# Vision 2050


Central Marine Fisheries Research Institute

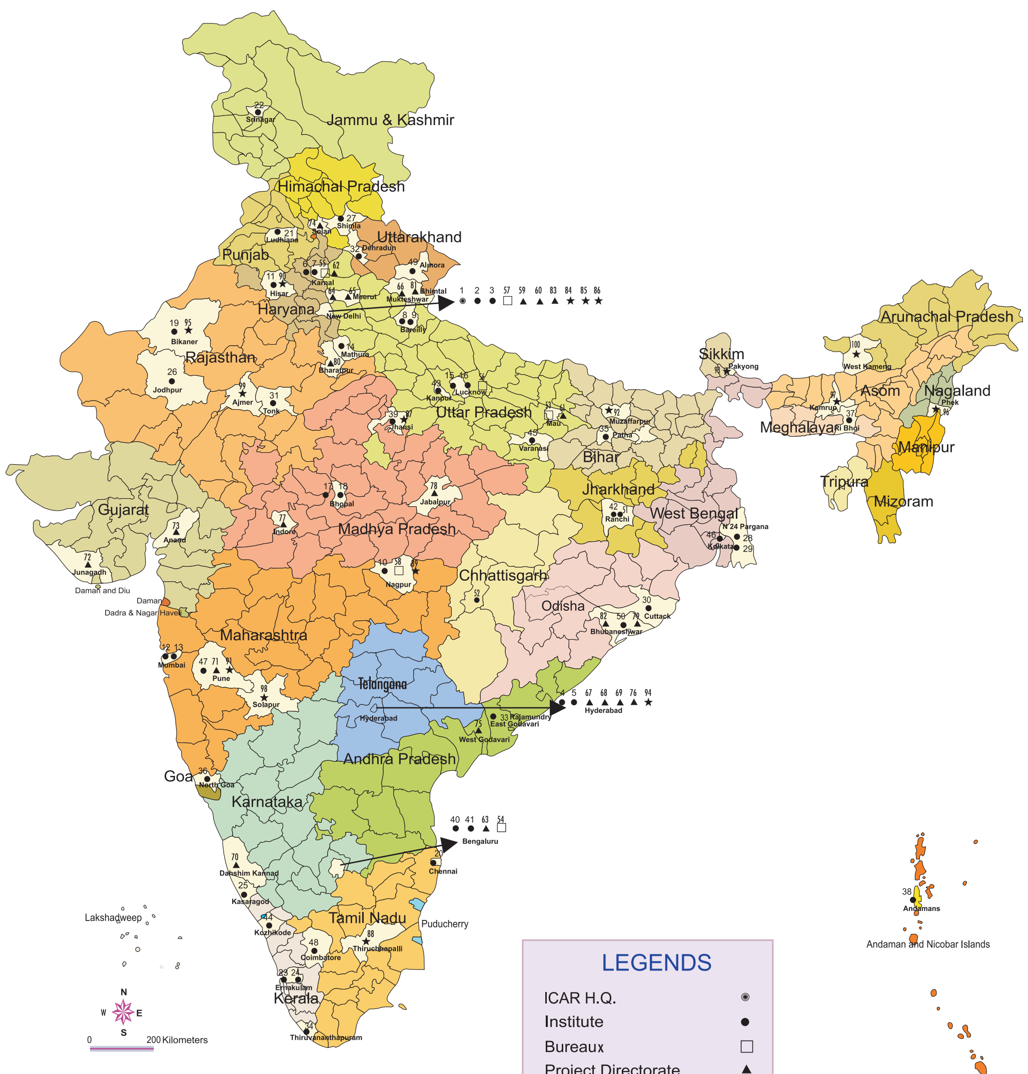
Indian Council of Agricultural Research

भाकृअनुप
ICAR

सी एम एफ आर आइ
CMFRI

# INDIAN COUNCIL OF AGRICULTURAL RESEARCH

## Institutes, Bureaux, Directorates and National Research Centres



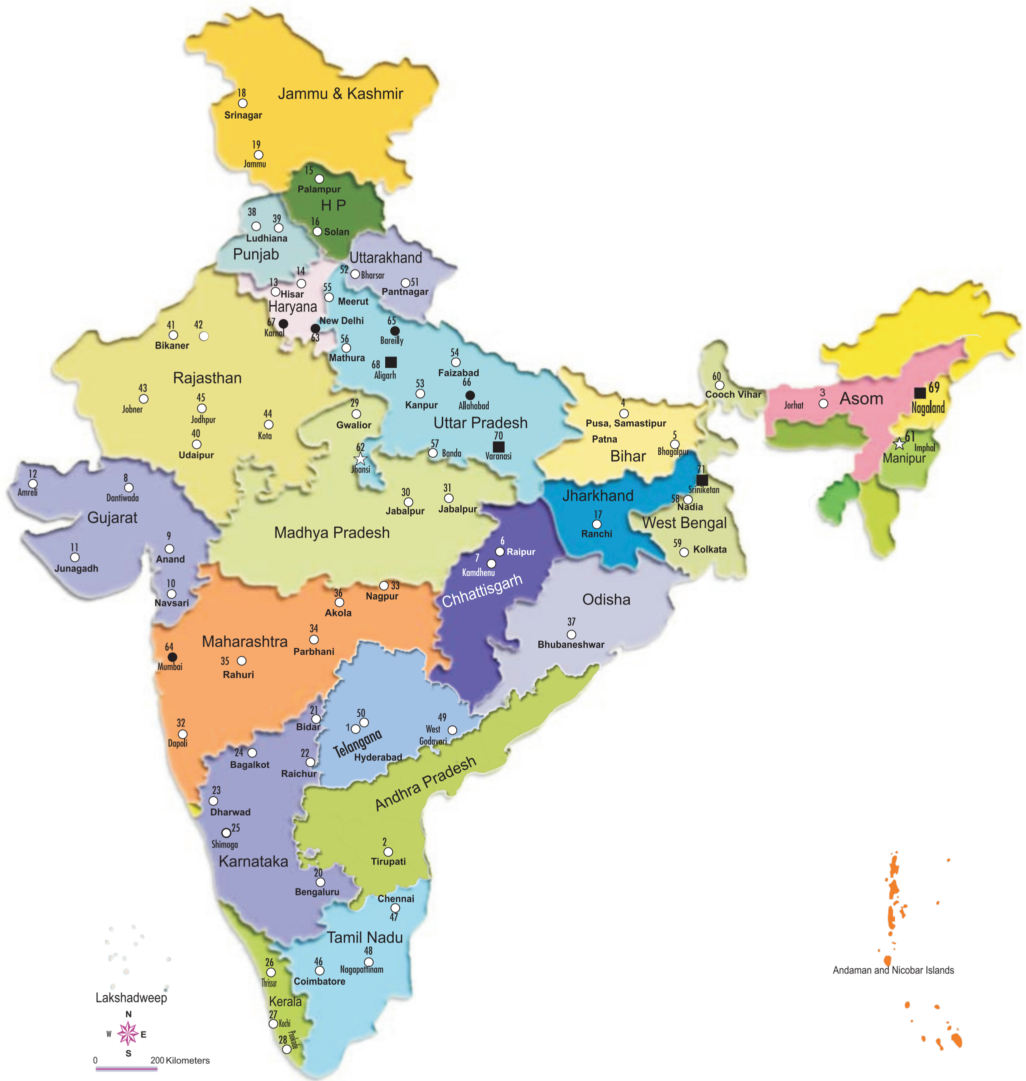

### LEGENDS

| | |
|---|---|
| ICAR H.Q. | ◉ |
| Institute | ● |
| Bureaux | □ |
| Project Directorate | ▲ |
| National Research Centre | ★ |

● 64 Research Institutes ● 6 Bureaux ● 15 National Research Centres ● 15 Project Directorates

# INDIAN COUNCIL OF AGRICULTURAL RESEARCH

## Agricultural Universities




### LEGENDS

| | |
|---|---|
| State Agricultural Universities | ○ |
| Central Universities with Agricultural faculties | ■ |
| Central Agricultural Universities | ☆ |
| Deemed Universities | ● |

# Vision 2050

सी एम एफ आर आइ
CMFRI

Central Marine Fisheries Research Institute
(Indian Council of Agricultural Research)
Kochi, Kerala

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# संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

**( राधा मोहन सिंह )**

केन्द्रीय कृषि मंत्री, भारत सरकार

# Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pests and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Central Marine Fisheries Research Institute (CMFRI), Kerala has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

**(S. AYYAPPAN)**
Secretary, Department of Agricultural Research & Education (DARE)
and Director-General, Indian Council of Agricultural Research (ICAR)
Krishi Bhavan, Dr Rajendra Prasad Road,
New Delhi 110 001

# Preface

Will India's seas have enough fish to feed our coming generations in the year 2050? Will we be able to sustain our fishery resources? How do we fruitfully carry out our duties as stewards of marine resources? These were some of the questions that came to mind as we started preparing CMFRI's Vision 2050 document. Though initially the task appeared daunting, as we started moving ahead, I realized we are well prepared for it. This document is itself a step in the right direction for the development of India's marine fisheries sector. It made us think about the current status of the country's marine fishery resources and their management, what changes we foresee and, finally, how to face these changes. It made us identify our challenges, the opportunities that we have to overcome these challenges and showed us the direction in which marine fisheries research and management in the country should be oriented for sustaining our marine resources and ecosystems.

