World FISHERIES Day
21st November 2017

Souvenir

सत्यमेव जयते

World Fisheries Day
21st November 2017

Physical Progress Under Blue Revolution Scheme: 2015-17

Aquaculture Growth	Motorization of Crafts	Fishing Harbours & Landing Centres	Fish Markets & Mobile Marketing	Skill Development Program	Insurance Coverage	Saving-cum-Relief
86,497 Fish Farmers 36,330 ha developed	27,815 Fishers benefitted	98 Nos. Constructed 98,000 Fishers benefitted	69 Modern Fish Markets 21,384 Fish Vending Vehicles	59,478 Fishers/ Farmers trained	49.29 Lakh Fishers covered	4.32 Lakh Fishers benefitted

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World Fisheries Day

21st November 2017

Government of India
Ministry of Agriculture and Farmers Welfare
Department of Animal Husbandry, Dairying & Fisheries
Krishi Bhawan, New Delhi

राधा मोहन सिंह
RADHA MOHAN SINGH

D.O. No. 2868 /AM

कृषि एवं किसान कल्याण मंत्री
भारत सरकार
**MINISTER OF AGRICULTURE & FARMERS WELFARE
GOVERNMENT OF INDIA**

सत्यमेव जयते

17 NOV 2017

संदेश

मुझे यह जानकर प्रसन्नता हो रही है कि पशुपालन, डेयरी एवं मत्स्यपालन विभाग, कृषि एवं किसान कल्याण मंत्रालय द्वारा 21 नवंबर 2017 को "विश्व मात्स्यिकी दिवस 2017" का एन.ए.एस.सी. काम्प्लेक्स परिसर, नई दिल्ली में एक भव्य और सार्थक रूप से आयोजन किया जा रहा है। कृषि एवं किसान कल्याण मंत्रालय द्वारा 'विश्व मात्स्यिकी दिवस' को राष्ट्रीय स्तर पर एक समारोह के रूप में मनाने का निर्णय, भारत सरकार की मछुवारो एवम मत्स्य-किसानो के विकास के प्रति प्रतिबद्धता को दर्शाता है। मेरे लिये यह हर्ष का विषय है कि इस नई परम्परा का सृजन कर इसे लगातार चौथे वर्ष जारी रखते हुये यह आयोजन किया जा रहा है।

मात्स्यिकी क्षेत्र में वृद्धि की संभावनाओं और देश में मत्स्य और मत्स्य-उत्पादों की बढ़ती माँग को दृष्टिगोचर रखते हुए, माननीय प्रधानमंत्री श्री नरेन्द्र मोदी ने मात्स्यिकी के क्षेत्रों में- "नीली-क्रान्ति" का जो आह्वान किया था, तदनुसार, भारत सरकार ने 3000 करोड़ रुपए के व्यय से केन्द्रीय क्षेत्र की योजना "नील क्रान्ति: मात्स्यिकी का एकीकृत विकास और प्रबंधन" की शुरुआत की जा चुकी है। इस एकछत्र योजना में राष्ट्रीय मात्स्यिकी विकास बोर्ड (एन.एफ.डी.बी.) के क्रिया-कलापों के अतिरिक्त, अन्तर्देशीय मात्स्यिकी, जल-कृषि, समुद्री मात्स्यिकी जिसमें गहरे समुद्र में मत्स्यन, पोस्ट हार्वेस्ट एवं अवसंरचना विकास तथा मैरीकल्चर आदि भी शामिल हैं। इस योजना का किसानो एवं मछुवारों की आय को वर्ष 2022 तक दोगुना करने के लक्ष्य में महत्वपूर्ण योगदान रहेगा।

सम्पूर्ण विश्व में कार्यरत मत्स्य-किसानों, मछुवारो और मत्स्य कर्मकारों को संगठित करने के उद्देश्य के साथ 21 नवम्बर 1997 को नई दिल्ली में एक आयोजन हुआ था। तभी से विभिन्न देशों मे मछुआरे प्रतिवर्ष 21 नवम्बर को "विश्व मात्स्यिकी दिवस" के आयोजन के माध्यम से एकजुटता और गौरव का प्रदर्शन करते चले आ रहे हैं। हम भी "विश्व मात्स्यिकी दिवस 2017" के इस आयोजन को देश के मछुवारा समुदाय की उन्नति, समृद्धि और खुशहाली की शुभ कामनाओं के साथ देश मे मात्स्यिकी सेक्टर के चतुर्मुखी विकास को समर्पित करते हैं।

मैं इस आयोजन की शानदार सफलता की कामना करता हूँ।

(राधा मोहन सिंह)

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कृष्णा राज
KRISHNA RAJ

कृषि एवं किसान कल्याण राज्य मंत्री
भारत सरकार
MINISTER OF STATE FOR
AGRICULTURE & FARMERS WELFARE
GOVERNMENT OF INDIA

संदेश

मुझे यह जानकर हार्दिक प्रसन्नता हो रही है कि पशुपालन, डेयरी एवं मत्स्य पालन विभाग, कृषि एवं किसान कल्याण मंत्रालय द्वारा 21 नवंबर 2017 को एन.ए.एस.सी. काम्प्लेक्स परिसर, नई दिल्ली में "विश्व मात्स्यिकी दिवस 2017" का वृहद् रुप में आयोजन कर रहा है।

मछुआरों के एक अन्तर्राष्ट्रीय संगठन- डब्ल्यू.एफ.एफ.-ने एकता, गौरव और एकजुटता का प्रदर्शन करने के लिये दिनांक 21 नवंबर 1997 को नई दिल्ली में इस सम्मेलन का आयोजन किया था। इस दिवस को "विश्व मात्स्यिकी दिवस" के रूप में मनाया जाता है, और हम इस आयोजन को जारी रखते चले आ रहे हैं। प्रत्येक विश्व मात्स्यिकी दिवस के साथ-साथ, हम मत्स्यपालकों, मछुआरों और उनके परिवारों, समुद्रतटीय समुदायों, महासागरों की दशाओं और मत्स्य-भंडारों की प्रास्थिति में अधिक गहरी समझ प्राप्त करते हैं। हम यह समझते हैं कि सतत मत्स्यन, खाद्य सुरक्षा और पर्यावरण से भी परस्पर जुड़ा हुआ है।

एक अर्थ में, विश्व मात्स्यिकी दिवस, हमें वैश्विक रुप से विचार करने और स्थानिक रूप से कार्य करने का एक अवसर प्रदान करता है, क्योंकि हम इसके आयोजन के क्रम में अपने स्थानीय मछुआरा समुदायों तक स्थानीय के माध्यम से पहुँचते हैं। इस आयोजन के माध्यम से हम अपने मछुआरों, अपने राष्ट्र और विश्व को एक संदेश देते हैं कि मात्स्यिकी एक प्रमुख क्षेत्र है जो देश के सामाजिक-आर्थिक वृद्धि में महत्वपूर्ण योगदान करता है। भारतवर्ष में मात्स्यिकी और जल-कृषि मात्स्यिकी के विभिन्न क्रिया-कलापों में कार्यरत डेढ़ करोड़ से अधिक व्यक्तियों को लाभदायक रोजगार और सहायता प्रदान करते हैं।

समुद्रों, नदियों, नहरों, जलाशयों, टैंकों, तालाबों, बाढ़ वाले मैदानों, मुहानों, झीलों, खारे पानी के क्षेत्रों के रूप में मौजूद विभिन्न जलीय संसाधन देश में मात्स्यिकी के विकास के लिए वृहद् क्षेत्र-विस्तार प्रदान करते हैं। देश में प्रारम्भ की गई नीली क्रान्ति योजना (नीली क्रान्ति मिशन) का प्रमुख उद्देश्य सन् 2020 तक मत्स्य उत्पादन को 15 मिलियन टन तक बढ़ाना है। किसानों की आय वर्ष 2022 तक दोगुना करने के लक्ष्य में मात्स्यिकी एक महत्वपूर्ण भूमिका अदा करने जा रही है।

मैं विश्व मात्स्यिकी दिवस 2017 के आयोजन की शानदार सफलता की कामना करती हूँ।

(कृष्णा राज)

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Government of India
Ministry of Agriculture & Farmers Welfare
Department of Animal Husbandry, Dairying & Fisheries
Krishi Bhawan, New Delhi-110001

17/11/2017

MESSAGE

India is perpetually working towards enhancement of food and nutritional security for its people. Fisheries and aquaculture are playing a very important role in not only meeting the food and nutritional security but also broadly contributing to the socio-economic growth of the country. To enhance fish production through sustainably exploring the potential resources, the umbrella Scheme "Blue Revolution: Integrated Development & Management of Fisheries" was introduced. Under 'Blue Revolution Scheme', both inland and marine sector are focused to encourage and uphold the financial capacity of the farmers so as to enhance the production. This scheme has been directly or indirectly benefiting the farmers and supporting the livelihoods of many resource based communities. Under these schemes, around 31,942 fish farmers have been trained, 11,480 houses constructed for the fisher's community and 63,672 fish farmers were benefited. The thrust for the current year is on developing infrastructure for fish seed production and fish marketing, development of reservoir fisheries and cold water fisheries, upgradation of new technologies in aquaculture such as Recirculation Aquaculture System (RAS) etc. With all these, the fish production for the year 2017-18 is expected to be 12.57 million metric tonnes against 11.41 million metric tonnes in 2016-17 (P).

I am indeed very happy to learn that the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture and Farmers Welfare, Govt. of India is celebrating the ***World Fisheries Day, 2017*** *with the* ***theme-Kisan Ki Aay Ho Dugna- Sankalp Se Siddhi*** *to highlight the importance of fish, fishers and fisheries in the country. I congratulate NFDB for organizing this grand event.*

I wish the World Fisheries Day-2017 a grand success.

(Devendra Chaudhry)

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बी. किशोर, आई.ए.एस.
संयुक्त सचिव
B. Kishore, IAS
Joint Secretary

भारत सरकार
कृषि और किसान कल्याण मंत्रालय
पशुपालन, डेयरी और मात्स्यिकी विभाग
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Govt. of India
Ministry of Agriculture and Farmers Welfare
Department of Animal Husbandry,
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Krishi Bhavan, New Delhi - 110001

Message

Fisheries touch our lives in countless ways. If well maintained, they can feed millions of people, generate jobs and income, help maintain log-standing community and cultural traditions, and provide a range of products. **World Fisheries Day**, observed annually on November 21st, is an opportunity to reflect on the importance of fisheries around the world and what we can do to ensure that they stay healthy and productive.

