effort-based (macro) methods, and 86% were found to be sustainably fished[11]. This indicates that under the current technological and governance scenario, most assessed stocks are being fished sustainably. However, to fully reap the benefits of the blue economy, we need to move forward from the existing capture fisheries systems through improved access to resources, technological advancements and better governance.

Improved access to resources: Over 90% of India's marine catch comes from nearshore areas (within 50 m depth), resulting in intense fishing pressure on these resources. Deep-sea and offshore resources are currently harvested at 12% of their potential yield, which can be increased substantially and sustainably through the effective use of technology and resource management tools[12] (Table 2).

To ensure the effective harvest of deep-sea and offshore resources, it is critical to make this sector financially attractive for the users, for which the following recommendations are proposed: (i) Financial incentives/schemes to attract technology and investment in deep-sea fishing and value-chain development; (ii) national policy, legal and institutional frameworks to be developed for the effective management of deep-sea fisheries; (iii) establishment of a regional deep-sea fisheries management organization for regional cooperation, and (iv) enhancement of skills of fishermen and researchers through training in deep-sea fishing, inventorying fished deep-sea catch and post-harvest techniques[13].

Improved access to resources can also be achieved through revitalizing marine ecosystems, which are currently stressed primarily through the Ecosystem Approach to Fisheries Management. A major initiative in this direction is the establishment of artificial reefs (ARs) which have proven to aid in long-term habitat reconstruction through a build-up of natural reef-like fauna and flora. Currently, in India, ARs have been deployed along four states (132 locations, 26,575 units, with a total area of 37 ha), leading to a 17–30% increase in the local fishery[14]. GoI is also giving a major boost to ARs through the Pradhan Mantri Matsya Sampada Yojana.

Technological advancements can also enhance access to resources. A few promising areas include: (i) remote sensing technology – for ocean observation and marine fisheries

with more effective sensors to study the ocean's surface in greater detail; (ii) drone technology – for biodiversity studies, behavioural studies, etc. which can observe marine fauna in their natural habitat, and (iii) artificial intelligence and big data – for a comprehensive analysis of data collected from ocean systems[15].

Improved fisheries governance: According to India's marine fisheries governance structure, the maritime States and Union Territories have jurisdiction within the territorial sea (12 nm), whereas governance rights over the Exclusive Economic Zone (EEZ) (12–200 nm) rests with the Union Government (Article 21 of the Indian Constitution[16]). The Ministry of Fisheries, Animal Husbandry and Dairying (MoFAH&D), and the Ministry of Agriculture and Farmers' Welfare (MoA&FW), GoI, are the nodal agencies for research, development and extension activities in marine fisheries. Conservation actions fall under the ambit of the Ministry of Environment, Forests and Climate Change (MoEF&CC), GoI. The State Fisheries Departments have the flexibility to chart and implement their own rules and regulations for fisheries management and conservation within the ambit of the Marine Fisheries Regulation Acts (MFRAs). The MFRAs have various provisions for regulating fishing and conservation measures in the territorial waters.

Despite the governance tools in place, there are constant reports of violation of zonation norms under MFRAs, use of prohibited gear, illegal, unreported and unregulated (IUU) fishing, etc. To combat IUU fishing in its various forms, maritime states have been strengthening monitoring, control and surveillance systems, on-line registration of fishing vessels, issuance of biometric identity cards to coastal fishers, implementation of colour code and RFID cards for fishing vessels, mandatory vessel monitoring systems, and so on. The existing fishing efforts in the EEZ are made robust through scientific recommendations such as mesh-size regulations for fishing gears and minimum legal size stipulations to regulate the capture of non-target and juvenile fish. ICAR-CMFRI has continuously directed research efforts towards the formulation of policy advisories for the management of marine fisheries through state fishery management plans[17–19], resource-based fishery management plans[20–22], and other need-based studies.

Mariculture

The world will need to produce 50% more food by 2050 to feed an expected global population of 9.1 billion by then[23], which is going to be highly challenging due to the already scarce land and freshwater resources, in addition to impending climate change and geopolitical impacts. In the context of the blue economy, aquaculture is emerging as a rapidly expanding sector, boasting an impressive annual growth rate of over 6.7% in the past two decades. Among the various segments within aquaculture, mariculture is the fastest-growing, thanks to the vast marine resources available. Mariculture refers to cultivating marine organisms for food or other purposes in seawater, enclosed sections of the ocean, or in tanks, ponds or raceways filled with seawater[24]. Responsible mariculture can supplement land-based economies, conserve marine capture fisheries, and support global food and nutrient supply[25].