It is a matter of great pride that the Central Marine Fisheries Research Institute (CMFRI) will be one of the institutions leading India's development in the marine fisheries sector. Mandated with monitoring and assessing the exploited and under-exploited marine resources of India's EEZ; understanding the influence of environment on the abundance of marine fishery resources, developing mariculture technologies to supplement capture fisheries, being a repository of marine fishery resources, carrying out transfer-of-technology, education and extension and providing consultancy services, CMFRI stands strong on a solid foundation of achievements, such as the development of the National Marine Fisheries Data Centre stock health report cards of state-wise and national fish stocks, management advisories for state fisheries departments, the first ever certification by the Marine Stewardship Council for an Indian fishery resource, studies on trawl ban, use of artificial reefs; inventory of India's immense marine resources, seed production technology of marine fin and shellfish, sea-farming and coastal mariculture technologies, nutraceuticals from marine organisms, fish feeds for mariculture, marine pearl culture; genetic characterization of fish stocks and the digital repository- eprints@CMFRI. There is no research organization better suited for leading India's marine fishing sector to greater heights.

India's marine sector is at crossroads today. Our coastal fish stocks are optimally fished and, in some cases, overfished. On the other hand, a potential expansion of our EEZ to 350 nautical miles will increase our marine area and resources. In the years to come, the marine sector will have to meet the protein requirements of the increasing population of our country. The sector will also have to account for intensified climate change. Hence, a 'business-as-usual' scenario will not work anymore. We need to change our thinking and attitude towards marine fisheries management in order to sustain our resources and ecosystems in the challenging period ahead.

Our Vision 2050 document aims to do just that. It maps out the challenges faced by the sector and puts forth the opportunities available with us to overcome these challenges. It is high time to realize that fish and fisheries are only a part of the entire marine ecosystem. Managing them alone will not lead to sustainability. Instead we need to think of the services provided by the entire ecosystem and develop appropriate management interventions. Hence, we propose a shift towards Ecosystem Approach to Fisheries Management (EAFM) which aims at development and management of fisheries while considering the health of the entire ecosystem.

We see a future with intensified climate change and a marine fisheries sector that has to account for these changes. There is and will be a growing awareness among stakeholders regarding the 'blue carbon' stored in our mangroves, seagrass meadows and marshy coastal wetlands. The day when carbon trading starts in the marine fisheries sector is not far away and when it happens we need to ensure that local fishing communities harvest the benefits.

We predict a greater integration of cutting-edge technologies such as remote sensing and biotechnology in marine fisheries research in the coming years. India is a world leader in satellite technologies and remote sensing. We hope that in the future, a satellite dedicated entirely to marine fisheries will be made available. Integrating remote sensing into marine fisheries for the establishment of 'e-infrastructure' is an exciting possibility. While we have been utilizing coastal resources thus far, technology will aid us in exploring oceanic areas for resources. Similarly the use of biotechnological tools, primarily transgenesis, will revolutionize the sector. Transgenesis offers an excellent opportunity for modifying or improving the traits such as growth and efficiency of food conversion, resistance to pathogens, tolerance to environmental variables, commercially significant flesh characteristics, colour variants of ornamental species, control of reproductive activity and also in producing novel medicinal molecules with fewer animal welfare problems than when mammals are used. We will also be utilizing the microbial biodiversity of the oceans via bio-prospecting for bioactive compounds and bio-molecules.

We envisage mariculture as the future of the marine fisheries sector in India and opportunities for the development of mariculture in the country. Opportunities exist in expanding the number of species that can be cultured, standardizing seed production technologies, production of small sized live feed and development of bio-secured brood fish facilities. Opportunities exist for the production of 'ready-to-use' algae which can go a long way in making mariculture a viable venture. Expansion of sea cage farming with the support of GIS-based tools and appropriate legislation is the need of the hour. Augmentation of ornamental fish production and promotion of seaweed culture is also foreseen. Seaweed culture will provide additional benefits to farmers through carbon trading. We also need to focus our research on algal biofuels and use our immense oceanic areas for farming algae from the sea. Integrated Multi-trophic Aquaculture (IMTA) and mariculture for biodiversity conservation are also areas which need more focused research.

The developments in the marine fisheries sector will benefit fishermen and fish farmers only when they get better returns from their profession. A Sophisticated Market intelligence and Information System using a combination of real time data and ICT needs to be established. Establishing a National Fish Marketing Council which will spearhead changes in the domestic fish marketing system is crucial. Meanwhile development of Alternate Livelihood Options is also essential. Bio-prospecting, mariculture of non-conventional organisms and carbon trading are proposed as some options for alternate livelihoods.

We have also laid out a strategy to actualize the Vision. The strategy combines collaboration at various levels, support for research, capacity building and stakeholder consultation along with mainstreaming the Vision in the country's development agenda with appropriate policy support. It is my sincere hope that future generations of marine fisheries researchers will make use of this document to direct their research towards holistic development of the marine fisheries sector in India.

I am indebted and deeply thankful to Dr. S. Ayyappan, Secretary, DARE and Director-General, ICAR for giving me the opportunity to present and prepare CMFRI's Vision 2050 document. I am grateful to Dr. E Vivekanandan, former Principal Scientist and Head, Demersal

Fisheries Division, CMFRI and Dr. G Gopakumar, former Principal Scientist and Head, Mariculture Division, CMFRI for their invaluable contributions towards preparation of this document. I am also thankful to my colleagues, especially the team of scientists who helped me to develop the Vision 2050 document for their insight and imagination.

May this 'Vision' bear fruit and future generations realize the dream "Seafood for all and forever". Jai Hind!

**A. Gopalakrishnan**
Director
ICAR-CMFRI, Kochi

# Contents

# Context

### Seafood for All and Forever

Fish and fishing have been an integral part of Bharat's existence. Probably the first reference to fishing comes from the Mahabharata where a fisherman finds Shakuntala's ring in a fish's gut and by returning it changed the course of the history of our nation. Millennia later, fish is the last wild animal that we continue to hunt and we do so, in large numbers. Over generations, the ancient Indian ethos of being part of nature gave way to viewing nature as a provider of materials for human consumption. Thus, the oceans came to be viewed as an inexhaustible source of resources from which we could take as much we wanted. Even as recently as forty years ago, the fish stocks were considered bountiful, and the focus of the fishing sector, research institutions and governments was to catch more and more fish. There was a limited understanding of, or concern about fish stocks and the environmental impacts of fishing. Fishing was opportunistic and supply was determined by whatever was caught.

But during the last forty years, the marine fisheries sector of the country changed tremendously. The sector began playing a vital role in the Indian economy through its consistent contributions to the GDP, besides becoming a vital source of livelihood for about four million people including 1.6 million active fishermen. The fishing fleet became larger and more energy-intensive, and the catch and trade of marine fish increased substantially. Meanwhile in several countries, fish stocks started collapsing, thus indicating that fish stocks were limited. Concerned by the increasing fishing effort and the possibility for overexploitation and depletion of important fish stocks in the country, the status of important fish stocks was assessed scientifically. Consequently, attempts were made to shift from open access fisheries to regulated access through Marine Fishing Regulation Acts (MFRAs). However, conflicts in sharing the limited resources intensified within and with other sectors and this, in turn, had high economic, social and environmental costs. Thus, in recent years, the sector recognized the need for effective management for sustainable fisheries and a healthy marine environment through ecosystem approach and habitat restoration. These changes are encouraging, but across the country, unsustainable fishing still remains, causing major concern. Meanwhile attempts were also made to develop hatchery and farming technologies of marine species to augment production, but these did not meet with success initially except for large scale farming of brackishwater shrimps. In recent years, however, success has been achieved in mariculture, raising hopes of producing plentiful fish in future from farming marine fish.

An understanding of the direction, pace and type of progress in marine capture fisheries and mariculture in the last forty years provides a clue on future progress of the sector. By 2050, the fisheries sector is expected to be different from what it is now, but we do not know how much and what differences there would be. One factor we are sure of is the rise in human population and India emerging as the most populous country in the world. Coupled with the awareness of fish as a health-food, the demand for seafood will increase substantially. We are also sure that climate change will intensify by 2050 and though climate outcomes cannot be precisely predicted, the probability towards greater impacts of climate is becoming clearer. The distribution, abundance and phenology of fish stocks would have changed and there would be a novel mix of organisms, impacting the structure and functions of ecosystems and ocean productivity. While the compulsion to make available plentiful fish will continue, production will have to come from marine systems undergoing intensified climate change.