Neel Kranti Mission - 2016, envisages "Creating an enabling environment for integrated development of the full potential of fisheries of the country, along with substantial improvement in the income status of fishers and fish farmers keeping in view the sustainability, biosecurity and environmental concerns".

Fishers, the backbone of the *Neel Kranti Mission*, are going to be benefited through the schemes initiated by the Govt. of India. Fish farmers are covered under insurance scheme and many fishermen are also being provided relief during the non-fishing season.

I hope World Fisheries Day celebration will contribute significantly in creating awareness and successful promotion of 'Blue Revolution'.

Date: 10/11/2017
New Delhi

(B. Kishore)

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मुख्य कार्यपालक
I. Rani Kumudini, IAS
Chief Executive

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पशुपालन, डेयरी और मात्स्यिकी विभाग
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National Fisheries Development Board
Dept. of Animal Husbandry, Dairying & Fisheries
Ministry of Agriculture & Farmers Welfare
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Foreword

India is endowed with diverse water resources such as major and minor rivers, lakes, reservoirs, flood plains, wetlands, estuaries, mangroves, coastal lagoons, seas, etc., that not only harbour a rich aquatic biodiversity but also sustain valuable fisheries resources. Over the decades, the country made rapid strides in the fisheries sector progressing initially from subsistence fisheries to commercial fisheries and subsequently, with transfer of technology from lab to land, commercial aquaculture in the country recorded exponential growth. Currently, with an annual production of about 10.80 million tonnes India stands second among the leading fishing nations in the world and nearly 70% of this production comes from Inland Capture Fisheries and Freshwater Aquaculture.

The overall growth that the country has achieved in Fisheries and Aquaculture Sector is being celebrated on the World Fisheries Day on 21st November 2017 with the participation of a cross section of the stakeholders involved. On this occasion a Souvenir is being brought out with 11 articles written by some of the leading fisheries scientists and academicians in the country. A wide variety of topics of interest, covering some of the issues that the sector is facing as well as the opportunities that are available to enhance fish production and productivity, are presented. The significant points made in the articles are worth mentioning here.

The Fisheries sector in India evolved from artisanal fishing to sophisticated technologically advanced fishing industry through excellent scientific innovations and infrastructure. Studies made in the country over the years have led to the need for implementing measures to conserve natural resources using selective fishing gear. Issues of seed quality and disease incidence in shrimp aquaculture were tackled with better management and diversification of species. New technologies such as cryopreservation of gametes, genomics, biofertilization, etc., have made aquaculture more efficient and specialized.

In situ conservation, stock enhancement through ranching, *ex situ* conservation through cryopreservation of gametes and embryos, tissue banking, DNA Bar-coding, development of fish cell lines for fish virology studies would lead to improving the nation's fish wealth. The Eastern Himalayas are home to rich freshwater fish diversity exemplified by 596 species under 123 genera and 37 families that are threatened by overexploitation, pollution, habitat degradation, climate change and invasion by exotic species.

A case study on management of multi-use water bodies in Chhattisgarh reveals the intricacies, conflicts among stakeholders, the nature of technical, socio-economic-cultural-political and environmental interdependencies. Freshwater aquaculture requires diversification of fish species including small and indigenous species, integrated fish farming, cage and pen culture, opening of one-stop aqua shops, and skill development. Fish health issues in aquaculture arise from breakdown of balance between host, pathogen and environment, emerging pathogens, trans-boundary movement of live animals and live feeds, use of antibiotics and veterinary drugs, and there is an urgent need for aquaculture certification.

Sea Cage Farming provides immense opportunities for enhancing marine fish production while simultaneously reducing fishing pressure on natural stocks and providing livelihood to coastal communities. Artificial Reefs are found to restore marine ecosystem and enhance marine fish production with community participation and ownership along Tamil Nadu coast.

There is immense scope for development of Ornamental Fisheries in the country. Hatchery technology for production of 10 marine ornamental fishes has been standardized at ICAR-CMFRI; success was achieved in the case of Clownfish, Damselfish and Firefish. Also a method has been developed for sustainable trade from wild collection of ornamental fish.

Advanced technologies adopted at ICAR-CIFT are being popularized for post-harvest fish processing and packaging to enhance the safety and shelf-life of fish products, and a variety of value-added products, ready to serve fish products, extruded products and fishery byproducts have been developed.

I compliment the authors for their valuable contributions that not only trace the growth of the fisheries sector in the country and highlight the technological advances made but also show us the way forward for sustainable fisheries development in the country.

I would also like to place on record my sincere appreciation to Dr. K. Ravindranath, Senior Consultant (Technical), NFDB, for the excellent editing.

Hyderabad
17 November 2017

(I. Rani Kumudini)

CONTENTS

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Research for Development (R4D) in Fisheries

S. Ayyappan

Former Secretary, Department of Agricultural Research and Education (DARE) and Director General, Indian Council of Agricultural Research (ICAR), New Delhi

Indian fisheries is one of the most comprehensive and representative fisheries globally, with both marine and inland fisheries, as also warm as well as cold water fisheries, in terms of the ecosystems. Further, there are few countries with significant components of both fisheries and aquaculture, as we have. Over the last seven decades, fisheries has moved centrestage from fisher hamlets, with demonstrated contributions to the economy in terms of nutritional security, livelihoods, employment and exports. Globally too, fish is more than just a protein source, with low cholesterol-highly unsaturated fatty acids, micronutrients and vitamins, also the most efficient conversion animal model.

The utility share of fish globally is 81% for human consumption and rest for non-food purpose. With a share of 6% of all protein sources, the per capita consumption is around 17 kg that is expected to increase by 15% even in the next ten years. With the world's population projected to be over nine billion and the Indian population about 1.4 billion, the global fish production is required to be over 215 mmt and accordingly, the Indian fish production also to be around 20 mmt. While the aquaculture production has to double to 140 mmt at the global level, it calls for tripling in the country, if we are to meet our target as indicated above. About 80% of the production is expected from Asian countries, as also over 51% of the world's fish exports.

Contributing over 5% to the Ag-GDP and employing over 14 million people, fisheries is often called a sunrise sector. While there are traditional fishers and farmers in fisheries and aquaculture, there is also a flavor of industry in fish processing and trade. Given the canvas and opportunities, it was a long felt need of an institution, to link science with commerce, research with business, as also coordinate entrepreneurship with finance, and thus was formed the National Fisheries Development Board. It is a matter of pride and pleasure to note that NFDB completed a decade of its establishment, housed in a fish-building in Hyderabad, unique in the entire country.

Research

Fisheries research in India dates back to early 19th century, though the research institutions are as young as the independent India. Biology of commercially important fish (finfish and shellfish) species engaged the attention of early researchers, including age and growth, migration patterns, feeding and reproduction. Biodiversity, productivity of natural ecosystems, exploratory surveys and stock assessment, mapping of fishing grounds and related aspects were also addressed. In marine fisheries, increasing the production was the main focus, with harvest technologies, pertaining to new boat designs and gears, motorization and mechanization, diversification of fishing gears, gradually addressing the needs of conservation of natural resources. The concept of regulation of the natural resources that are not inexhaustible led to selective fishing gears, introduction of TEDs (Turtle Exclusion Devices), BRDs (By-catch Reduction Devices) and so on.

Fishery enhancement in terms of synthetic gear material, acoustic fish detection methods, potential fishing zones, vessel monitoring system, etc. as also those such as fish aggregating devices or cage aquaculture have been worked out. Concepts of Ecosystem modeling, Stock certification, Ecosystem Approach to Fisheries Management, Catch-Photograph-Release as a part of eco-tourism and game fishing are gaining importance in the recent past. Mariculture, with cage farming of finfish like seabass and cobia, mussels, oysters and seaweeds, has provided a major option for augmenting fish production from the seas.

Coastal aquaculture, with a predominance of shrimp farming is earning the country significant foreign exchange, contributing to over 17% of the agricultural exports. Addressing the issues of seed and diseases, also in line with the global trends, the research efforts have provided for management and diversification in the area. There is also much scope in finfish cultivation, for which both the hatchery support and market linkage have to be strengthened.

The segment of inland fisheries, with resources of rivers, estuaries, reservoirs, lakes & wetlands, has been approached from both the fish production enhancement and conservation points of view. Ecosystem services from these waters have also been discussed from time to time. While siltation and water flows (minimum/environmental) have been a concern in the riverine systems in the recent past, freshwater discharge into the estuaries is reducing, with more dams and anicuts across the rivers. Increasing resource of reservoirs has received much attention and yield levels of 100-300 kg/ha/year have been possible in different reservoirs. Studies on estuaries have focused on breeding grounds for several fish species. Fisheries and ecosystem dynamics including biodiversity loss, habitat degradation, water abstraction, entry of exotics are being worked out in the recent years. There are also dimensions of eco-tourism and game fisheries added to fisheries conservation, propagation, management and production, more pronounced in Coldwater fisheries.

It is interesting to record that several States have declared important fish species as State-Fish, as in *Hilsa* by West Bengal, *Magur* by Bihar, *Pabda* by Tripura, Golden *mahseer* by Arunachal Pradesh, Himachal Pradesh, Jammu & Kashmir and Uttarakahand, *Kalbasu* by Haryana, *Karimeen* (Pearl Spot) by Kerala, *Pengba* by Manipur, Carnatic carp by Karnataka, *Chital* by Uttar Pradesh, *Mahanadi mahseer* by Odisha, Chocolate *mahseer* by Nagaland, and Murrel by Telangana. Driven by research efforts towards conservation of aquatic biodiversity, this not only demonstrates the sense of ownership by the States with regard to fish species, but would impact the policies in various ways.

Freshwater aquaculture, transforming from a backyard activity in Eastern India to a commercial enterprise, has become the mainstay of Indian fisheries, contributing to more than half of the fish production. Its annual growth rate of over 6% is perhaps the highest among the food production systems. The researches got a fillip with the All India Coordinated Research Projects on carps and airbreathing fishes, and several packages of practices were developed to suit the highly diverse nature of resources of ponds and tanks in the country. Development of induced breeding and hatchery techniques for mass scale seed production as well rearing systems, selection programmes and multiple breeding of carps, introduction of exotic carps, carp-based polyculture models, catfish breeding and culture, prawn farming, pearl culture, integrated farming systems, support mechanisms through feed and health management measures, have enabled a revolution in the sector, as also capacity building across the country. While Recirculatory Aquaculture systems, Organic farming, Inland saline aquaculture, Ornamental fish culture have provided for intensification and diversification of culture systems depending on the resources and demands, new science in terms of gamete cryopreservation, genomics, molecular markers, stem cell research, barcoding, biofertilization are opening new vistas for efficient and specialised aquaculture.