Combined global mariculture production, including seaweeds, reached 68.1 MT in 2020. Food fishes accounted for 33.0 MT, constituting roughly 27% of the global aquaculture food fish production[26]. In India, the rapidly growing demand for seafood cannot be met solely through capture fisheries. Mariculture emerges as a frontier with immense potential along the country's 8118 km coastline and the EEZ of 2.3 million km^2. Despite having a mariculture production potential of 4–8 MT annually, the current output is ≈0.1 MT (ref. 27), offering significant opportunities for blue economic growth. To fully harness this, India must establish a strategic mission addressing species prioritization, hatchery and grow-out technologies, identification of potential mariculture sites/parks, and hand-holding with policy support.

Prioritization of mariculture species and hatchery technologies: Selecting target species for mariculture should be based on market demand, ecological sustainability, biological attributes and economic viability. India's mariculture began with the initiatives of the ICAR-CMFRI in the 1970s. Subsequently, the institute expanded its scope to include the captive induction of maturation and breeding of various finfish and shellfish species. In 2017, 76 species were prioritized for mariculture, including 23 finfishes, 7 molluscs, 6 crustaceans and 31 ornamental species, with 4 region-specific species and 5 species of conservation interest[28]. Breeding and seed production technologies have been standardized and demonstrated for various finfish, shellfish and seaweeds, further enhancing India's capacity to harness its marine economic resources.

Sustainable grow-out technologies: The development of sea cage farming by ICAR-CMFRI marked the beginning of commercial mariculture production in India. Comprehensive guidelines[29] and good aquaculture practices (GAPs) in sea cage farming[30], marine finfish hatchery[31], good mussel farming practices[32] and good seaweed farming practices[33] have also been emphasized. Farming finfish species like cobia, Indian pompano, silver pompano, orange spotted grouper, and John's snapper in floating marine cages yields 14–22 kg/m^3 of water annually. From a standard circular cage of 6 m diameter, fish production of up to 3.0 tonnes/yr is possible, with a net economic return of Rs 1.5–2.5 lakhs/crop.

Land-based mariculture in controlled environments in ponds, tanks, raceways and recirculatory aquaculture systems (RAS), holds promise within the context of the blue economy[27]. Along the coastline of India, there is about 8.9 million ha of inshore saline areas and 1.7 million ha of

estuaries, backwaters, brackish-water lakes and swamps suitable for mariculture[34]. Land-based mariculture systems are better amenable to GAPs. Automation and genetic improvements are likely to enhance the efficiency and profitability of the sector[35]. Land-based mariculture facilities can synergise with wind, solar and tidal energy sources to reduce the carbon footprint[36]. With the Coastal Aquaculture Authority (Amendment) Act, 2023, in place, India is expected to gain better impetus in this sector.

Technologies for seaweed cultivation, integrated multi-trophic aquaculture, culture of mussels and oysters, coastal pond farming and RAS have also been popularized and demonstrated in the coastal regions.

Mapping of potential mariculture sites: Potential areas for mariculture activities, including the establishment of mariculture parks, hatcheries and nurseries need to be demarcated based on scientific criteria through spatial planning to allow their harmonious coexistence with the other sectors. ICAR-CMFRI has already mapped and identified 317 potential seaweed farming sites covering 23,970 ha (ref. 37), and has identified and geo-referenced 146 potential sites for sea cage farming within 10 km of the coastline, with a production potential of 2.13 MT of fish per year.

Policy support and other enabling factors: The National Fisheries Development Board established a committee to draft the National Mariculture Policy, which focused on sustainable expansion, leasing and licensing practices, culture systems, species selection, environmental health, seed and feed resources, animal health, certification, insurance and market initiatives[38]. The document is under consideration by MoFH&D, GoI.