In 'business-as-usual' scenario, fish catches in the tropics are expected to decline by 2050 and since most of the seafood comes from wild capture, such a situation will be detrimental to our food security. We have to change this situation by reducing our dependence on wild capture and instead, promote mariculture. Mariculture, the farming and husbandry of marine plants and animals in the marine environment, is the fastest growing subsector of aquaculture. Globally, mariculture produces many high value finfish, crustaceans, and molluscs. In India, the potential of mariculture production remains largely untapped. It has been realized that the vast coastal areas of our country are suitable for mariculture where high value finfish, shellfish and sea plants could be farmed. Presently, standardized hatchery and farming technologies are available only for a limited number of marine finfish and shellfish species. Hence there is a need to enhance mariculture production from a large number of marine species, extend areas of marine farming, and introduce new production systems. The increased application of biotechnological tools such as transgenesis, chromosome manipulation, cryopreservation, gene banking and marker-assisted genetic improvement can revolutionize production of farmed marine fish. By 2050, the proportion of production from coastal and marine aquaculture should be aimed at 40% and in terms of value, at 70%.

It is being increasingly recognized that marine ecosystems have manifold services, much beyond what we have been using so far. Aquatic resources are now regarded as major contributors to provisioning services that include health-food supply and pharmaceutical products. There are tremendous opportunities to advantageously make use of the rich biodiversity; and the provisioning, regulatory, cultural and supporting services of our seas to meet the emerging demands of humankind. Since biodiversity and ecosystem functioning is inextricably linked to human societies, we have to value the services of marine biodiversity and ecosystems, considering the growing costs of biodiversity loss and ecosystem degradation. A greener environment with enhanced ecosystem services will be beneficial to the ecological and human well-being.

By following state-of-the-art practices and effective planning, it is possible to achieve blue revolution. The government's role is to manage the fisheries assets on behalf of societies and to derive maximum benefits for future generations. The role of research institutions such as Central Marine Fisheries Research Institute (CMFRI) is to provide scientific support and suggestions to the governments, and do reality checks while undertaking the journey. A sustainable fisheries sector is essential for ensuring seafood for all and forever.

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# Challenges

To ensure seafood for all and forever, the overarching challenge is to increase and sustain the contribution of marine fisheries to food security, employment and national economic development. The driving challenge would be the increase in human population and demand for health food. The contribution of fish to food security comes not only from fish produced for direct local food consumption and exports, but also from income through employment. Integrated interventions cutting across several sectors and specific interventions on fisheries sector are required to address these challenges. The key challenges to be addressed, which are of technological, economic, societal and governance importance, are as follows:

**General**

- To sustain production from coastal waters and increase production from offshore waters
- To reduce the impacts of fishery and non-fishery stressors such as pollution, tourism, and coastal and marine area development on fish production
- To resolve conflicts among multiple users in sharing the productive coastal areas and resources
- To adapt to climate change and build resilience of marine ecosystems and coastal communities
- To share and conserve trans-boundary resources
- To shift the priority of increasing production from capture fisheries to mariculture
- To resolve potentially increasing international trade barriers
- To take decisions and implement plans with full agreement and involvement of all stakeholders
- To understand the uncertainties in the functioning of ecosystems, and enhance the quality of science-based advisories
- To improve the capacity of research and management institutions, policies and governance to address emerging issues
- To adapt governance to address emerging issues in fishing and mariculture
- To mainstream fisheries in the nation's development agenda

**Specific**

- Weakness of fisheries governance mechanism driving overfishing and stock decline
- Implementing contemporary policies and legislations to eliminate IUU fishing
- Declining biodiversity and ecosystem services in the coastal and marine environment
- Anticipated decline in population of active fishermen in the fisheries sector
- Developing hatchery and farming technologies for a number of potential marine species
- Developing breeding/propagation techniques for endangered/ threatened species for conservation and sustainable utilization
- Developing improved health management strategies for mariculture
- Intensifying climate change impacts and natural disasters causing uncertainties in the development of the sector as well as increasing vulnerability of coastal communities
- Developing integrated climate change models to predict, develop and implement plans for development of marine fisheries
- Developing cost-effective green technologies in fishing and mariculture, and identifying blue carbon potential in marine systems and advantageously using them for carbon trading
- Allocation of marine resources and areas for multiple users
- Arriving at regional cooperation on sharing and conserving trans-boundary resources
- Acceptance of changes in the system and willingness for participation by stakeholders
- Evolving well developed domestic marketing system by reducing the monopoly of middlemen and erosion of quality of products
- Financial allocation in proportion to anticipated development of the sector

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# Operating Environment

Food production from aquatic systems varies widely from that of terrestrial systems. In terrestrial systems, food is harvested from the first and second trophic levels and thus is energetically more efficient; capture of solar energy is more efficient for Gross Primary Productivity, while energy transfer between trophic levels is not very efficient. Of all the myriad species of plants or animals whose products are useful to people, agriculture directly uses only a few hundred species. About 12 plant species provide approximately 75% of our total food supply, and only 15 mammal and bird species make up more than 90% of global domestic livestock production. In aquatic systems, major quantity of harvest is from the higher trophic level viz., carnivorous species which is energetically less efficient. Capture of solar energy leading to gross primary productivity in the aquatic systems is also less efficient due to absorption, reflection and scattering of sunlight by water and its optical constituents. In the oceans, as on land, only a few species comprise a significant proportion of the total seafood harvest consumed as food, with the ten most harvested species accounting for approximately one third of the total. Yet, the marine environment is more stable and better buffered against environmental changes than terrestrial systems and contains areas of high biodiversity and abundance, much more than that on land. The biological diversity of marine biosphere offers enormous scope not only for selecting new species for augmenting food production but also for the discovery of novel products and processes which have application in food production, synthesis of polymers, biocatalysts, biomedical products and organics; bioremediation and bio-mining, to name a few. Thus, the marine environment offers manifold services that can go a long way in improving life on earth.

However, the current operating environment in marine fisheries is focused on short-term profits and livelihood instead of long-term sustainability and profitability. This 'business' environment is harmful to the oceans, fishermen, traders, consumers, and the coastal communities. Fishermen need predictable and stable access to fisheries and a flexible management regime that allows them to improve their financial security while safeguarding the invaluable marine ecosystems.

India's marine fisheries sector is poised for greater opportunities as well as challenges in the years to come. On the benefit side, India

**The Indian Exclusive Economic Zone (EEZ) – From 2.2 million to 3.2 million square km**

The United Nations Convention on Law of the Sea (UNCLOS) delineates the continental shelf as the seabed and subsoil of the submarine areas of a coastal State that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin (comprising the geological shelf, slope and rise), or to a distance of 200 nautical miles from the territorial sea baselines where the outer edge of the continental margin does not extend up to that distance (http://www.un.org/Depts/los/clcs_new/clcs_home.htm). A Coastal State which is desirous of establishing the outer limits of its continental shelf beyond 200 nautical miles has to submit details of the new limits to the UN Commission on the Limits of the Continental Shelf (CLCS) along with supporting scientific and technical data. India undertook a major programme of collecting, processing, analyzing and documenting the requisite scientific and technical information for demarcating the outer limits of the continental shelf in the Arabian Sea and the Bay of Bengal including the western offshore areas of the Andaman-Nicobar Islands. The programme provided a wealth of scientific data on the nature of the seabed and sub-seabed in and off the Indian EEZ. On 11th May, 2009, India filed her first partial submission to the CLCS, under the provisions of article 76 for a continental shelf extending beyond 200 nautical miles (M) from the Indian baselines (http://www.un.org/Depts/los/clcs_new/submissions_files/submission_ind_48_2009.htm). A second partial submission has also been finalized for filing before the CLCS. India currently has 12 nautical miles of territorial sea, 200 nautical miles of the Exclusive Economic Zone (EEZ) and 2.2 million sq. km of EEZ. With the anticipated extension of the EEZ, India's seabed and sub-seabed area would become almost equal its land area of 3.274 million sq. km.
(*Source:* http://www.ncaor.gov.in/pages/researchview/8)

is contemplating extension of EEZ up to 350 nautical miles from the present 200 nm which will result in a physical operating environment much larger than the land mass of India. This will increase our resource base tremendously which needs to be quantified scientifically by way of exploratory surveys and remote sensing for sustainable utilization and management of the resources. This necessitates upgradation of infrastructure and introduction of innovative technologies for fishing and mariculture. These enhanced capabilities will also enable India to explore and harness the immense resources of the Southern Ocean. These opportunities are likely to revolutionize the operating environment of the Indian fisheries sector and compensate for the likely scarcity of animal protein from terrestrial systems.

With the growing importance on ecosystem services, there is going to be lot of importance given to biodiversity conservation and biotechnological interventions. India being rich in marine biodiversity, there are opportunities for providing monetary benefits to the coastal communities through benefit sharing from biodiversity conservation. The profit should motivate the community to conserve biodiversity. A consortium of biodiversity conservationists, biotechnologists and communities will change the operating environment of the sector from solely fishery dependent activities to "earning from biodiversity conservation".

On the down side, increasing marginalization or even complete disappearance of traditional fishing communities and small-scale fishermen is likely. The changes in species composition, distribution and abundance of fish stocks due to climate change impacts are likely to alter the fishing types, costs and benefits. As these changes will be beneficial to larger boats with greater mobility, small-scale fishermen may find fishing unviable. With the anticipated addition of Marine Protected Areas, marine sanctuaries and no-fishing zones, a large number of fishing communities are likely to be displaced. As a result, we are likely to see an outflow of skilled human labour (fishing communities) seeking a non-risky and sustainable livelihood option and inflow of unskilled migrant labourers from non-coastal States into marine fisheries. Increased mechanization and correspondingly increased dependence on fossil fuels will occur. Thus the operating environment in the capture fisheries sector would see an increasing cost of fishing coupled with scarcity of skilled manpower. Consequently, the government agencies will have to either increase financial flow or attract funds in to the sector to meet the requirements (labour, capital and infrastructure) of the transformed industrialized marine fishing sector.