Fish preservation and processing technologies are being upgraded continuously, to the level of ready-to-cook and ready-to-eat products, battered and breaded products from low value species, industrial products and high value compounds like chitin and chitosan, therapeutics and nutraceuticals. Packaging and storage as well as effluent treatment from processing plants to ensure zero pollutant discharge, use of renewable energy in operations, are the areas of interest.

Climate Change

The universal concern of climate change is operating on fisheries and aquaculture in a pronounced manner. The carbon dioxide emission in the atmosphere has increased from 275 ppm in 1750 to 383 ppm in 2005 and may reach 450 ppm by 2030. Continued rises in the concentration of carbon dioxide will lead to a global sea surface water pH reduction of up to 0.4 units by 2100. Similarly, the global average air temperature rose by 0.74°C during the 100 year period ending in 2005, and will increase by 2.2 to 4.8°C by 2100. The seawater mean temperature has increased by 0.06°C in the last 50 years and the increase is not even, with the upper 300 m of the oceans rising by 0.31°C. The mean sea surface temperature in the Indian Seas warmed by 0.2°C in the last 45 years. Being poikilotherms, even a difference of 1°C or 0.1 unit pH in seawater or change in oceanic current direction and speed will affect distribution and life processes of many aquatic organisms including fish.

The main impact of fluctuating climate on intertidal ecosystems would be through changes in sea level and temperature, and exposure to warmer environment during low tide. This may result in different kinds of changes, *viz.*, Category 1: Extension of distributional boundary (oil sardine & Indian mackerel); Category 2: Shift in latitudinal distribution (catfish); Category 3: Shift in depth of occurrence (Indian mackerel); and Category 4: Phenological changes (threadfin breams). Species with wider ecological niches, greater mobility, fast growth, quick turnover of generations are able to adapt; they are mostly low value, small sized, short lived species contributing more than 25% to Indian marine fish catches. However, species with narrow ecological niches, sedentary/sessile with calcareous exoskeleton, slow growth may not be able to adapt quickly.

Prediction models indicate that coral bleaching events would become a regular feature after 2030, and corals would become remnant after 2050 in coral dominant regions of the Indian seas. This may cause erosion of economic returns to the fishermen and hence have to adapt by changing their craft and gear combinations, depending on the available species. Effective actions to tackle climate impacts include: adopting Code of Conduct for Responsible Fisheries and Integrated Ecosystem-based Fisheries Management; Supporting energy efficient fishing craft (evolving emission standards) and gear (promoting static gear); Cultivating aquatic algae and plants for carbon sequestration, food, and pharmaceutical purposes; Establishing Weather Watch Groups for fisheries sector; Evolving decision support and disaster management systems; Developing a compendium on indigenous traditional knowledge (ITK) in the fisheries sector and explore opportunities for its utilization; and Intensifying efforts to increase climate literacy among the stakeholders in fisheries sector.

Education

Human resource for various fisheries research and development activities has been provided by Universities, Fisheries schools and other educational institutions over decades, through progrmmes of degrees, diplomas and certificate courses. Formal fisheries education in the country started in 1969 with the College of Fisheries, Mangalore, and presently, there are 22 Fisheries Colleges offering degree programmes, with an annual output of nearly 800 graduates and over 200 post graduates.

Trained manpower is required in Development Departments of State Governments, Financial institutions, Universities and related organisations in the public sector; hatcheries, farms, fishing units, processing plants, feed plants and so on in the private sector. Further, there is new science coming up in terms of remote sensing, sensor applications, nanotechnology, as also international negotiations and instruments, along with the old fields like taxonomy, classical anatomy and physiology, which need new inputs as well as revisits. It is estimated that the requirement of trained manpower would be twice the present availability, with an emphasis on skills and diversified areas of science, technology, innovation and policy, for knowledge-based fisheries management.

Issues

The issues that have come up in the recent years in fisheries and aquaculture pertain to water, energy, quality seed and feed, exotic fishes, biosecurity and disaster management. With regard to water budgeting, it is estimated that 300-400 litre of water is required to produce a kilogram of fish and 50- 60 litre for shrimp, as compared to 3,000 l/kg rice and 900 l/kg wheat. In this context, recycling of wastewater for aquaculture as also employing aquaculture for wastewater treatment are emerging as major options. Several models in this regard are available, that could be upscaled, customized and adopted in different situations across the country.

The areas that need attention are Data warehousing and management, Sustainable marine fisheries management, Capacity building in deep sea fisheries, Fisher welfare in a comprehensive manner from productivity enhancement to risk management, Resilient riverine and wetland fisheries, scientific management of reservoirs, Community involvement in common property resources such as canals, Hatchery accreditation and seed certification, Feed management, Aquatic biosecurity and quarantine, Disease surveillance and reporting systems, Customised cold chain for domestic marketing, Revisits to policies relating marine and inland fisheries as also aquaculture.

India is a 10 million tonne fish-country and is projected to achieve 15 million tonne mark in the next 3-4 years. Addressing the above areas as well as looking into the potentials of the island systems, providing support to small scale fishers and farmers, integrating fish with other commodities for diversification and enhancement of farmers' income in a holistic manner, due consideration to natural resources in terms of carbon footprints, value chain approach in different segments from seed-to-market, could realise the target. Fish-Fisher-Fisheries: Diversity-Welfare-Sustainability must be the watchwords to bring 'Profit & Prestige' to the Indian fisher, who is the most vulnerable person in the country to natural calamities as well as manmade disasters. NFDB would do well to keep the Fisher at the centre of all its efforts towards 'Fish for All'.

2

Status of Fish Genetic Resources in India and their Management Strategies

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India with its huge inland and marine open-water resources in the form of 29,000 km of rivers, 0.3 million ha of estuaries, 0.9 million ha of backwaters and lagoons, 3.15 million ha of reservoirs, 0.2 million ha of floodplain wetlands, 0.72 million ha of upland lakes and 2.02 million km^2 of Exclusive Economic Zone (EEZ) has been the home for about 10% of global finfish biodiversity. The country also takes the pride of occupying second rank in the world in total fish production. While marine sector is almost constituted by capture fisheries, aquaculture has been the principal contributor in inland fisheries sector. Beside primarily being source of food and nutrition, the genetic resources, in several cases, are also important source of various pharmaceutical and other commercial products and sustain other related trades like ornamental fishes. It is known that the developing countries produce and consume more fish than developed countries and it is further predicted that the dominance of developing countries will grow further. To meet these challenges, besides aiming at increased production from aquaculture, appropriate planning for conservation of fish diversity and its sustainable utilization, need to be given greater importance.

In general, aspects of biodiversity and conservation of the ichthyofauna in the Asian region, in comparison to those of Africa, Europe and North America have been relatively less documented. Among all the countries India contributes maximum number of endemic freshwater finfish species (27.8% of the native fish fauna) followed by China, Indonesia and Myanmar. The share of endemic fish species in some of the hotspots of the country viz., Western Ghats has been as high as 69%. While capture fisheries had been the major source of inland fish production till mid eighties, the production from natural waters like rivers, lakes, etc., declined over the years due to proliferation of water control structures, indiscriminate fishing and habitat degradation. The development of Indian marine fisheries from a traditional subsistence oriented one to industrial fisheries through Five Year Plans has been phenomenal. The present scenario, however, is characterized by over exploitation of coastal resources up to 50 m depth. Declining yields from the inshore waters and continuing increase of demand for fish in domestic and export markets have led to consider alternative options for sustaining the production through oceanic and deep sea fishing, large-scale sea-farming and coastal mariculture.

Diversity of Fish Species

Coldwater fish diversity: The aquatic resources above 914 m MSL in Himalayas, sub-Himalayan zone and mountains of the Deccan are known as coldwaters. The temperature of the upland coldwater ranges between 0 and 20^{o}C with an optimal range between 10 and 12^{o}C. The lakes and streams of high altitude are characterized by high transparency and dissolved oxygen as well as sparse biota. Most of the fishes are small-sized, exhibiting distribution pattern depending upon the rate of flow of water, nature of substrata and food availability. Some fishes living in turbulent steams have developed special organs for attachment. The major coldwater resources are upper stretches of Indus, Ganga, Brahmaputra rivers and their tributaries as well as several coldwater lakes and reservoirs, which harbour fishes belonging mainly to six different families such as Cyprinidae, Balitoridae, Cobitiidae, Sisoridae, Psilorhynchidae and Homalopteridae. Some of the commercially important Indian coldwater species are *Tor putitora, T. tor, T. mosal, T. progeneius, T. khudree, T. mussullah, T. malabaricus, Naziritor chelynoides, Neolissochielus wynaadensis, N. hexagonolepis, Schizothoraichthys progastus, S. esocinus, Schizothorax richardsonii, S. plagiostomus, S. curvifrons, S. micropogon, S. kumaonensis, Barilius bendelisis, B. vagra, B. shacra, B. (Raiamas) bola, Bangana dero, Labeo dyocheilus, Crossocheilus periyarensis, Garra lamta, Garra gotyla gotyla, Glyptothorax pectinopterus, G. brevipinnis, G. stoliczkae* and *Lepidopygopsis typus*. The Trans-Himalayas is a fragile biome, characterized by extremes of both climatic and biotic factors. Very low productivity and a high degree of resource seasonality and unpredictability give rise to a unique diversity of life that is persistently prone to any kind of disturbance. Flora and fauna of this cold desert are adapted themselves to extreme conditions and have low population abundance.

Warmwater fish diversity: The 14 major river systems in the country share about 83% of the drainage. The important rivers are Ganga river system (with a combined length of about 8, 047 km), Brahmaputra system (combined length 4,023 km), Indus river system (Beas and Sutlej), East Coast river system consisting of Mahanadi, Godavari, Krishna, Cauvery (combined length 6,437 km) and West Coast river system including Narmada and Tapti (combined length 3,380 km). River Ganga harbours 250 fish species (freshwater, brackish and marine) of which about 150 are basically freshwater species. The fish diversities of other rivers are Brahmaputra 167, Mahanadi 99, Cauvery 90, Narmada 95 and Tapti 57, several species of which are common to different river systems. There are many small west-flowing rivers originating from the Western Ghats such as Chalakkudy, Periyar, Sharavathi, Nethravathi, etc that are rich in fish diversity and harbour several endemic genera such as *Gonoproktopterus, Homaloptera, Bhavania, Lepidopygopsis, Horabagrus, Oreonectes, Schistura, Horaglanis*etc. Commercially important species of the country largely contributed by carps and barbs (*Catla catla, Labeo rohita, Cirrhinus mrigala, L. calbasu, L. dussumieri, L. bata, L. fimbriatus, L. dero, L. dyocheilus, Cirrhinus cirrhosa, C. reba, Puntius sarana, P. dubius* and *P. carnaticus*), catfishes (*Clarias batrachus, Heteropneustes fossils, Sperata aor, S. seenghala, Wallago attu, Pangasius pangasius, Silonia silondia, Bagarius bagarius, Rita rita, Eutropiichthys vacha, Ompok pabda, O. bimaculatus*), murrels (*Channa striatus, C. marulius, C. punctatus, C. diplogramme*), featherbacks (*Chitala chitala* and *Notopterus notopterus*) and other important ones like *Anabas testudineus*.