India has the potential to produce ≈4.1 MT of marine fish annually through cage culture alone, if just 1% of the country's extensive coastline is brought under mariculture. To ensure adequate availability of seed (approximately 2460 million) and feed (around 6.15 MT), besides other related infrastructure and financial resources, we must focus on establishing (i) dedicated hatcheries, nurseries and mariculture parks in suitable locations and breakwaters; (ii) leasing of marine areas with stakeholder participation; (iii) assess carrying capacity and habitat/environment health concerns; (iv) scale-up existing technologies/packages; (v) attract private investment; (vi) explore global markets; (vii) establish standards, and (viii) develop institutional and governance frameworks. Hence, sustainable mariculture necessitates emphasizing several techno-economic, techno-environmental and social parameters that vary across regions and socio-demographic settings[39].

Other cross-cutting priority areas

Marine spatial planning: To effectively manage its extensive coastal stretch, India relies on several critical frameworks, including Marine Protected Areas (MPAs), Integrated Coastal Zone Management (ICZM), Environmental and Social Management Framework (ESMF) and Coastal Regulation Zones (CRZ)/Island Protection Regulations. The ICZM programme adopts a holistic approach, aiming to harmonize environmental, economic, social and cultural objectives while emphasizing community engagement, sustainable resource utilization and resilient infrastructure development[40]. Besides these efforts, the MPA framework designates protected areas for marine biodiversity conservation, enhancing coastal resilience and promoting sustainable development in the face of climate change challenges[41]. ESMF plays an instrumental role in managing environmental and social risks associated with coastal development projects. Additionally, CRZ/Island Protection Regulations establish a legal framework imposing restrictions on construction and development, thereby preserving fragile coastal ecosystems and mitigating climate change risks[42].

GoI launched Mission LiFE (Lifestyle for Environment) as a global initiative to combat climate change, which emphasizes responsible resource use, waste reduction and ecosystem conservation, allowing individuals and communities to reduce their environmental footprint. This aligns with both the conservation goals of MPAs and the sustainable resource use objectives of ICZM, promoting a harmonious coexistence between these strategies. Specifically, LiFE focuses on reducing energy consumption through renewable sources like solar, advocating for energy-efficient appliances and using eco-friendly transportation options. Addressing plastic pollution and waste reduction is achieved through reusable items, minimal packaging and participating in community clean-up drives.

Climate-proofing of the maritime regions: The anticipated climate change scenarios and the associated variability in ocean processes indicate serious challenges to the coastal regions[43]. Effectively addressing these challenges necessitates a multifaceted approach, incorporating adaptation strategies such as coastal protection measures, land-use plans that consider sea-level rise and flooding risks, and policies that promote sustainable management of the coastal ecosystems. Considering this, ICAR-CMFRI carried out a comprehensive study to discern the vulnerability framework of different coastal districts across India's maritime states and union territories[44]. The interplay between climate change and marine ecosystems poses significant challenges to sustainability of global fisheries. To counter such challenges, climate-proofing solutions in mariculture are being developed for the coastal areas. A climate-resilient, carbon-neutral IMTA package of practice developed by ICAR-CMFRI is another promising initiative. Thermo-resilient candidate mariculture species *Trachinotus blochii* seed production that can withstand +2.8°C higher seawater temperature than the ambient temperature can be a trendsetter in future. Many more such solutions for climate-proofing marine fisheries and mariculture are under various stages of development.

Marine bioprospecting and other biotechnological applications: Biotechnological interventions offer huge potential for tapping the rich resources of the ocean and meeting the SDGs towards the realization of a blue economy in India. Blue biotechnology can support the commercial utilization of marine bioresources for pharmaceutical, biomedical, cosmetic, nutraceutical, agri-food and other industries[45]. Marine organisms are adapted to a wide range of environmental conditions, which vary physically, chemically and hydrologically[46]. Production of biomolecules mainly for communication, protection against predators and pathogens, and combating stress is a widely used strategy by most marine biota, from microbes to higher-level vertebrates.

Seaweeds have been traditionally exploited for carrageenan or other polysaccharides, commonly used as food additives. Several bioactive compounds have been identified and utilized from marine taxa, like sponges, tunicates, bryozoans and cnidarians[46] that are host to complex microbiota, which produce secondary metabolites against pathogens, fouling organisms or predators[47]. ICAR-CMFRI has developed several nutraceutical compounds from seaweeds[48]. Microorganisms can be sustainably exploited for product development and scaling-up. Marine invertebrates and vertebrates are rich sources of polyunsaturated fatty acids, anti-inflammatory agents, anticancer agents, antiviral agents and metabolites that are important for cellular processes. Marine organisms adapted to extreme environments like hydrothermal vents can be explored for bioactive compounds and cellular products.