Along with all the changes in the capture fisheries sector, a progressive shift towards fish farming is also anticipated to change the operating environment. Development of an entirely new set of technological interventions and infrastructure such as state-of-the-art hatcheries, feed mills and ancillary facilities will be seen with changes in the entrepreneurship, trade and societal responses.

All the changes envisaged in the operating environment will result in a broader scale of operation with change in the composition of stakeholders. The anticipated open trade of fish and fish products will add another dimension to the sector which warrants an increase in India's competitiveness and bargaining power in international trade.

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# Opportunities & Strengths

The changes in the operating environment of the marine fisheries sector will have to be transformed into opportunities. This, along with technological advances in other sectors such as remote sensing and biotechnology, provides an environment for holistic development of the marine fisheries sector which benefits the fish, the fishermen and the environment.

**1. Strengthening current fishery management regime**

It has been recognized that coastal fish stocks are fully exploited and there is limited scope to increase their production. For sustaining production from coastal fish stocks, a transformation to a well-managed fishery is needed. (i) For an effective transition, strengthening the database on fisheries statistics and scientific assessment is critical, so that decisions concerning management and development options could be more rational and well informed. (ii) To avoid overfishing and overcapitalization of coastal fisheries, effective fisheries management plans are required with a strong will to implement, with the acceptance of all stakeholders. (iii) There is a need to shift from open access fisheries to regulated fisheries. (iv) The current management regime is based on input control such as seasonal and spatial closures and mesh size regulation. In addition to strengthening these input control measures, we have to implement output control measures such as catch quotas and certification. (v) Vulnerable species need to be identified and protected by following standard methodologies. (vi) The performance of management interventions should be reviewed from time-to-time and adapted.

**2. Ecosystem Approach to Fisheries Management (EAFM)**

It has now been recognized globally that fish and fisheries are only a part of the marine ecosystem which provides us with innumerable goods and services. This paved the way for "Ecosystem Approach to Fisheries Management" which aims at development and management of fisheries while considering the health of the marine ecosystem. India too needs to shift from traditional single species management approach to EAFM for sustainable ecosystems. EAFM addressing ecological and human wellbeing with good governance has proved to be an effective option for sustaining the fisheries in several cases. EAFM involves identifying and prioritizing issues and threats, developing and implementing plans with quality checks and adapting. An EAFM approach would address our concerns regarding production from over-burdened coastal stocks, production from under-utilized off-shore and non-conventional resources, pollution of the seas, overcapitalization of coastal fisheries, biodiversity loss and so on.

An important component of EAFM is regulated and well-managed fisheries. For well–managed fisheries we need an effective management regime that sustains the fish stock while taking care of stakeholder and environmental requirements. Just like any system, an effective management regime will have input, processing, output and feedback components. The input is the database on fisheries statistics which needs to be strengthened. The processing component is the scientific assessment of fish stocks and ecosystems resulting in advisories on fishery regulations (spatial and temporal, gear, and catch controls) in conjunction with other uses of the ecosystem (mariculture, tourism, biodiversity conservation). The output component is effective implementation of fishery regulations which is the weakest link of our current management regime. The performance of management interventions would be reviewed from time-to-time and adapted accordingly, which would form the feedback component.

One of the important components of EAFM is Marine Protected Areas (MPAs) which have been a primary management approach to alleviate anthropogenic pressures on marine ecosystems. Solid evidences from MPAs, particularly for No-take Zones (MPAs that allow no extraction), show that protection can increase average size, diversity, abundance and biomass of species. MPAs can also play an important role in climate change adaptation, enhancing ecosystem resilience and protecting vital ecosystem services.

EAFM aims at protection and conservation of marine ecosystems especially through biodiversity conservation. Throughout the world's oceans, there is growing evidence that marine conservation works best when local communities are responsible for ecosystem health. In India too, management of coastal ecosystems, resources and biodiversity should eventually be divested to local communities with the government management agencies acting as facilitators.

The inherent strength of EAFM is that it considers the entire gamut of services provided by marine ecosystems. To effectively know the worth of a marine ecosystem, we need to value its services, both tangible and intangible. So far no work has been carried out in India on marine ecosystem valuation. A move towards EAFM gives us a seminal opportunity to work towards ecosystem valuation and to assess how various management interventions will affect ecosystem economics.

We need a 'tool' for effectively delivering EAFM in the marine context. Marine Spatial Planning (MSP) is such a 'tool' that maps the varied uses of the marine environment and increases the efficiency of EAFM. It is a strategic plan for regulating, managing and protecting the marine environment that addresses the multiple, cumulative and potentially conflicting uses of the sea. MSP will serve both as a framework and a process for more integrated decision making. Its goal is a fully comprehensive, integrated, plan-led system of management for the present and future exploitation and development of marine resources and for the use of contested space. The most important task for marine fisheries in an MSP regime is establishing the broad aim of MSP and elaborating this through a coherent set of more specific objectives with reference to fisheries.

**Ocean Health Index**

It is common knowledge now that the oceans provide innumerable goods and services that are essential for human and terrestrial health. Thus efforts are now being made to study and understand the ocean as a whole taking into account all its tangible and intangible assets. However, this is not an easy task and we need good tools to assess the health of the oceans. The Ocean Health Index is the first assessment tool that scientifically measures key elements from all dimensions of the ocean's health — biological, physical, economic and social — to assess how sustainably people are using the ocean. This OH Index allows us not to only understand the oceans but also to prepare suitable strategies for improving the health of oceans. The OH Index deals with measurements of food provisioning services, traditional fishing opportunities, non-food products, carbon sequestration, livelihoods and economies of coastal communities, tourism and recreation value, aesthetic value, biodiversity assessment of marine ecosystems.

### 3. Exploration of the Oceans: Our Last Frontier

So far we have been concerned with coastal resources which are being fished optimally and in certain cases have become over-exploited. The oceans however have many more resources to offer which have not been explored fully. Indeed the oceans have been called man's "last frontier" indicating the limits of our knowledge of oceanic realms and their inhabitants. The oceanic waters of the Indian EEZ too remain less explored and exploited where high quality large pelagic fish such as tunas, barracudas, mahimahi, sharks, billfishes, oceanic squids and pelagic crabs are abundant. The anticipated extension of EEZ up to 350 nm will add to our exploitable area and potential. The excess fishing capacity of inshore waters can be effectively re-deployed to the oceanic waters for exploiting the oceanic resources. This in turn will relieve the coastal stock from fishing pressure and may enhance the stock health and yield. Exploratory surveys indicate the presence of huge untapped mid and deep-water non-conventional resources in the Indian EEZ and contiguous international waters, dominated by lantern fishes which offer potential new frontier for commercial fisheries. Additionally, a huge stock of krill is available in the Southern ocean (India's share 90,000 tonnes raw krill/year in 2014, of total catchable 8.6 million tonnes), mesopelagics (potential of 1.7 million tonnes from the Indian EEZ) and oceanic squids (potential 2.5 million tonnes in the central Arabian Sea). India has an immense opportunity to harvest these resources. At present, these non-conventional resources are not used for human consumption. However, they are excellent source of protein and other essential nutrients, and can be utilized for human consumption through proper processing and value addition.

There also exists opportunities for extraction of bio-molecules from marine microbes and minor invertebrates. Vast potential exists in bio-prospecting for bioactive compounds and secondary metabolites to develop wonder-drugs with potent pharmacological and nutraceutical properties, from an enormous untapped source of marine organisms including microbes, minor invertebrates and marine micro/macro algae. There is scope for application of the latest developments in "omics" sciences in harnessing these resources in addition to the need for a focused, multidisciplinary approach.

## 4. Adaptation to Climate Change Impacts

Climate change is now recognized as one of the greatest long-term challenges to marine ecosystems and fisheries. The implications of climate change are far reaching and hence there is a need to develop and implement management actions to increase the resilience of marine systems. The action plan should comprise of the following key elements:

(i) Targeted science: Address critical knowledge gaps about climate change impacts; identify thresholds, improve monitoring, and evaluate strategies; and translate information into active management responses;

(ii) A resilient coastal ecosystem: Minimize impacts through local management actions; adapt existing management to incorporate climate change considerations; and maximize resilience by protecting vulnerable ecosystems and species;

(iii) Adaptation of industries and communities: Identify risks and resilience of fisheries industries and communities; maximize resilience by planning regulations, policies and guidelines and assist in adaptation responses;

(iv) Reduced climate footprints: Increase knowledge and involvement of stakeholders; and work with organizations and individuals to reduce their climate footprint.