During the last decade many fish species from the biodiversity hotspot areas like North-East and the Western Ghats region have emerged to be new species. Under ICAR-NATP Project 32 new species were described from the above region. While several other new species have also been described in the recent years, many more new species could be distributed in the drainages of the Western Ghats, North East and other unexplored areas and therefore require more biodiversity explorations.

Brackishwater fish diversity: The salinity of brackishwater, i.e. the transition zone between freshwater of the rivers and the saline water of seas, ranges from 0.5 to 30 ppt. The major estuarine systems of the country are Hooghly-Matlah, Mahanadi, Godavari, Krishna, Cauvery, Narmada, Tapti and other estuaries of East and West Coasts including large brackishwater lakes such as Chilka, Pulicat and Vembanad. The brackishwater systems of the country known to harbour 113 taxa including commercially important species like *Chanos chanos, Mugil cephalus, Valamugil seheli, V. cunnesius, Liza macrolepis, L. tade, L. parsia, Rhinomugil corsula, Etroplus suratensis, E. maculatus, Lates calcarifer, Tenualosa ilisha, Elops saurus, E. machnata, Mystus gulio, Nematolosa nasus, Pseudosciaena coibor, Gerres setifer, G. oyena, Sillago sihama,* *Megalops cyprinoides*, *Polynemus tetradactylus*, *P. paradiseus*, *Eleutheronema tetradactylum*, *Ephinephelus tauvina*, *Lutjanus argentimaculatus*, and *Tachysurus* spp. It also harbours important shrimp and prawn species like *Penaeus monodon, P. semisulcatus*, *Fenneropenaeus (Penaeus) indicus*, *Metapenaeus monoceros, M. dobsoni, M. affinis, M. brevicornis*, *Palaemon styliferus*, *Macrobrachium rosenbergii* and *M. malcolmsonii*.

Marine fish diversity: Marine fisheries resources of the Bay of Bengal, Arabian Sea and Indian Ocean include coastal, offshore and deep sea as well as islands comprising 1887 taxa including the commercially important species like sharks, rays, Bombay duck (*Harpadon nehereus*), sardine (*Sardinella longiceps, S. fimbriatus, S. gibbosa, S. albella*), perches (*Lethrinus* spp., *Epinephelus* spp.), white fish (*Lactarius lactarius*), Silver bellies (*Secutor muconius, S. insidiator, Leiognathus dussumieri, L. bindus, L. lineolatus*), seer fish (*Scomberomorus commersoni, S. guttatus, S. lineolattus, Acanthocybium solandri*), mackerel (*Rastrelliger kanagurta*), tuna (*Auxis thazard, A. rochei, Sarda orientalis, Euthynnus affinis, Thynnus tonggol*), carangids (*Caranx caranax, Megalaspis cordyla, Decapteus russelii, D. tabl*), polynemids (*Eleutheronema tetradactylum, Polynemus indicus, P. heptadactylus*), pomfrets (*Pampus argentius, P. chinensis, Parastromateus niger*), barracudas (*Sphyraena commersoni, S. obtusata, S. acutipinnis, S. jello*), red mullets (*Upeneus sulphurus, U. vittatus, Parupeneus indicus*), ribbon fishes (*Trichurus lepturus, T. gangeticus, T. pantulli, Eupleurogrammus intermedius, E. muticus*), anchovies (*Coilia dussumieri, Anchoviella commersoni, A. indica, A. heterolobus, A. benganensis*) and catfishes (*Tachysurus thalassinus, T. tenuispinis, T. dussumieri, T. sona, T. serratus, T. jella, Plotossus canius* and *P. angullaris*) and shellfishes such as *Parapenaeipsis stylifera, P. hardwickii, P. sculptilis, Penaeus merguensis, P. indicus, P. semisulcatus, Metapenaeus monoceros, M. dobsoni, M. affinis, M. brevicornis* and *Solanocera crassicornis*.

Threats to Fish Diversity

The aquatic environments over the years have been experiencing serious threats to both biodiversity and ecosystem stability. These environmental threats have been man-made and natural or in combination, resulting in cascading and interlinked impacts. Habitat alterations, overexploitation of resource, reduction of natural habitat area, construction of dams restricting fish migration, diversion or reclamation of river beds for urbanization, that reduce water discharge in rivers, unsustainable fishing, introduction of non-native species and global climatic variations etc. Destructive natural events viz., floods, cyclones or disease outbreaks have also been found to damage the aquatic ecosystems. Although earthquakes and tsunamis are infrequent, but found to have dangerous consequences with regard to habitat alteration/destruction thereby affecting the biodiversity. Pollution, increased sedimentation, flow alteration and water diversion, and introduction/entry of exotics are identified as the main causes for decreased ichthyo-faunal diversity in Asian countries. Coastal zone development coupled with population increase, has stressed the coastal marine environment. Some of the marine finfishes threatened by indiscriminate fishing are the whale sharks (*Rhincodon typus*), marine catfishes of the genera *Tachysurus and Osteogeneosus*, the white fish *Lactarius lactarius*, the flat head *Platycephalus maculipinna*, the threadfins *Polynemus indicus* and *P. hepatadactylus*, and Sciaenids *Pseudosciaena diacanthus* and *Otolithoides brunneus*.

Damming, deforestation, diversion and withdrawal of water for irrigation, urban and industrial consumption has caused large-scale changes in the channel bed and hydrology of the river in terms of flow, flow-rate, flood-rhythm and regime. Hydraulic structures have changed river morphometry, flow, increased bank erosion and created barriers for migratory fishes. Dams impede upstream spawning migration of fishes and displace populations from their normal spawning grounds. In India, the construction of Farrakka barrage on River Ganga has grossly affected abundance and migration of hilsa (*Tenualosa ilisha*). Inbreeding and genetic drift are the common problems in a small population that reduce genetic variability. Siltation from the catchments, besides changing the ecology due to construction of dams, has obstructed the feeding and breeding grounds of many fishes.

The population size gets reduced because of disturbances in age structure and sex composition as a result of overexploitation affecting demography of fish population. Over-exploitation of fishery resources due to its higher economic value has exacerbated the vulnerability of the population in different ecosystems, viz. *Puntius denisonii* in rivers originating from the Western Ghats and pomfrets in marine waters.

Pollution is one of the most significant factors causing major decline in the population of many fish species. Industrial, sewage and pesticides pollution have been causing an environment detrimental to fish life in many water-bodies. An excessively nutrient-rich environment (eutrophic) encourages algae blooms and the growth of other organisms. Such a situation in coastal coral reef areas can stifle corals or outcompete them for space. Leaking fuels, petroleum spills, anti-fouling paints and coatings, and other chemicals can leach into the water, adversely affecting corals and other species.

Destructive fishing in the seas and estuaries without any consideration to conserve mother and juvenile fish stock have taken a heavy toll on natural recruitment of standing stock of many commercially important fish species of low fecund groups. Even spawning grounds were not left out. Fishing operations still depend on locating areas of concentrations and use of dynamite to catch more quantity from one place, bull trawling to sweep the entire fauna of the sea bottom, purse seining to catch fish shoals, and bag net fishing in estuaries to catch migrating stock of millions of juveniles daily during both high tide and low tide are going on all over the world oceans for short-term economic gains. Coral reef habitats are over fished and/or overexploited for recreational and commercial purposes. Mass killing by the use of dynamites, electric shocks and poisoning of brood fishes in spawning season and juveniles during post-monsoon periods have affected a number of food, ornamental and game fishes of upland waters Himalayan and Western Ghat regions.

The use of exotic species for fisheries and aquaculture diversification has been practiced since the middle of the 19^{th} century. Although many such introductions have been successful, others have resulted in highly publicized failure, generating controversy over protection of native biodiversity, spread of pathogens and disease. Several exotic species have been introduced in the Indian waters, and some are now well established too, with varying experiences. They include *Salmo gairdnerii, S. trutta fario, Pangasianodon hypophthalmus, Aristichthys nobilis, Oncorhynchus mykiss, O. nerka, Salveninus fontinalis, Cyprinus carpio, Carassius carassius, Oreochromis mossambicuss, O. niloticus, Ctenopharyndon idella, Hypopthalmichthys molitrix, Tinca tinca, Osphronemus goramy, Clarias gariepinus,* etc. The recent illegal introduction is pacu – *Piaractus brachypomus* which has been reported from Periyar River, Kerala. The success of introduction should be measured by its benefits to the community and the fact that it should not unduly harm existing species. Therefore, the introduction and transfer of exotic species and breeds for aquaculture purposes may be done with extreme caution as it can change or impoverish the biodiversity and genetic resources through interbreeding, competition for food, habitat destruction and through transmission of diseases.

Management of Fisheries Resources

Inland Fisheries: The open-water resources have been under stress due to increased water management projects, efflux of large volumes of sewage and other waste waters, which in turn have been affecting the biotic communities and fisheries adversely. Developing suitable mitigation action plans with EIA studies would be of paramount importance for safeguarding the utility functions of these ecosystems. Lack of reliable database on open water fisheries, both physical as well as biological, remains an impediment in formulating appropriate management norms. Aspects of minimum and environmental flows for the riverine systems are important to be dealt through inter-departmental deliberations for sustenance of fisheries and also conservation of biodiversity. Efforts on scientific management in several small reservoirs have shown enhanced yields of 100-300 kg/ha/yr in different reservoirs. Thus, immediate thrust is sought to exploit the fisheries potential of at least the 1.5 million hectares of small reservoirs, and subsequently the medium and large reservoirs through proper species and stock enhancement. Floodplain wetlands offer tremendous scope for both culture and capture fisheries. Production levels of as much as 1,000-1,500 kg/ha/yr have been demonstrated in such waters, while the present level remains at one-tenth of the potential. In the coldwaters, there is a significant potential for developing sport fishery based on trouts and indigenous mahseer, which can generate economic avenues for people in remote hill areas through fish-based eco-tourism.