Genome mining and pathway analyses can contribute to extracting information regarding the biosynthetic gene clusters involved in biosynthetic processes leading to bioactive natural products, along with their functional roles. Molecular tools such as fluorescence *in situ* hybridization offer great opportunities to quantify and follow the dynamics of specific bacterial groups[49] and their biosynthetic pathways.

The complete genome sequence of marine bacteria, invertebrates and vertebrates is being characterized at a rapid pace, leading to unlocking of novel genes and signalling pathways contributing to natural products and processes, adding momentum to blue biotechnology and blue economy.

Re-aligning investment and management paradigms

Investing in research and innovation

Blue growth that hinges on sustainable fisheries and aquaculture necessitates nudging research investments towards inclusive and sustainable blue sectors. Some of these green investments in the field of research and development in fisheries and aquaculture should focus on[44]: (i) development of energy-efficient vessel propulsion and fish harvesting systems; (ii) use of renewable energy for fishing and aquaculture; (iii) by-catch reduction devices; (iv) fishing gears equipped with exclusion devices for turtles and other endangered marine fauna; (v) environmentally benign culture systems with minimal carbon footprint; (vi) enclosed systems with minimal biofouling; (vii) breeding and seed production of fishes suitable for intensive culture; (viii) aqua-feeds with high feed conversion ratio; (ix) precision culture protocols; (x) application of frontier technologies such as nanotechnology, AI, space technology and blockchain technology; (xi) digital tools for database and decision support systems; (xii) marine biotechnology and bioprospecting; (xiii) energy-efficient fish processing, packaging and storage systems; (xiv) fish product certification and branding, and (xv) technologies for fish-waste utilization. Furthermore, there is a need to foster a strong science–policy interface wherein investment policies draw their key inputs based on innovations in science and technology.

Mobilizing capital for 'blue growth'

One of the fundamental requirements for meeting the blue economy targets is mobilizing necessary financial commitments from governments, banks, public and private investors, and insurers towards identified investment areas. Some useful strategies that can contribute to mobilizing investment for blue economy include: (i) clearly outlining priority sectors and desired activities based on objective criteria such as returns on investment, payback period and sustainability metrics; (ii) specifying undesirable investments based on *ex-ante* sustainability outcome assessments; (iii) recommending promising technologies; (iv) simplifying procedures and codal formalities for ease of doing business; (v) clear guidelines on standard operating procedures, national regulations and policies; (vi) anticipating challenges based on risk assessments and strategizing for risk mitigation; (vii) arrangements for capital-pooling and risk-spreading through investor consortia networks; (viii) exploring innovative finance vehicles such as blue bonds, social impact bonds and debt-for nature-swap projects, (ix) documenting case studies and success stories, and (x) mechanisms for legal assistance and dispute settlement[50,51].

Incentives for sustainable outcomes

Recent research evidence indicates that implementing the right incentive structure for stakeholders can bring about positive sustainability and economic outcomes in coastal and maritime regions. Conversely, undesirable actions that adversely affect sustainability can be discouraged by appropriately disincentivizing such actions. Well-designed economic incentives and attempts at modifying social norms can create conditions that incentivize stakeholders to fish sustainably, curb illegal fishing, or create large marine reserves as steps to enhance reputation or self-image[52,53]. Territorial use rights, especially if paired with marine reserves,

have proven potential in realizing better management and sustainable fishing outcomes in developing countries like India[54]. Developing a strong ecosystem services framework and associated trade-offs also serve as incentives towards conservation and management. Similarly, given the right incentives, corporate social responsibility funds can be channelled into developing and implementing programmes that foster responsible fisheries governance. On the other hand, some commonly adopted dis-incentivization programmes include sanctions to check IUU fishing, penalties for lack of compliance with fishing regulations, stipulating responsible fishing practices to qualify for green subsidy programmes, under-pricing of seafood products that lack traceability or certification, and so on[55]. Along with the above, it is equally important to phase-out existing perverse incentives such as market-distorting subsidies that pose a threat to the sustainability of fisheries and aquaculture[56].