The complex nature of physical, ecological and social systems challenges our capacity to accurately predict changes and consequently develop adaptation strategies based on realistic forecasts. Quantification of feedbacks between the biophysical environment (climate and oceanography and species biodiversity and abundance) and socio-economic environment (marine communities, market drivers and policy and governance arrangements) provides a means to advance our understanding of marine ecosystem health, resilience and productivity. Thus, strategically designed monitoring programmes at spatial and temporal scales that will capture processes driving marine systems and links between the biophysical and socio-economic arenas are integral to advance our modelling capabilities and to generate innovative assessment tools.

The revelation that coastal ecosystems such as mangroves, seagrass meadows and marshy coastal wetlands trap and store vast quantities of carbon has created new interest for exploring the role of these habitats in climate change adaptation and mitigation schemes. These ecosystems form important coastal carbon sinks, also termed ‘blue carbon’. In spite of availability of vast expanse of mangroves, seagrass meadows and marshy coastal wetlands in India, the opportunity for using blue carbon has not been adequately realized. It is, therefore, important to seriously examine the role and potential of blue carbon at national level. Understanding the opportunity blue carbon presents is important to India in the long-term. This would lead to financial incentives through carbon trading to protect and sustainably manage all blue carbon ecosystems as part of wider climate change adaptation and mitigation strategies with a core focus on local communities.

### 5. Integration of Satellite Technologies into Fisheries Management

India is a global leader in satellite technology which can be effectively utilized for managing marine fisheries sector. Deploying a dedicated satellite for marine fisheries will provide several opportunities

**Blue carbon: A win-win situation for India**

Carbon dioxide is a greenhouse gas emitted from anthropogenic and natural sources, which is now modifying the atmosphere and terrestrial and ocean systems. Increasingly, carbon will be regulated and priced under national (e.g. emissions trading schemes) and international agreements (e.g., Copenhagen Agreements). One of the primary natural processes that reduces carbon levels is 'Blue Carbon'. The term 'Blue Carbon' describes the natural processes by which atmospheric carbon is captured and stored (sequestered) by marine environments. 'Carbon sequestration' means carbon storage that is unlikely to be reintroduced to the atmosphere for more than some period of time (say 100 years). Coastal wetlands have the potential to sequester carbon in the tissues of plants and sediments, just as trees on land sequester carbon. Carbon sequestration and storage in seagrass, mangrove and wetland ecosystems is considered to be extremely high (rates of up to 5 times those of tropical forests) and turnover is low in undisturbed systems. And yet these ecosystems are the ones facing the greatest challenge from humans. India is blessed with large areas of mangroves and coastal wetlands which give us a distinct advantage in a carbon-led economy. However in order to utilize the economic benefits arising from 'Blue Carbon' we need to conserve these sensitive ecosystems and propagate them in the years to come. Additionally a viable market needs to be created for carbon trading (as on land – called the Green Economy), although significant efforts are required to develop this into reality, including science background and policy reform.

and applications for the fisheries sector. At present, the Potential Fishing Zone Advisories present a good example of integration of Satellite Remote Sensing (SRS) and fisheries. SRS can also be used for establishment of "e-infrastructure" in the marine fisheries sector. The concept of "e-infrastructure" deals with establishment of infrastructure (hardware and software) for greater data sharing and connectivity. The same principle can be used for SRS in marine fisheries in India. The data collected by SRS on synoptic temporal and spatial scales on various ocean parameters along with *in-situ* data can be validated at dedicated data centres in the country. The advisories sent out by data centres can then be used by various management agencies or de-centralized agencies such as Panchayats for effective management of resources. Guided fishing using SRS technology in turn can play a major role in precise fish stock assessments and management practices. Studies on fish larval transport are already underway which would give us a better estimate of future fish recruitment which will again increase the precision of stock assessments. SRS data can be used for trophic modelling and EAFM. Ocean health can also be monitored by SRS data and is currently being used for coral reef health advisories. SRS can be integrated with Geographic Information Systems for Marine

Spatial Planning. Mapping the various users of marine ecosystems and their real time occurrences will play a big role in EAFM in India. The Vessel Monitoring and Surveillance (VMS) will increase the effectiveness of management. Identification of appropriate environment in the ocean from SRS data for release of fish juveniles as well as for inoculation of algal species for algal bioengineering of the oceans is also a possibility. Identification of suitable off-shore mariculture sites where culture will have minimal impacts on ocean health is also possible with SRS data.

### 6. Innovations in mariculture

Mariculture is envisaged to be the future of Indian marine fisheries. Despite enormous potential, mariculture has not yet developed into a major contributor of seafood production in India. The approaches for the development of mariculture for 2050 are (i) evolving viable technologies for seed production and farming of a large number of marine fin and shellfish species; (ii) expansion of farm area in coastal saline and suitable inshore and offshore regions; and (iii) diversifying production systems such as coastal pond, raft and pen farming, and inshore and offshore cage farming.

Globally, marine finfish seed production and farming is expanding very fast in recent years. In India, research on seed production has gained momentum; however, we are far behind not only on a global level but also in the Asia-Pacific Region. The urgent need is to develop and standardize seed production and farming techniques for at least two dozen species of high value marine finfish within the next ten years so that the farmers will have a choice for selection of species. India, being rich in marine biodiversity, can offer a plethora of species for mariculture for which suitability tests need to be carried out by the R&D sector. It is possible through concentrated R&D efforts to enable diversification of potential mariculture species. Until the time seed production techniques are standardized, Capture-based Aquaculture (CBA) or the practice of collecting seed material from the wild is an option to address seed scarcity for mariculture. Extensive surveys to assess the abundance of seed of high value marine fin and shellfishes at various locations in the country need to be undertaken. Large-scale collection and conditioning of wild collected seed and establishment of seed banks are urgently required. This will facilitate the farmers and entrepreneurs to get the required seed.

Once fish seed are produced and it grows in to larvae, the first feeding has to be initiated with suitable live microscopic organisms (live feeds) of required (small) size and nutritional quality. Hence, live feed technique is critical to the development of marine finfish seed production technology. Developing super small strain of rotifer, resting eggs of rotifer, and culture technology for selected species of copepods are the challenges and opportunities ahead. Studies on nutritional profile of phytoplankton and their effect on zooplankton and consequently fish larvae also need concentrated efforts. Development of alternate feed technologies such as algal paste for non-seasonal use and 'ready-to-use' algae will pave the way for setting up algal paste factories which can go a long way in making mariculture a viable venture.

Developing bio-secure brood bank for high value finfish breeding and seed production programmes deserves prime attention. The broodstock tanks with continuous bio-filtration system can be used to develop and maintain brood-stocks of high value marine finfish such as cobia, pompano, groupers, snappers, and breams. Establishment of a few marine finfish broodbank is needed to provide fertilized eggs/ newly hatched larvae to the hatcheries where further rearing and seed production can be carried out. A recirculation aquaculture system with components such as drum filter, fluidized-bed bioreactor, protein skimmer, UV sterilizer and egg collection facility, is inevitable for healthy maintenance of the marine finfish broodstock. The system will serve to develop the broodstock into spawners through photo-thermal conditioning. Thus, the safety of the spawners and year-round controlled spawning are ensured in this system. Hence, recirculation units have to be established to ensure year-round seed production of the required species. The application of recirculation aquaculture technology for growing fish in high densities under controlled conditions is a promising opportunity. This approach to fish production minimizes the use of water and land and can be potentially expanded to locations that are normally unsuitable for seafood production. The development of cost-effective grow-out feeds and appropriate health management practices also require prime attention.

During the past twenty years, aquaculture in sea cages has grown rapidly. India initiated farming in sea cages less than a decade ago, and in that way, is a late starter. A series of demonstration programmes with fishermen participation were conducted at various locations along the Indian coast which has created an awareness regarding the potential of sea cage farming to enhance fish production. In the years to come, when land availability will become scarce, sea cage farming will prove to be an opportunity to fish farmers. A massive research thrust needs to be given for the development of commercial level seed production technologies and establishment of hatcheries by fisheries developmental agencies to cater to fish seed production for cage farming. GIS-based site selection, by taking into account the social logistics, is an immediate requirement for the expansion of cage farming. In the context of potential extension of Indian EEZ from 200 to 350 nautical miles, it is necessary to develop offshore cage farming technologies including submersible cages by developing suitable cage designs and mooring systems. Further, policy for leasing suitable sites, bank finance, and governmental support through subsidy assistance is the need of the hour.

Another immense opportunity for India is to augment marine ornamental fish production. On a global level, marine ornamental fish trade has emerged as a multi-million dollar enterprise. There is scope to develop breeding and seed production technologies for a number of species which have high market demand, and develop trade for hatchery produced marine ornamentals in India. The techniques for breeding more than a dozen species of ornamental fishes have already been developed by CMFRI and research focus is needed to develop technologies for more species since the trade is based on diverse species. Parallel to this, establishment of small-scale ornamental fish hatcheries can lead to income generation for rural communities. By formulating appropriate policy regulations and guidelines for wild collection of species as exemplified by the international agencies like the Global Marine Aquarium Database (GMAD) and Marine Aquarium Council (MAC), and developing commercial production of selected species through available hatchery technologies, India has the capacity to emerge as one of the major source countries for marine ornamental fish trade.