Marine Fisheries: Marine fishing activity, as in several parts of the world, has largely remained unregulated in India. Marine fisheries operations remained essentially an inshore activity till about the mid 1980s. Though fishing subsequently extended to offshore areas, only about 20 per cent of the total landings were from the offshore areas. This causes enormous pressure on the coastal fish stocks. Increasing competition among different fishing fleets as to who should have access to coastal fisheries resources and thereby, benefit directly from the use of these resources, is leading to conflicts and confrontations. Increasing fishers' population has implied reduction in fishing area available per fisher. Trawlers have become the mainstay of the fishing sector, contributing to major non-selective fishing practices.

Given the fisheries situation that exists in India, temporal restrictions *i.e.* seasonal closure of fishing appear to be an option, which could be effectively implemented. At present, the maritime State Governments in the East and West Coasts independently decide on the seasonal closure of fishing (also known as monsoon ban) on a year-to-year basis prior to or during the Southwest Monsoon for about 45 to 60 days in a year. The obvious need for sustaining marine fisheries production is to regularize the fishing effort, particularly in the inshore, traditional fishing grounds. Installation of fish aggregating devices (FADs) and artificial reefs (ARs) in the recent years has shown significant beneficial effects in terms of enhancing local fish yields. Despite the tremendous growth in India's marine fisheries during the past 50 years and the declaration of the EEZ in 1977, there has not been any significant commercial deep sea fishing.

Conservation and Management of Fish Genetic Resources

While the development in the fisheries and aquaculture sector has to continue as it is correlated to social upliftment, the long-term sustainability and conservation of biodiversity have to be given adequate attention as these are interlinked. A developing country like India has to maintain balance between development and conservation of natural resources. Conservation of aquatic biodiversity is important from the fact that majority of the genetic resources for food still come from the wild due to low level of domestication in fisheries sector. While in development, there are conflicts over land and water resources and economic and social issues, in conservation and biodiversity programmes, one of the major issues is economics. Conservation needs must be aimed towards preserving existing biodiversity and also the evolutionary processes that foster biodiversity. The approaches towards fish genetic resource conservation & management are as follows:

Documentation of fish diversity: Knowledge of species and communities can reveal crucial facts necessary to the management of ecosystems and habitats as well as to the identification of important genomes and genes. Identification, cataloguing and prioritization of species are important tasks in conservation. The NBFGR has developed a database on Indian fish diversity comprising of 2936 indigenous (1887 marine, 113 brackishwater and 936 freshwater) and 462 exotic finfishes. The database is updated regularly to include newly described species and those exhibiting new distributional ranges. In addition, the database also is available with consolidated lists of freshwater fishes found in the Western Ghats and north eastern hill region biodiversity hotspots. Checklists of macro fauna and flora of Gulf of Mannar Biosphere Reserve (3,065 species) and the Ramsar Site-Vembanad Lake (185 species) have been prepared which will help in sustainable utilization and management of resources of the region. However, it is necessary that unexplored aquatic regions are surveyed to describe germplasm resources in future.

***In situ* conservation and protected areas:** *In situ* conservation programmes aim to develop strategies for the conservation of fish germplasm resources in their natural habitat through the integration of knowledge on fish and habitat diversity, habitat utilization, life history traits as well as human interference and other socio-economic issues. The major advantages of *in situ* conservation are: (i) continued co-evolution wherein the wild species may continue to co-evolve with other forms, providing the breeders with a dynamic source of resistance that is lost in *ex situ* conservation, and (ii) national parks and biosphere reserves may provide less expensive protection for the wild relatives than *ex situ* measures. Such conservation efforts can be meaningful only with people's participation through mass awareness programmes and involving the stakeholders. In India, the protected area covers about 5.2% of the total land area, including 5,456 sites, and nine threatened fish species inhabiting these areas (IUCN). Through this conservation strategy, not only the genetic diversity of species is maintained, but also the evolutionary adaptations that enable them to adapt continually to shifting environmental conditions, such as changes in pest populations or climate.

Stock enhancement through ranching: One of the many ways in which to replenish declining natural stocks is through captive breeding or hatchery programs. Often juvenile fish are removed from their natural habitat and are then allowed to reach sexual maturity and breed within the safe confines of an aquaculture or lab environment and the young ones reared in captivity are released back (ranching) to the natural environment. Captive breeding programmes have become the major tool used to compensate the declining fish populations and simultaneously to supplement as well as enhance yields of wild fisheries. Though culture, breeding and larval rearing technologies for the major carps have been developed for several decades but many non-conventional freshwater fish species having enormous commercial value are yet to achieve the demonstrated status. These include *Chitala chitala, Ompok pabo, O. pabda, O. malabaricus, Labeo dussumieri, Semiplotus semiplotus, Clarias dussumieri, Channa diplogramme, Anabas testudineus, Nandus nandus, Cirrhinus reba, Barbodes carnaticus* and *Puntius sarana*. These species are threatened in their natural habitat. The development of captive breeding technology will help in developing region-specific models for furthering freshwater aquaculture. The technique assumes significance, as these can be source of seed for ranching into natural waters as one of the major components of *in situ* conservation programme. A holistic collaborative research effort involving scientists and farmers may solve the constraints related to induce breeding, raising seeds and production of table size fish. The programme on mass-scale breeding, seed production and ranching of important threatened endemic fish species through establishment of live gene banks in three locations initially is a significant step forward towards conservation. More regional live gene banks in different agro-climatic zones may be established in collaborative mode to accommodate more species and developing some of these repositories into 'fish parks' or eco-tourism zones to create mass awareness.

For a successful stocking programme, the genetic structure of the original wild population should be determined before any new fish are released into the waters. With the help of appropriate molecular markers like microsatellites, general information about the genetic diversity of fish populations can be established. This information can be used to develop hatchery guidelines for breeding fish for stocking purposes. By ensuring that the stocked population is having the same alleles as the wild population, reintegration of the stocked fish will likely be more successful and deviations from the original genetic structure will be minimal. NBFGR in a joint programme with the RARS, Kumarakom, Kerala successfully carried out stock-specific, breeding-assisted river ranching of two fishes (*Horabagrus brachysoma* and *Labeo dussumieri*) in Kerala; the landings of *H. brachysoma* after two years increased from 1.8% to 11% and that of *L. dussumieri* showed an increase from 0.68% to 3.9% of the total-landings from the Vembanad Lake and adjacent rivers in the state.

Around 350 species of brightly coloured attractive native freshwater ornamental fishes such as loaches, *Nemacheilus* and *Travancoria* and species of very elegant barbs such as *Puntius arulius, P. denisonii, P. narayani, P. filamentosus, P. manipurensis, Danio malabaricus*, etc. are available in India especially along the biodiversity rich Western Ghats and the North-Eastern Hills. Considering the increased popularity of ornamental fish at household level and to curb indiscriminate exploitation from wild, captive seed production and rearing technology of 15 indigenous species having export potential such as *Pristolepis marginata*, *Horabagrus nigricollaris*, *Chela fasciata*, *Danio malabaricus, Puntius filamentosus,P. fasciatus* and *Mesonemachilus triangularis* have been standardized by the College of Fisheries, Kochi in a joint programme with NBFGR. Programmes are also in place for breeding important endemic ornamental fish species in some ICAR institutes and other organisations, which necessarily is to be intensified in coming days.

Concept of State Fish: When an increasing number of species are being reported to be endangered and threatened, there needs to be concerted efforts towards in management of the biodiversity. Hence, an innovative approach to fish conservation by declaring a State Fish was adopted for the first time in the country at NBFGR in 2006. This involved integration of the key stakeholders in the conservation plan where 17 states of the country became partners with NBFGR in developing strategies for conservation and enhancement of their selected State Fish in order to achieve the real time conservation success. A dedicated approach is required to trash out the problems and issues relating to the management of the State Fishes of India and their promotion.

***Ex-situ* conservation – Cryopreservation of fish gametes and embryos:** Storage of fish spermatozoa, eggs and embryos without loss of viability is of considerable value in aquaculture and conservation. In India, NBFGR is the primary organization carrying out fish sperm cryopreservation for long-term gene banking. The fish sperm cryopreservation needs development of species-specific protocols. Such protocols are developed through experimental standardization of various parameters, after the captive breeding protocol is developed. This becomes a bottleneck due to protracted breeding season and low domestication of most of the aquatic species, especially marine fishes. Nevertheless, in all such cases, time available in a year for conducting experiment is short and determined by breeding cycle of the species. In view of the constraint, it is essential that candidate species for sperm cryopreservation are prioritized. Species-specific sperm cryopreservation protocols have been developed for over 28 species. Inadequate milt production or asynchronization in maturity of two sexes is generally reported in several cultivable species. In artificial propagation, sperm cryopreservation can be an important tool where such milt related problems exist.

Fish gamete cryopreservation research still faces a major challenge in the form of long-term storage of fish eggs and embryos except the minute fertilized abalone eggs. Owing to large size, large amount of yolk and tough chorion or zona radiata with a low permeability coefficient, egg and embryo cryopreservation of teleosts and crustacea have not met with success anywhere in the world so far. Development of fish cell lines, embryonic stem (ES) cells and germ cells from Indian fishes and cloning technology as an alternative to long term storage of finfish eggs and embryos has been emphasized. Embryonic stem (ES) cells are pluripotent stem cell lines that are derived from early embryo and these cells can differentiate to become any tissue in the body. Successful protocols for grafting of embryonic cells to host embryos, for germline transmission of desired genome, can be instrumental in evolving effective programmes for production of transgenics and rehabilitation of endangered species.

Tissue banking: Tissue banking is a fast mode of storing the biological material for longer durations and it can be used to retrieve genetic information and genetic manipulation studies in future. Tissue repository accessions unlike sperm banking protocol do not require species-specific protocol. Nearly, 15,000 tissue accessions of freshwater and marine fish species collected from mainland and island ecosystems are maintained in the tissue bank of NBFGR. Further, it may be necessary to establish a network of researchers across the country so that tissue accessions of all fish from different ecosystems can be made.

Registration of germplasm: Securing the intellectual property rights related to fish genetic resources is an important aspect in the era of technological revolution so that the country is able to maintain its stake on its natural wealth and their potential benefits. The germplasm registration process on fish genetic stocks and variability within species is yet to be studied for Indian species. There is urgent need to develop repositories of genetic resources including registered germplasm accessions, accessions of genetic stocks discovered/ varieties discovered. The information with the registered accessions can serve as means to protect the traditional knowledge. It is necessary that the ongoing network project on fish genetic stock being operated at present for genetic characterization of important fish and shellfish species of economic and conservation value are further extended to more and more species of importance.