Building sustainable food value chains

The sustainable food value chains (SVFCs) are integral to the blue economy[57]. Maintaining sustainable aqua-food value chains implies the ability to: (i) produce safe, nutritious and healthy food; (ii) guarantee consumer affordability; (iii) support viability and diversity of stakeholders involved; (iv) respect biological limits of inputs and resources; (v) minimize the carbon footprint arising from all value-chain activities; (vi) maintain social welfare of value-chain actors; (vii) provide due care for ethical considerations and animal welfare, and (viii) sustain intergenerational equity and resource availability[58]. From this perspective, some of the practical considerations to enable SVFCs for blue economy include: (i) strengthening fish landing and market infrastructure for hygienic fish handling; (ii) establishing fish quality certification systems at the landing centres and wholesale markets; (iii) promoting e-auction solutions to ensure transparency of transactions; (iv) establishing traceability of products; (v) strengthening cold chains; (vi) market intelligence systems; (vii) product certification; (viii) establishing special fish processing hubs; (ix) incentivizing green storage and packaging solutions; (x) minimizing post-harvest losses, (xi) promoting start-ups for utilization of fish waste, and (xii) aligning trade policies so as not to compromise resource health for foreign exchange earnings.

Ensuring blue justice

As the 'blue growth' paradigm gathers momentum in coastal economies across the globe, it is important to ensure 'blue justice' for all major stakeholders whose livelihoods are dependent on ocean-based economic activities. Bennett *et al.*[59] highlight ten social injustices that might be produced by 'blue growth' – (i) displacement, dispossession and ocean grabbing; (ii) environmental justice concerns from pollution and waste; (iii) environmental degradation of ecosystem services; (iv) livelihood impacts for small-scale fishers; (v) lost access to marine resources; (vi) inequitable distribution of economic benefits; (vii) social and cultural impacts; (viii) marginalization of women; (ix) human and indigenous rights abuses, and (x) exclusion from governance. It is therefore argued that an explicit blue justice framing may be adopted in all policies and decision-making processes related to the blue economy. Such framing may have provisions to address 'recognitional justice' (due regard for pre-existing actors and practices), 'procedural justice' (due regard to just procedures and practices) and 'distributional justice' (due regard for equity across actors, space and time).

Furthermore, a vibrant blue economy should place due emphasis on providing the fishers protection against occupational risks, natural hazards and temporary deprivation; by assisting in old age; help increase education levels, and improving food security and health; by assisting in measures to enhance people's capabilities and by enacting policies which address inequality and foster greater inclusion[60]. This underscores the need for providing access to services that are appropriate for small-scale fishing communities, such as advance weather warning and on-board communication services as well as savings, credit, insurance and pension schemes, with special emphasis on ensuring the access of women to such services[61,62].

Challenges and the way forward

India's pursuit of a strong blue economy is well underway through the upcoming National Policy aiming for optimal and sustainable utilization of maritime sectors. The fisheries and aquaculture sectors are set to play a pivotal role in this transformative journey, backed by significant technological advancements. Nevertheless, implementing strategies to achieve this substantially encompasses several challenges. These challenges extend from ensuring responsible resource use to alleviating threats to marine ecosystems, governance regulations, institutional mechanisms and coping with climate change impacts. Addressing data gaps and generating fresh data to address scientific and political intricacies of technology and policy alignment add to this complexity. The development of mechanisms to contain unfair trade practices, buffer and manage natural disasters, and check the looming geopolitical unrest are other challenges.

Addressing the above challenges necessitates a harmonious synergy between technology and governance to enhance productivity, minimize environmental impacts and improve the livelihoods of millions of people dependent on these sectors. Forward-looking governance frameworks are crucial to providing regulatory support and policy incentives for responsible resource management, combating overfishing and promoting sustainability. Additionally,

fostering platforms and partnerships is essential to stimulate investment in infrastructure, skill development and market access. India's success in the blue economy can serve as a valuable lesson for other nations facing similar challenges. Sharing knowledge, best practices and technological advancements can contribute to a global shift towards a more sustainable and inclusive blue economy.

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