Seaweed farming offers immense scope as a livelihood opportunity and for developing a large number of byproducts with several applications. Seaweed farming has the advantage of low capital input as it is a primary producer requiring no feed inputs. Additionally in future years, seaweed farming can earn carbon credits to the farmers. In India, seaweed farming is at its infancy even though we have technologies for farming many species. The current industrial demand for raw material is not met by farmed and wild collected seaweeds. Hence, research and development thrust is needed to address the issues facing seaweed farmers and to popularize seaweed farming in India.

The production of algal biofuels is a novel area of research in India. Algae are known to produce more oil per unit area than conventional oil crops. Research on production of biofuels from microalgae is being carried out in many countries. India too needs to explore the opportunities of production of fuel from algae since we have a diverse and rich microalgal resource and suitable environmental conditions for

**Algal biorefinery-based industry: an approach to address fuel and food security for a carbon-smart world**

Scientific literature as well as popular media are abuzz with catchwords of 'biofuel', 'green house emissions', 'carbon sequestration', 'green technologies' and 'cap and trade' these days. These words are seen as viable alternatives to the current "carbon constrained world" where fossil fuels are the engines of development but whose stocks worldwide are limited. World food demand is expected to nearly double by 2050. However, the productive agricultural land on our planet is confined and actually decreasing. Due to extreme weather the global food security is already in jeopardy. Presently biofuel is being manufactured from food crops but there is no doubt that the shift in land usage and crop utilization for biofuel will have global repercussions in the food demand-supply equation. There is increasing fear that developing biofuel based on food crops could reduce the production of badly needed basic food stuffs. The need for renewable energy is inevitable for future generations but it shouldn't be at the cost of putting millions of people at hunger.

It is in this context that using algae as a source of biofuels presents a future of immense possibilities both for India and the world. India can build a framework to integrate the algal biofuel-based biorefinery, with other industries such as livestock farming, ligno-cellulosic industries and aquaculture. The various coproducts from the algal biofuel processing can be used as inputs for a number of other industries for e.g. the pharmaceutical industry which will bring in additional benefits to the algal biofuel industry in India. Policy and regulatory initiatives for synergistic development of the algal biofuel sector with other industries can bring many sustainable solutions for the future existence of mankind.

large scale culture. Instead of land-based facilities, innovations that allow direct inoculation of microalgae into the sea, culture of microalgae in the sea and subsequent harvest should be developed.

Integrated Multi-trophic aquaculture (IMTA) is the practice which combines appropriate proportions of finfish / shrimp with shell / herbivorous fish and seaweeds in farming to create balanced systems for environmental and economic stability. We have not yet ventured into this new practice and research and development is needed to develop IMTA systems at suitable locations. The system will not only contribute to enhance biomass production from unit area but also to mitigate any adverse environmental impacts, through biofiltration by seaweeds.

Mariculture can also be used for biodiversity conservation and augmentation. Development of artificial propagation of hard and soft corals, sponges, sea anemones and hatchery seed production techniques for highly endangered/threatened/vulnerable marine fishes are needed for conservation and stock enhancement of the concerned species.

For sustainable mariculture in the country, the mariculture practices

**Better utilization of seaweeds in view of global demand**

FAO estimated the total world production of seaweeds in 2013 to be 23.8 million tonnes, of which nearly 90% came from the Asia-Pacific region. The seaweed wealth of India is estimated at 3.3 lakh tonnes wet weight comprising 896 species; 228 species from Chlorophyceae, 210 species from Phaeophyceae, 455 species from Rhodophyceae and three species from Xanthophyceae. Currently only a meager amount of 21,000 t is harvested from Indian waters. The south Tamil Nadu coast, Gujarat coast, Lakshadweep and Andaman Nicobar Islands have been identified as areas good for seaweed culture in India.

Mariculture of seaweeds in India until 1990s mostly dealt with cultivation of *Gracilaria edulis* due to its high regenerative capacity. Recently the cultivation of *Kappaphycus alvarezii*, a carrageenophyte was found to be very encouraging and will prove to be an answer to overcome the shortage of raw materials for extraction of carrageenan. Seaweeds can be used not only for food purposes but also as supplementary feeds for livestock and as liquid fertilizer. They can also be used for removing heavy metal pollution since they are good agents of biosorption or metal adsorption from water. Nutraceuticals and metabolites obtained from seaweeds play a major role in health and pharmaceutical industries.

Marine primary producers are good carbon sequestering agents since they utilize large quantities of dissolved $CO_2$ thereby controlling ocean acidification. It is estimated that the seaweed biomass along the Indian coast alone is capable of utilizing 3017 t $CO_2$/d against emission of 122t $CO_2$/d indicating a net carbon credit of 2895 t/d. Thus, large scale mariculture of seaweeds along with finfish/shellfish as integrated multi-trophic aquaculture (IMTA), which is a green technology employing seaweeds and other secondary metabolites from them can help mitigate major greenhouse gas and can check ocean acidification, while the seaweed farmers can make a living out of the harvest.

should aim at optimum production and maintain a 'green environment'. The lessons learnt from the shrimp farming is an eye opener as intensive shrimp farming resulted in environmental deterioration and consequent disease problems which called for a need for **'Better Management Practices'** and species diversification. A green environment necessitates the need to adopt Ecosystem Approach to Aquaculture (EAA) by taking into account the knowledge and uncertainties of biotic, abiotic and human components of the ecosystem including their interactions, within the ecologically and operationally meaningful boundaries. In many areas, there is lack of diagnostic support for mariculture. The farmers should be educated on the negative environmental impacts that will in turn affect their production. In this regard, establishment of SPR and SPF brood facilities can go a long way to avoid the environmental health hazards to farmed fish species. An SPF certification is therefore important. Finally, carrying capacity assessments are essential before any species is farmed either in the sea or land. This is particularly relevant while expanding sea cage farming in the country. The total number of cages in a given area, stocking density of fish per cage, and feeding intensities should be taken into consideration.

### 7. Biotechnological Approaches

The increased application of biotechnological tools can certainly revolutionise production of farmed marine fish in addition to its role in environment management and biodiversity conservation. Increased demand for seafood has encouraged researchers to study ways to increase the production of marine food products through biotechnological interventions. Modern biotechnological tools can be used as adjuncts to and not as substitutes for conventional technologies in solving problems. The potential applications of biotechnology in mariculture include induced breeding, cryopreservation of gametes and gene banking, marker assisted genetic improvement, chromosome manipulations (especially polyploidy, in bivalves), health management and production of transgenic fish with superior traits. The area of modern biotechnology which will probably have the most significant impact on genetic improvement of aquaculture species is transgenesis. Transgenesis offers an excellent opportunity for modifying or improving the traits like growth and efficiency of food conversion, resistance to pathogens, tolerance to environmental variables, commercially significant flesh characteristics, colour variants of ornamental species, control of reproductive activity and also in producing novel medicinal substances with fewer animal welfare problems than when mammals are used.

A variety of **Genetically Modified Fish (GMF)** with advantageous traits is envisaged. These include transgenic "Superfish" with controlled reproduction. Gene transfer studies in fishes have been initiated for developing certain superior strains useful in aquaculture. The most popular gene used in aquatic species is the growth hormone (GH) gene with an aim to enhance the growth rate of cultivable species. Data available on GH transgenics suggest high monetary benefits that could be obtained from use of these fish. The introduction of transgenic technique has simultaneously emphasised the need for production of sterile progeny in order to minimize the risk of transgenic stocks mixing with the wild populations. The technical development has expanded the possibilities for producing either sterile fish or those whose reproductive activity can be specifically turned on or off using inducible promoters. This would clearly be of considerable value allowing both optimal growth and controlled reproduction of the transgenic stocks while ensuring that any escaped fish would be unable to breed.

Genetic manipulation has also been undertaken in order to increase the resistance of fish to pathogens, which is currently being addressed by the use of DNA vaccines and antimicrobial peptide genes. Transgenic fish with tolerance to high/low temperature, in the context of climate change related rise/fall in temperature is also being produced. There is ample scope for development of fluorescent "glowfish"/colour variant marine ornamental fishes by transgenesis. Medicinal fish which serve as "bio-reactors" to produce pharmaceuticals can be produced. Smart fish or GM fish used as biosensors/environmental sensors to monitor aquatic pollution with fish changing colour or which fluoresce in presence of particular pollutant/stressor are also possible. GM fish has potential for use in basic research in genetics and development. They can also be used in drug discovery and are also being explored for benefits of unlocking human diseases and tissue/organ failure mysteries. The most promising tool for the future of transgenic fish production is undoubtedly the development of the embryonic stem cell (ESC) technology. Cloning can help fish researchers to produce new varieties of fish to feed the under-nourished human population. Other potential applications of cloning include preservation of species, biomedical research and drug production. There are several applications of nanotechnology for enhancing production from aquaculture and fisheries. There is vast scope for developing nanotechnological tools which can aid in captive breeding, disease detection, delivery of drugs, vaccines and hormones, safe and efficient non-viral gene delivery, water treatment, control of bio-fouling in aquaculture structures and monitoring aquatic pollution (nano-biosensors).