DNA Barcoding: DNA based approach to taxon identification which exploits diversity among DNA sequences and can be used to identify fishes and resolve taxonomic ambiguity including discovery of new species. "DNA Barcoding" - DNA sequence analysis of a uniform target gene (Cytochrome Oxidase-I of mitochondrial genome) is the most recent and reliable approach to discriminate eukaryotic species including fish. Barcoding offers a simple, rapid and reliable means of identifying not only whole fish, but fish fragments, eggs and larvae. DNA barcodes of more than 600 finfish species are reported from India so far. This could be of great utility in sustainable exploitation, management and conservation of Indian fish species. However, it is necessary that such effort is intensified through initiation of a mission mode programme to barcode all available finfish and shellfish species available in the country.

Genetic characterization: The primary objective of the genetic characterization is to assess the distribution and pattern of genetic variability at intra- as well as inter-specific population levels, through the use of identified genetic markers. The first priority for such research is identification of appropriate genetic markers to assess the genetic diversity. The conclusions from genetic diversity data have varied application in research on management and conservation of fish species, to understand the pattern of migration of fish stocks, nature of breeding populations and also in taxonomy/ systematics. Several marker types are highly popular in aquaculture/fisheries genetics. In the past, soluble proteins, gene products (allozymes) and mtDNA markers have been popular ; more recent marker types that are finding service in this field include restriction fragment length polymorphism (RFLP), randomly amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), microsatellites, single nucleotide polymorphism (SNP) and expressed sequence tag (EST) markers. The choice of markers is crucial in achieving precise information that is useful for desired application. A concerted effort made at different ICAR Institutes over last 10 years has provided description of genetic variation and population structure for about 30 prioritized fish and shellfish species from their major range of natural distribution. Distinct population structure was observed in many of these species indicating that propagation assisted restoration programmes must be stock-specific to replenish declining populations.

Exotics and Quarantine: Many introductions of exotic species for fisheries and aquaculture diversification have been successful; but others have resulted in highly publicized failure, generating controversy over protection of native biodiversity, spread of pathogens and diseases. To safeguard our indigenous fish genetic resources from infectious exotic diseases and to develop effective protocols for fish quarantine adequate facilities and expertise have been developed in the country over the years. Rapid diagnostic capability for detecting the OIE listed 11 fish pathogens using molecular and immunological tools are available today. Success has also been achieved in developing monoclonal antibodies against *Labeo rohita*, which will be extremely useful in serodiagnostics for pathogen surveillance in aquaculture of Indian major carps. We have been able to establish referral laboratory for all OIE (World Organization for Animal Health) listed pathogens in India. The National Repository of Fish Cell Lines, established at NBFGR with financial support of DBT, possessing 50 fish cell lines is a significant step forward for undertaking research on fish virology in coming years.

Conclusion

India has diverse fish germplasm, which if effectively managed can increase biological wealth. Prospects for the conservation of fish germplasm and future strategy have to be drawn up based on past growth and the potential for future expansion, taking into consideration likely availability of funds, infrastructure, trained manpower, and on the impact of research data monitoring on fish germplasm and resource conservation. Maintaining the genetic health of the fisheries wealth is equally important for up-scaling aquaculture production and sustaining the fish yield from natural waters. Therefore, conservation needs must be aimed towards preserving existing biodiversity and also the evolutionary processes that foster biodiversity. The conservation of fish diversity and aquatic resources of the country requires concerted efforts by integrating capture, culture fisheries and environmental programmes using latest technological innovations. There are concerns regarding the stagnating capture fisheries yields and unregulated access in open waters. The issues in inland and marine fisheries that need to be addressed pertain to biodiversity loss and depletion of fish stocks, excess coastal fishing, oceanic and deep sea fisheries, impact of climate change on fisheries, trans-boundary fisheries issues, inland and coastal pollution, large-scale sedimentation of rivers, estuaries and lakes/wetlands and effective compliance of code of conduct of responsible fisheries. Suitable programmes must hence be formulated to build in resilience in fisheries including regulated fishing and capacity reduction in mechanized sector, FADs, diversified fishing in deep sea and oceanic resources; culture-based fisheries in reservoirs with stocking of advanced fish fingerlings, and implementing code of conduct of responsible fisheries. It is expected that research programmes on the priority areas in consortia mode involving different research organizations, developmental agencies and community and stakeholder participation will certainly generate more results with respect to sustainable utilization of fish genetic resources and management fisheries.

3

Freshwater Aquaculture in India: Opportunities, Challenges and the Way Forward

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Our Hon'ble Prime Minister has given a clarion call that fish production as well as the farmers' income should be doubled in the next five years. Our track record during the past Twelve Five Year Plans will be cited by the doubting minds to say "it is unachievable". It's a Herculean task, no doubt! However, nothing is 'impossible' – not because the word did not exist in Napolean's lexicon – but because we have examples when 'impossible' was made 'possible'. Barely a little over six decades ago, Hillary and Tensing made possible what was till then considered impossible and on 25 May 2014, Malavath Poorna, has set a glorious example when this little 13-year old tribal girl from Andhra Pradesh achieved the feat where men fear to tread! While there is no denying that there is no end to challenges, one should not forget that there are opportunities galore. "One should have a vision", said our Late President Abdul Kalam, "and work hard to achieve the goal". Here is the vision and also the goal, should it still be difficult to achieve it if we the passionate scientists, fishers and fish farmers with steel will dedicate ourselves to achieve these objectives.

Present Status

India is the second largest producer of fish in the world, next only to China both in terms of total (10.80 MMT) as well as aquaculture production (6.00 MMT). However, this is no satisfaction as it produces only $1/5^{th}$ of the total and $1/8^{th}$ of China's aquaculture production, and the per capita consumption of fish in China being 26 kg as against 9 kg in India. Of the total inland fish production of 7.20 MMT during 2015-16 in India, the share of freshwater aquaculture was about 5.70 MMT (79%). It has shown a remarkable growth of 6.0% per annum.

Physical and biological resources for aquaculture

India is gifted with vast and varied resources for freshwater aquaculture – ponds and tanks, rivers (the gene bank) and reservoirs, wetlands and waste waters – besides a unique endemic fish fauna comprising species that are fast growing and catering to the taste of its people; in addition to scientific manpower developing technologies and searching processes to increase fish production coupled with fishers and farmers who are keen to work with scientists and adopt new technologies and systems for profitable aquaculture. True it is, the scenario is not as green as one would expect but it is also not that gloomy too to make us feel that the glass is half empty – truly speaking, *the glass is more than half full*!

Carp culture

India is basically a carp country relying mainly on the trinity – catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) – the so-called Gangetic or Indian major carps. About five decades ago, a trio of fast-growing exotic carp, viz., silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) was incorporated in the traditional combination to boost the production. The exotics have certainly proved valuable so far as increasing the total production is concerned but have failed to gain a favourable market – both in terms of quality (taste) as well as value (price). Many a farmer has given up raising the 6-species combination and either modified or worked out alternative combinations incorporating regionally preferred species whether carps, catfishes or others. It is indeed unfortunate that in aiming at increasing the production some highly preferred and choicest species were thrown into oblivion and relegated to a position of no importance so much so that some of these are now listed as endangered or vulnerable. About a dozen of *Labeo* species are widely distributed and are not only good to eat but also command a high price in the market and so are a few other species from different families that deserve a better attention.

Carp breeding and seed production

The Gangetic river system was the original source of seed of cultivated carps till about the late sixties when gradually seed from the hatcheries started pouring in the market and the dependency on riverine seed given up. *Bundhs*, both wet and dry, especially the latter, too contributed to the development of carp culture as the seed was considered to be better in quality and arriving ahead of the riverine spawn enabled enough time to grow before the onset of winter and the festivals to make good money. While the advantageous of dry-*bundh* breeding could not be denied, the practice missed certain valuable principles and could not stand the competition with hatchery seed. However, now that we know how easily it could be improved and effectively utilised for mass production of not only the carp seed but also that of several other species that are monsoon breeders, it is time to revisit the *bundhs*, today lying in disuse, revive and reutilize it to our advantage.

Bankura and West Midnapore districts in West Bengal had the sole propriety rights of *bundhs* which was shattered by mid-sixties when a dry *bundh* was established in each one of the districts in Madhya Pradesh with Nowgong (Chhatarpur district) having the distinction of eight around the vicinity of the town. Simulating the *bundhs*, fish has also been bred in pits lined with plastic sheets for easy egg collection just by pumping water from the pond and creating a current and allowing it to go out through the other end. While the *bundh* is far cheaper to construct and operate, the cemented eco- or portable FRP hatcheries need an overhead tank and a diesel or electric pump to fill it with tube well or pond water – an expensive proposition indeed! It is worthwhile mentioning how Mr Kuddus Ansari in Purulia has designed the hatchery using the gravity flow to fill the breeding pool as well as the hatching pools and allow it to drain again by gravity. Perhaps, the cheapest ever!

Quality broodstock is a *sine qua non* for good quality and healthy offsprings. It is better to have 2- to 3-year old healthy fish stocked at 1500 kg/ha in well fertilised ponds provided with bagasse for development of periphyton and fed at 1% of the body weight with groundnut oilcake-rice polish (1:1). CIFABROOD™ – a formulation developed at CIFA – is a wonderful product that brings about early and complete maturity when fed to the broodstock.

Gone are the days when the farmer worried about the availability of inducing agents like pituitary extract (PE), HCG, GnRH-A and dopamine or LHRH ever since Ovaprim, an extremely effective inducing agent, is available off-the-shelf and could be used for spawning any of the cultivable fish. What is needed is a standardised dose which, if required, may have to be modified/ manipulated depending on the environmental conditions. A scientist or an expert is no longer needed to select the broodfish or to inject and handle it with care. It is "skill" that works and we need to train the fish farmers to develop it.

The carps normally breed only once during the monsoon season but using the fish that were bred during the previous year as the broodstock for the current year, feeding it on a rich diet and partially replenishing the pond water brings about early maturity and the fish are ready to be spawned by April. With proper care, the same fish could be bred again after an interval of about 45 days in June and then again in August. There is a recorded case of a Catla that was bred four times during the same season at CIFA. While multiple breeding during a single season did bring about an increase in seed production, the pursuit for year round seed availability through photo-thermal manipulation has met with great success. Rohu has been bred during July-August, then in October-November and again in February-March. Though certainly an expensive proposition it would help lay the foundation for developing industrial aquaculture!

Meanwhile, the application of hypophysation technique for breeding various species other than the major carps under controlled conditions has helped in diversification and introduction of other elements in polyculture.

Of the Labeos – except for *L. nandina* with restricted distribution in Assam, Meghalaya and Tripura and *L. kontius*, the famous Cauvery carp – *L. calbasu*, *L. fimbriatus*, *L. dyocheilus*, *L. gonius*, *L. bata*, *L. dussumieri*, *L. pangusia*, *L. boga*, *L. boggut* and *L. dero* have been bred at one or the other site and also incorporated in the culture system in the region of abundance/demand. Some of these are high priced and greatly preferred and need to be produced for culture to add to production and income. Besides the Labeos, there are other cyprinids such as *Cirrhinus cirrhosa*, *C. reba*, *Puntius sarana*, *P. pulchellus*, *Osteobrama cotio*, *O. belangeri*, *Raimas bola*, *Amblypharyngodon mola*, *Bengala elanga* and *Parluciosoma daniconius*, which are known for the quality of flesh or nutritional value and are bred or collected from nature and cultured. In addition to these, there are some sport fishes, viz. *Tor* spp. and *Neolissocheilus hexagonolepis*, good for game and eating too; being high priced add to farmers' income.

The National Freshwater Fish Brood Bank (NFFBB) has been established at Kausalyagang (Odisha) with funding support from the NFDB. The Bank will supply quality broodstock to the hatcheries while CIFA will provide the breeder seed of all the species.

Catfish Culture

The catfishes – both air-breathing, singhi (*Heteropneustes fossilis*) and magur (*Clarias batrachus*), and, non-airbreathing, *Ompok pabda*, *O.bimaculatus*, *O. malabaricus*, *Sperata seenghala* and *S. aor*, *Wallago attu*, *Pangasius pangasius*, *Rita pavimentata, Mystus cavasius, M. vittatus* and *M. gulio* and *Horabagrus brachysoma* – also constitute an important component of freshwater aquaculture, some of these being as highly in demand and priced as much as Rohu amongst the carps.

Most of these, except a few, could breed in ponds while others spawned in the rivers during the monsoon season. The air-breathing fishes being migratory in habit moved into the culture ponds or otherwise its seed was collected from the paddy fields and used for stocking in ponds.

Air-breathing catfishes

Successful year-round spawning/maturity of *H. fossilis* through photo-thermal manipulation was achieved in Delhi University as far back as the early sixties as an academic exercise but was not followed for spawn rearing and seed production as the carp seed production technology itself was in its infancy then. Both *H. fossilis* and *C. batrachus* are now being bred through hormone administration and the seed produced. Broodstock at 2-4 fish/ m^2 are reared in cement cisterns provided with a thin soil base, Unfortunately, it is the 1-year old fish (100-120 g) that is often used and being low fecund, the eggs produced could be counted on fingers. The greatest disadvantage lies in that the males do not release milt naturally as in case of carps, hence the females have to be stripped and the eggs fertilised using the sperm suspension, prepared in advance by removing the testes and macerating it in normal saline solution which could be kept at room temperature but should be used within 24 hours.

While the brood fish is provided a rich diet (30-35% protein), the small-mouthed larvae are fed on micro-zooplankton, tubifex and Artemia nauplii which is graduated to larger zooplankters as the fish grows.

Except in one single case where it is reported to have produced 100,000 fingerlings from 100 (250-g) broodstock, there is no record of such a high rate of production. While the farmers are not only ready but keen to culture these high value species, especially in Assam and West Bengal, non-availability of the seed in required quantities – the rate of stocking in monoculture being about 75,000 to 100,000 fingerlings/ha – is the biggest impediment.

It would be worthwhile to modify and adopt the pond- or the paddy-field breeding technique using 200-g fish for mass production of fry to obtain fingerlings required for mono- as well as polyculture in carp ponds. Presuming to take up monoculture even in 100 ha to be stocked at 100,000 fry/ha and polyculture in 1,000 ha of carp ponds to be stocked at 10,000 fry/ha, the fry requirement itself would be of the order of 20 million. Where is the seed?

Non-air-breathing catfishes

Except for *Rita pavimentata*, all the non-air-breathing fishes mentioned above have responded to controlled spawning through hormone administration in field conditions. However, each one of these species has a problem.

Wallago matures in ponds when about 3-year old and has a low fecundity of 25,000 eggs/kg body weight. One can imagine the maintenance cost of this heavy predator, shark of the freshwaters! While the adults are predatory, the young are cannibals as even the 1-day old larva with its heavy yolk sac devours its sibling thus reducing the survival rate! However, rearing the larvae in red light at a low density coupled with frequent removal of larger larvae and feeding goat liver or a rich compounded diet reduces cannibalism which is very high in total darkness. A production of 1,000 kg/ha/a has been possible when fed heavily on dry fish.

Sperata spp. mature when 3-4 year old and are amongst the low fecund species with 3,000-5,000 eggs/kg in *S. aor* and 9,000-10,000/kg body weight in *S. seenghala*. They breed ahead of the monsoon in rivers and ponds and build circular nests, resembling pits, in shallower areas. While both the parents participate in nest building, it is the preserve of the male to look after the larvae that feed on the slimy secretion on its abdomen. There is a need for intensive research to improve the response to hypophysation and survival rates during larval rearing so that adequate quantity is available for developing the culture techniques.

Pangasius females mature when 4 to 5 years old though males mature two or three years earlier. Its response to hormone induction has not been very successful so far. The fish is hardy and suitable for culture in derelict or sewage-fed ponds as it is a voracious feeder on molluscs. It is slow growing in ponds and attains a weight of about 800 g during the first year though picks up during the second (1.5 kg) and third year (3.0 kg).

Horabagrus brachysoma is an ornamental fish when young but a favourite food fish of Kerala when adult, as such it is imperative that it is spawned under controlled conditions so that it could provide the young ones for hobbyists and export to raise the farmers' income and also satisfy the requirements of the palate on the dining table. Its fecundity is sufficiently high (18,000 eggs/100 g body weight). Milt cryopreservation and controlled breeding techniques have been standardised. The fry is fast growing and attains a weight 30-40 g in as many days when stocked at 100-150 fry/ m^2 while the adult grows to about 75 cm weighing 500 g.

Of the three ***Ompok*** spp., *O. malabaricus* is confined to Goa and Kerala while the other two are widely distributed. *O. malabaricus* and *O.bimaculatus* attain larger sizes (40-50 cm/300-

400 g) than *O.pabda* (15 cm/30 g); the latter is, however, in great demand. All the three are amenable to controlled breeding through ovaprim and the larvae survive well initially on zooplankton and later on tubifex, chironomid and insect larvae. *O. pabda* is being bred in hatcheries in West Bengal and incorporated in carp ponds.

While magur and singhi are cultured along with carps, monoculture is not practical owing a heavy requirement of fingerlings. Other catfishes have been experimented with but with no successful results.

Coldwater fishes

The coldwater physical resources are abundantly distributed along the Himalayas and to a limited extent in the south at different altitudes comprising the rivers (10,000 km), lakes (18,980 ha), wetlands (3,000 ha) and reservoirs (265,000 ha) and, though not directly amenable for aquaculture, are of great economic value. Some of the coldwater streams harbour the exotic trout and the indigenous mahseers and snow trout, the former two offering great sport inviting tourists, creating a variety of economic activities and bringing a name to the country: Kashmir trout streams rank among the world's best for angling. Himachal Pradesh leads in trout farming and seed production where infrastructure facilities were modernised with assistance from Norwegian Government and EEC and improved strain of rainbow trout (*Oncorhynchus mykiss*) made available. Presently, there are 62 trout farms with 369 raceways and 32 trout hatcheries having a production capacity of 13 million eyed ova besides 625 trout units in the private sector. NFDB's contribution in terms of rainbow trout hatcheries-cum-rearing units and a Feed Mill in J & K and 100 raceway units in Himachal Pradesh has provided an additional fillip to increasing trout production. Sikkim is a new entrant but doing well while trout framing is being taken to Leh in Laddakh.

Of late, seed production and farming the indigenous coldwater species (*Labeo dyocheilus, L. dero, L. Pangusia, Osteobrama belangeri*, and *Neolissocheilus hexagonolepis*) in addition to the exotic silver carp, grass carp and common carp is also an additional activity at lower altitudes. With a view to boosting the production, the fry of two new strains of common carp – Ropsha scaly carp, originally from Russia, and, Felsosomogy mirror carp of Hungarian origin – imported from Hungary, are now being cultured under the given names of Champa 1 and Champa 2 respectively, at different sites.

Chocolate Mahseer (*Neolissocheilus hexagonolepis*) – a valued fish known as Katli in Darjeeling Himalayas (West Bengal), Arunachal Pradesh and Meghalaya – offers a good sport, sells at Rs 300-400/ kg and would make a valuable addition to farmers' income. Being a fish from fast flowing waters, culture initiative was taken up long time ago in a series of running water ponds called *Jhora* Ponds but sadly was not pursued. Of late, there is a renewed interest in culturing it in dug-up *Jhora* Ponds usually measuring 50 x 30 x 3 ft and receiving stream/ spring water. It is a fast growing fish; when 10-cm fingerlings are stocked and pig dung is applied as manure it attains a weight of 250 g in 3 months and grows up to 400 g in six months.

Runningwater Fish Culture

Indian aquaculture being pond-based, it is beyond imagination to think of running waters which is the normal habitat of most of the hill stream/ coldwater fishes including the cultivated carps. Many other species too are at home in running waters, depending on the flow (speed) and water temperature, as it provides a healthy environment rich in oxygen and free from metabolites that are continually washed away. It is not that trout could be raised only in raceways as these are also cultured in earthen ponds in Bavaria (Germany) with heavy aeration. Tanaka's, world famous running water fish culture, comprising a series of ponds laid the foundation of this system. Despite a large number of hill streams and a system of canals which could be a source of water to feed a series of ponds, the system has not been developed in India. In Indonesia, cement cisterns (5 x 15 m) with a water depth of 70 cm receiving water from the hill streams from one end and leaving through the other are stocked with 10-15 g common carp that grow to about 500 g in 120 days, each cistern produces 65 kg per crop and three crops are taken in a year.