The science for in vitro fish (Factory fish) meat is an outgrowth of the field of biotechnology known as tissue engineering. Fish produced in vitro that has never been part of a living animal has been proposed as a humane, safe and environmentally beneficial alternative to slaughtered animal/fish flesh as a source of nutritional muscle tissue. The basic methodology of an in vitro fish flesh production system (IFPS) involves culturing muscle tissue in a liquid medium on a large scale. A major advantage of an IFPS is that the conditions are controlled and can be manipulated. From animal models, it is concluded that the overall environmental impacts of cultured meat production are substantially lower than those of conventionally produced meat. The IFPS is expected to grow faster, become cost effective and develop in to commercial levels in the coming years by the growing demand for fish and the shrinking resources available to produce it by current methods. While widening the scope of the fish processing industry in practices and products, the IFPS will reduce the need for natural resources to produce fish.

### 8. Fish Marketing

An overhaul of the domestic fish marketing system is envisaged for better returns to the fishermen and continued economic viability of the sector. A **Sophisticated Market Intelligence and Information System** using a combination of real time data and ICT needs to be established. Establishing a **National Fish Marketing Council** which will spearhead changes in the domestic fish marketing system is crucial. A domestic fish marketing grid will help the fishers to receive the maximum share of consumer's rupee. This grid will enable the producers to sell their catch in a market where they get good net profit. The advanced market intelligence system ensured by the fish marketing grid will pave the way for profitable vertical and horizontal market integration.

Regulation of domestic fish market (price, inflow, outflow, unsustainable fishing practices) through market driven incentives, new marketing strategies (live fish market), online marketing and future trading in marine fish through well-developed market grids are some of the opportunities. All these developments should be bolstered by an increase in private capital formation in fisheries vis-à-vis public investment (upgradation of berthing facilities, development of onshore infrastructures like large-scale storage, etc.) in fishery infrastructure. Besides, investment in production of value added products will serve the needs of domestic consumers, who will be looking for ready to cook or eat items only due to their professional commitments.

### 9. Alternate Livelihoods

The fisher's households do not get a sustained income throughout the year due to various factors such as closed seasons, natural calamities like cyclones and other related factors, which affect their livelihood seriously. Hence a supporting income through any alternate livelihood options (ALO's) is very much essential. Various ALO's are being studied suiting to the location and their capability. Mariculture or sea cage farming including seaweed farming, repairing of crafts and gears are a few areas of ALO's which have proved successful. The ALO's will be successful only when it is linked with sustained market potential. Biodiversity conservation and the benefits arising out of that such as mariculture of non-conventional species (sponges, holothurians, gastropods etc.) could be developed as an alternate livelihood option for affected coastal communities. Bioprospecting from the marine ecosystems on a public-private partnership with active involvement of local communities is also another viable option. Carbon trading options for fishermen and fish farmers also must be explored. Developing successful rehabilitation models for launching any capital intensive labour displacement (alternate livelihood) is also essential.

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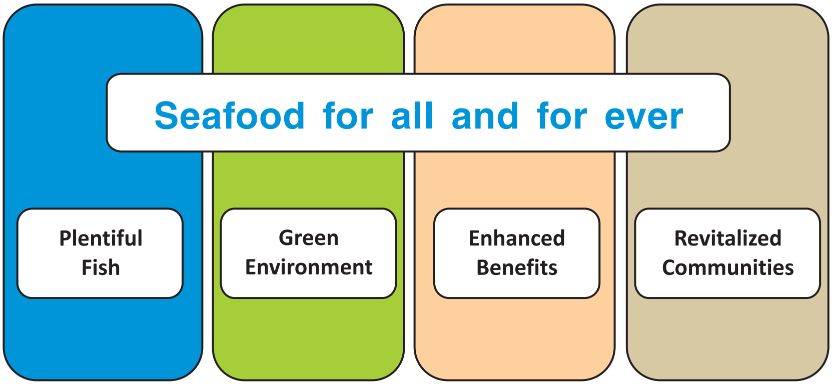
# Goals and Targets

The underpinning goals to meet the Vision "Seafood for all and forever" are:

1. Fish are plentiful, readily available, and valued source for nutritional security
2. Well-maintained, green environment for producing and consuming fish products;
3. Economic benefits and ecosystem services are enhanced, equitably distributed and internationally competitive;
4. Revitalized communities gain value from fishing and farming.



# Way Forward

Research institutions, governments and non-governmental organizations looking for achieving the vision of seafood for all and forever should consider a suite of appropriate approaches that will rebuild fisheries and ecosystems that can create incentives for stakeholders and lead to environmentally and economically sustainable fisheries and mariculture. Clear communication and engagement with all stakeholders can contribute crucial information to the Vision and help overcome potential initial resistance to some of the approaches. Targets and indicators for capture fisheries and mariculture will have to be identified for each approach. For example; annual production target of 6 million tonnes from coastal fisheries and offshore fisheries, and 1 million tonnes from mariculture may be fixed for the next 10-15 years. The following provisional **timeline** is suggested for the journey towards fulfilling the Vision:

| Approach | 2015-2020 | 2021-2025 | 2026-2030 | 2031-2035 | 2036-2040 | 2041-2045 | 2046-2050 |
|---|---|---|---|---|---|---|---|
| **Strengthening current fisheries management regime** | | | | | | | |
| 1. Strengthening fisheries database | | | | | | | |
| 2. Introduction of output controls | | | | | | | |
| 3. Management through regulation of fisheries | | | | | | | |
| **Ecosystem Approach to Fisheries Management** | | | | | | | |
| 1. Regulated fisheries | | | | | | | |
| 2. Creation of new MPAs | | | | | | | |
| 3. Valuation of ecosystems | | | | | | | |
| 4. Biodiversity conservation | | | | | | | |
| 5. Marine Spatial Planning | | | | | | | |
| **Exploration of the oceans: Our last frontier** | | | | | | | |
| 1. Capacity building | | | | | | | |
| 2. Offshore conventional fishing | | | | | | | |
| 3. Technological development for offshore non-conventional fishing | | | | | | | |
| 4. Bioprospecting, Biomining and Biomolecules (Microbes, minor invertebrates, seaweeds) | | | | | | | |

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| **Adaptation to climate change impacts** | | | | | | | |
| 1. Integrated climate Models | | | | | | | |
| 2. Blue carbon economy | | | | | | | |
| 3. Climate change adaptation | | | | | | | |
| **Integration of satellite technologies in fisheries management** | | | | | | | |
| 1. Development of 'e-infrastructure' | | | | | | | |
| - Creation of database and model development | | | | | | | |
| - Advisories from integrated data centres | | | | | | | |
| 2. Guided fishing | | | | | | | |
| 3. Trophic modelling and EAFM applications | | | | | | | |
| **Innovations in Mariculture** | | | | | | | |
| 1. Species diversification | | | | | | | |
| - Prioritization of species of finfish, shellfish and sea plants | | | | | | | |
| 2. Seed | | | | | | | |
| - State of the art technologies and infrastructure for hatchery production | | | | | | | |
| - CBA (wild sourced seed) – stress alleviation methods | | | | | | | |
| 3. Feed | | | | | | | |
| - Cost effective larval and nursery feeds | | | | | | | |
| - Cost effective grow-out feeds | | | | | | | |
| - Innovative feeds (nano) and feeding systems | | | | | | | |
| 4. Coastal mariculture systems | | | | | | | |
| - Area demarcation | | | | | | | |
| - Innovative technologies (diversified systems – onshore recirculation systems) | | | | | | | |
| 5. Inshore cage farming system | | | | | | | |
| - GIS based site selection | | | | | | | |
| - Cost effective cage and mooring systems | | | | | | | |
| - Innovative technologies | | | | | | | |
| 6. Offshore cage farming systems | | | | | | | |
| - Area selection/demarcation | | | | | | | |
| - Cage and mooring designs and automated systems for operation | | | | | | | |
| - Innovative technologies (thermal curtain) | | | | | | | |
| 7. Environmental impact assessment | | | | | | | |
| - Carrying capacity assessment | | | | | | | |

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|---|---|---|---|---|---|---|---|
| - Innovative systems for effluent and waste management | | | | | | | |
| 8. Integrated Multi-trophic Aquaculture (IMTA) | | | | | | | |
| - Area selection | | | | | | | |
| - Candidate species for integration at different trophic levels | | | | | | | |
| - Innovative methodologies | | | | | | | |
| 9. Ecosystem Approach to Aquaculture (EAA) | | | | | | | |
| - Assessment of mariculture on ecosystem | | | | | | | |
| - Development of responsible mariculture taking into account the environment and social aspects | | | | | | | |
| 10. Health management | | | | | | | |
| - Disease prevention (vaccines, immune-stimulants, probiotics, bioremediation, disease resistant strains, cell lines) | | | | | | | |
| 11. Conservation mariculture | | | | | | | |
| - Artificial propagation of endangered/ threatened/vulnerable fauna | | | | | | | |
| - Sea ranching and monitoring | | | | | | | |
| **Biotechnological and bioprospecting approaches** | | | | | | | |
| 1. Cryopreservation and gene banking | | | | | | | |
| 2. Improved varieties (selective breeding, chromosome manipulation) | | | | | | | |
| 3. Genetically modified fish transgenics, super fish | | | | | | | |
| 4. Cloned fish (factory fish) | | | | | | | |
| 5. Biodiversity conservation (endangered species, resurrection) | | | | | | | |
| 6. Fish resilient to climate variability | | | | | | | |
| 7. Therapeutic uses (medicinal fish) | | | | | | | |
| 8. Biosensors | | | | | | | |
| 9. Nanotechnological approaches (environmental management, delivery systems, water treatment) | | | | | | | |
| **Domestic Marine Fish Marketing Grid** | | | | | | | |
| 1. Collection of market information | | | | | | | |
| 2. Preparation of database | | | | | | | |
| 3. Implementation of market grid | | | | | | | |
| **Alternate livelihood options – livelihood reorientation** | | | | | | | |

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| 1. Identification of ALOs | | | | | | | |
| 2. Establishment of sustainable market links for the ALOs and implementation of ALOs | | | | | | | |
| **Legal and policy framework** | | | | | | | |
| 1. Marine Fisheries Policy at different levels | | | | | | | |
| 2. Policies for mariculture (leasing, effluent discharge, CZM, exotic species, GMO) | | | | | | | |

Several factors will pose challenges in meeting the goals of the Vision. Some would be positive and others negative. Some of the challenging factors may have the capacity to collapse the entire progress. Scenarios are a useful tool to explore uncertainties, to understand and to be prepared for shocks. Here, the potential optimistic and pessimistic scenarios are presented. These are not forecasts or projections, but are possible stories about how the future might unfold in the world of uncertainties.

**Optimistic and Pessimistic Scenario of Marine Fish Production**

| Optimistic | | Pessimistic | |
|---|---|---|---|
| **Scenario** | **Impact** | **Scenario** | **Impact** |
| Well-managed capture fisheries | (i) Stock recovery<br>(ii) High and sustainable production<br>(iii) Livelihood opportunities<br>(iv) Increase in fisheries contribution to GDP<br>(v) Nutritional security | Poorly- managed capture fisheries | (i) Collapse of capture fisheries<br>(ii) Production target could not be met<br>(iii) Loss of livelihood<br>(iv) Reduction in fisheries contribution to GDP |
| Expansion of area, species and systems of mariculture | (i) Production of high-value fish<br>(ii) Livelihood opportunities<br>(iii) Increase in fisheries contribution to GDP<br>(iv) Nutritional security | Poor growth in mariculture | (i) Production target could not be met<br>(ii) Loss of livelihood<br>(iii) Reduction in fisheries contribution to GDP |
| Green environment | (i) Healthy habitats and ecosystems<br>(ii) Fish stock and biodiversity recovery | Degraded environment | (i) Unhealthy habitats and ecosystems<br>(ii) Collapse of fish stocks and loss of biodiversity |
| Reduction in GHG | (i) Reduction in negative impacts of climate change<br>(ii) Fast recovery of fish stocks<br>(iii) Resilience of coastal communities | Increase in GHG | (i) Drastic biophysical changes in the oceans affecting ecological productivity<br>(ii) Decline of fish stocks, economic losses<br>(iii) Increase in extreme events and natural disasters leading to losses to properties of coastal communities |

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| Application of innovative technologies | (i) Electronic and remote sensing technologies can promote guided fishing and improve management<br>(ii) Green and blue carbon technologies can reduce GHG emission and promote ecosystem conservation<br>(iii) Processing technology can promote value added products<br>(iv) Biotechnology can revolutionize the sector by increasing fish production and bioprospecting | Lack of technology | (i) Will be a major setback to achieve the goals<br>(ii) Production cannot meet demands<br>(iii) Increase in cost of fishing and decline in value of fish products<br>(iv) Increase in GHG emission |
| Availability of high calibre human skill | (i) Availability of efficient prediction models<br>(ii) Efficiently managed fisheries<br>(iii) Availability of state of art technologies | Non-availability of efficient human skill | (i) Confusions in achieving goals and targets<br>(ii) Serious set-back to the progress of the sector |
| Highly cooperative and participatory stakeholders | (i) Good operating environment<br>(ii) More informed and transparent mechanism<br>(iii) Active, democratic participation<br>(iv) Proactive communities to changes in development | Non-cooperative and non-participatory stakeholders | (i) Disputes in science and management<br>(ii) Insensitive communities to changes in development<br>(ii) Socioeconomic hardship |
| Flexible trade regime | (i) Vibrant domestic and international trade | Trade barriers/ sanctions | (i) Export market collapse<br>(ii) Reduced income and economic benefits |

## Strategy

Marine Fisheries 2050 vision seeks to achieve improved economic benefit through smarter use of our fisheries resources and ecosystem services, and provides for increased non-commercial benefits, while protecting the health of the fishery and the marine environment. To support and meet the goals, a strategic plan for each approach listed in 'Way Forward' is needed. The strategic plan is to bring current and new works together in a comprehensive programme through consultations, engagement with institutions and stakeholders to provide direction for the sector. The plan outlines the framework of joint roles for the research and development agencies and governments. For each approach, the strategy should be to constitute a task force and prepare the plan by adopting the following steps:

a. Identifying issues/goals
b. Preparation of plan
c. Implementation of plan

d. Monitoring/evaluating the plan by developing indicators
e. Reality check and Adaptation

The framework for the strategy of preparation and implementation of plans should be characterized by participation of a large number of national research and development organizations, consultations with regional and global organizations, and stakeholders like fishermen associations, traders, processors, environmentalists, and conservationist. The role of each participant should be clearly defined when developing the strategy documents. It is important to recognize that the envisaged goals can be achieved only by participation of several relevant non-fishery sectors working closely with the fisheries sector. Several common themes underlie each approach which is essential for their success:

#### 1. Institutional, Regional and International Collaboration

Several tropical countries in the region are adopting advanced regulations, legal and policy framework for effective management of fisheries sector. Learning from these countries will give valuable information to manage our fisheries

Collaboration with survey agencies for information and infrastructure support, fishing industry for skilled human resource for exploration and harnessing offshore resources is important. For integration of remote sensing in fisheries and spatial management, collaboration with the space research agencies, oceanographic laboratories and numerical modelling groups are needed. To operationalize the domestic fish marketing grid, collaboration with regional fisheries research, education and developmental organizations are necessary. Policy formulation and implementation support from government agencies are essential to meet the goals.

In the production process, the services of the ecosystem are often ignored mainly because they are not valued. To overcome this lacuna, valuation of ecosystem services (the valuation of biodiversity, recreation value, and occupational value) is very much essential. In this context, collaboration with environmental economics research institutions need to be sought with an aim to pave way for incorporating natural capital accounting/green auditing in our GDP estimates.

On a global basis, breeding, seed production and farming technologies have been developed and commercialized for many marine species. A lot of innovative products and technologies are available in a few countries. In this context, instead of reinventing the wheel, it is worth collaborating with countries that have advanced in this field. It is also advisable to seek the support of national agencies in the country.

Globally, a lot of advancements have taken place in the area of biotechnological interventions for mariculture, biodiversity conservation, environmental management and product development. Collaboration with leading research organizations having cutting edge technologies such as DNA vaccines, transgenic fish, bioremediation, algal biofuels, bioprospecting and omics-sciences is needed.

### 2. Research Support

To address the challenges, it is necessary to have a strong scientific support. Research institutions like CMFRI should devise and execute projects to meet the goals of the Vision. The relevance of existing research institutions and their priorities may have to be revised. New institutions and centres of excellence may have to be established to address the need for state-of-the art technologies.

### 3. Capacity Building

With novel technologies to be integrated into the marine sector, we need upgradation of skilled human pool in scientific research for seamless integration in areas such as remote sensing in fisheries management, valuation of ecosystem and biotechnological applications in mariculture and bioprospecting. This calls for inter-disciplinary trainings and repeated exposure to cutting edge research methods including trainings on use of latest research equipments and software. Human resource development should also be paralleled by upgradation of research infrastructure. It is essential to train our scientists and technicians on the latest technologies in mariculture and biotechnology. Similar to research, the fishing industry will also be undergoing major changes with increasing industrialization, which would require skilled manpower and capital investment.

### 4. Stakeholder Consultation

Resource management can succeed only with the involvement and participation of all the stakeholders in the sector as well those from relevant non-fishery sectors. This involves developing vital links with all stakeholders.

### 5. Mainstreaming the Vision in the Country's Development Agenda

The contribution of fisheries to nutritional security, economic growth and livelihoods is often ignored. The priority is in convincing governments that the sector has an important role to play in the national development process by contributing to growth process in a substantive manner; and include fisheries and aquaculture in national development agenda. In this regard, it is essential to attract massive investments, to increase the public and private capital formation in fisheries sector, which will help achieving the goals envisaged in the vision document.

### 6. Developing Policies, Legislations, Acts

Any planned sectoral development needs appropriate policies, legislations and acts. As the existing policies are inadequate to meet the anticipated challenges in the sector, it is important to develop effective new policies. In the case of mariculture, as it is an emerging sector, there is need for developing leasing policies and other regulations.

It is easy to imagine, conceptualize and write Vision documents. What is more difficult is to have the will and determination to actualize it. May this Vision bear fruit and future generations have "Seafood for all and forever". Jai Hind!

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