We have a number of thermal power plants especially in the colder regions that discharge heated effluents. While its impact on stream fauna and flora has been studied as an academic exercise, no attempts have been made to utilise it to our advantage. In Hungary, the effluents are used in the hatchery at Czarvas, where the fish are matured, bred and fingerlings produced before the snow melts on the fish ponds. The carps that attained a marketable size in three years are now ready in two years. The spherical cages in Kiel fjord raising salmon and trout are moved closer to or away from the discharge point of the power station depending on the ambient temperature to achieve faster growth. There is not a single instance of such use in our country though carps do not feed and grow during the winter months and maturity is delayed by days and months depending on the region the farm is located.

Wastewater for Aquaculture

Wastewater aquaculture is well-known in China and also in almost all south-east Asian countries and, of late, from many western countries but two of the world's largest systems are found in Kolkata in India and Munich in Germany. While only common carp is raised in Munich, the Indian major carps as well as the Chinese carps are cultured in India; it is well-known that *Labeo calbasu* grows well in sewage ponds where molluscs are in great abundance but has not been given the place of pride that it deserves. Sewage fed aquaculture is a system that not only provides fish at no expense but also rids the environment of pollution which is the biggest menace and has turned the holy rivers of India unholy attracting the attention of the Government for over three decades with the launch of the Ganga Action Plan in 1985 which has thus far remained ineffective.

Sewage is rich in nitrogen, phosphorus, potash and micro-nutrients as also of high BOD as well as pathogens harmful to human beings. While raw sewage, fed into the ponds in Kolkata and elsewhere, creates problems of oxygen depletion resulting in fish mortality, treated sewage is safer and works better. Stocking densities as high as 10,000-15,000/ha are practised in view of the abundance of plankton, both phyto- and zoo-, as well as the benthic organisms and production rates of 4-6 t/ha to 8-10 t/ha registered with multiple stocking and multiple harvesting. When cooked well, the fish from sewage farms does not carry any infection to human beings; however, the fishermen who work in the ponds need to be careful and adopt high standards of hygiene. Most ponds are virtually infested with Water Hyacinth (*Eichhornia crassipes*) all along the margin that absorbs heavy metals along with excess nutrients.

In Bandung (West Java), rectangular bamboo cages are installed in sewage canals running through the centre of the town. Common carp, 8-10 cm, are stocked which attain a weight of 300-500 g in 2-3 months. This practice is possible to be adopted in open sewers in small towns in India provided the neighbours do not object to such installations. Air-breathing catfishes would be equally good candidates.

Since sewage can be profitably utilised for agri-aquaculture, it is imperative that the nutrients are harvested and the effluent thus rendered innocuous before it is let into the river systems. CIFA, under a Project funded by the Ministry of Environment and Forests, has made a significant contribution in this direction by developing a system and setting up a Pilot Plant covering an area of 0.76 ha for treating 1 million litres (MLD) of sewage/day. The system comprises (i) 18 duckweed ponds (25x8x1 m each, total 0.36 ha) where the sewage is retained for two days by which time the nutrients are absorbed, ammonia oxidised to nitrate by the bacteria in the root zone and nitrate to free nitrogen and organic matter decomposed; (ii) two fish ponds (50x20x2 m, total 0.2 ha) which receive the semi-treated sewage from duckweed ponds and retain it for three days, and, finally (iii) into two depuration or marketing ponds (40x20x2 m each, total 0.16 ha) where the fish are kept for a week before being marketed and the effluent released into the natural systems.

This cost-effective biological treatment system is not only environment-friendly but also easily adoptable. This system was established by CIFA at two points, Vani Vihar and Nicco Park, in Bhubaneswar City, in association with the Xavier Institute of Management (XIM-B), under 'Project WATER' financially supported by India-Canada Environment Facility (ICEF), New Delhi, with a view to demonstrate and improve the technology for treatment of larger volumes of sewage, 4.5 MLD in this case.

It would be worthwhile incorporating the system in the Ganga Action Plan as it would not only provide nutritive food but also generate employment and trade.

INTEGRATED FISH FARMING

It is not only human waste that can be recycled through fish ponds but that of domestic/farm animals too and high rates of production obtained. In addition, even farm wastes are made good use of in increasing production from fish ponds. The two systems: agri-aquaculture and livestock-aquaculture are organic aquaculture systems that help increase farm productivity. Multi-systems approach combining agri-livestock-aquaculture makes effective use of bioresources leading to environmental sustainability.

Agri-aquaculture system

It covers, at least, five systems, viz., paddy-, horticulture-, mushroom-, sericulture-, vermicompost- and aquatic weed-fish system though there could be many more.

Paddy-fish: Paddy fields are natural haunts of fish during the monsoon season where they normally enter and breed or grow, at least, for some time depending on the period the water is retained. Since paddy is a monsoon crop in most places, the fields are modified by provision of trenches or a deep pit in the deepest portion of the field to retain water for the fish to grow and also use it for irrigating the second crop of paddy. Pond dykes could be used for raising cash crops like banana, papaya or guava and also vegetable vines. The system saves the expenses on weed and pest control as fish consumes the insects that attack paddy plant. One of the finest examples is from Arunachal Pradesh where 300-500 kg fish is produced through integration.

Horticulture-fish: All kinds of flowers, fruits and vegetables including oil crops can be grown on pond dykes. Vegetable wastes are fed to grass carp in the pond which when stocked alone yield a production of 3-5 t/ha. No pesticide should be used for the crops raised on pond banks. Bamboo, arecanut or coconuts are planted on the outer side and care should be taken that these neither shade the pond nor do their leaves fall in the pond. Of late, broccoli is getting popular and is a high priced vegetable.

Mushroom-fish: Humidity is an essential requirement for mushroom cultivation which is available at the pond site. Paddy straw used for mushroom cultivation gets rich in protein and when fed to cattle increases milk yield. Spent mushroom substrate rich in nutrients is used both in agriculture and aquaculture.

Seri-fish: Mulberry plants are grown on dykes and irrigated by pond water. Wastes comprising silkworm pupae, faeces and waste water from processing units constitute the nutrient input for fish. Besides other products, fish production of 2-3 t/ha/annum is obtained.

Vermicompost-fish: *Pheretima elongata*, *Eisenia foetida*, or any other species of earthworm is used for composting which is highly rich in phosphorus (2.56%) and minerals is an excellent fertilizer for the fish pond. The protein content of dry earthworm ranges from 56-66% and they serves as a good feed for prawns, magur, singhi and koi.

Aquatic weed-fish: Duckweeds and Azolla are rich in protein (35-45%) and poor in lignin (2-3%) and easily digestible by fish. Carp polyculture with 50% grass carp and 10% each of the other five species stocked at 6,000-8,000 fry/ha gives a production of 5-6 t/ha/a of marketable fish. Application of 40 t/ha/a of Azolla meets the nutrient requirements (N:P:K 100 kg: 25 kg: 90 kg) as well as that of organic matter (1500 kg) of a 1-ha polyculture pond.

Livestock-aquaculture system

Cattle-fish: In most places, the cattle are raised on pond banks and the dung and urine along with the left-over grass and feed are washed into the pond. About 500 kg of dung and 4,000 l of urine are excreted annually by a grown-up cow, so 5-6 cows would provide enough nutrient for fertilizing a 1-ha pond to produce 4 t of fish. However, raw dung can create oxygen depletion as such it is better to recycle it through biogas plants and the slurry applied at 30-40 t/ha/a and a production of 4 t of fish obtained without any feed or fertilizer. Cattle dung as such is poorer in nutrient elements when compared to the wastes from other animals.

Poultry-fish: Raising poultry needs utmost care and guidance from a veterinarian otherwise the whole flock could be lost in less than 24 hours. Deep litter could be applied at 30 kg/ha/day. Chicken waste is rich in NPK, the values being 1.4%, 0.8% and 0.6% respectively. The dropping from 1,000 birds are enough to fertilise a 1-ha pond and produce 3-4 t of fish besides 90,000 eggs and 1,500 kg of meat every two months.

Duck-fish: Referred to as moving fertilising machines as these move about the whole pond during the day collecting its food and dropping the faecal matter which gets immediately dissolved in the water and helps in the development of plankton. Like the poultry birds, ducks also need considerable attention and the help of a veterinarian. The ducks should not be let in the pond till the fry attains fingerling size. About 3-4 t of fish could be produced from a 1-ha pond in addition to 4,000-6,000 eggs and 500-750 kg duck meat by maintaining a flock of 200-300 ducks/ha.

Pig-fish: Indigenous varieties of pigs are a common sight in rural areas especially inhabited by tribals but the exotic breeds such as White Yorkshire are preferred owing to meat quality and fast rate of growth. Housed in pens and fed on pig feed mixed with industrial and vegetable wastes, these attain a marketable size of 60-70 kg in six months. To fertilise a 1-ha pond, 40-45 pigs would produce enough excreta as a pig excretes about 500-600 kg of dung in a year. No feed or fertiliser is applied in pig ponds which are stocked with 8,000 fingerlings/ha and a production of 3-4 t obtained in a year.

Goat-fish: Goats need to be protected from heat and housed under shades. Vegetarian as these are, green fodder and vegetable wastes are preferred. Its droppings (2-3% N, 1.5-1.8% P and 2.5-3.0% K) are the richest of all animals involved in integration with fish. The droppings are in the form of pellets that float if applied as such, hence should be crushed, powdered and moistened before application. A herd of 50-60 goats – each weighing 20 kg and producing about 0.4 kg of pellets/day/goat – provides enough manure to fertilise a 1-ha pond and produce 4 t of fish in addition to 750-900 kg meat.

Rabbit-fish: Perhaps next only to goat and ten times richer than cattle dung in terms of N:P:K (2-3%, 1.0-1.5% and 0.8-1.2%), it is preferred over other types as the nutrients are released gradually and plankton production sustained for a longer duration. However, the numbers to be raised/ha and the quantity of fish possible to be produced is to be worked out.

While integration with animals is a common phenomenon on the rural scene, scientific approach is desirable as the animal have to be raised in a suitable environment and provided proper nutrition and health care.

SEED PRODUCTION AND CULTURE OF FRESHWATER PRAWNS

As for fish, so also for freshwater prawns, India is the second largest producer next only to China. The three species available in India are the giant prawn (*Macrobrachium rosenbergii*), widely distributed in the river systems on both the coasts; Godavari prawn (*M. malcomsonii*) with restricted availability in the rivers draining the eastern part of the country from the Hooghly to the Cauvery; and, the Gangetic prawn (*M. gangeticum*) available only in the upper and middle stretches of Ganga and Brahmaputra.

The seed production technology for all the three species has been developed and standardised. While mating and incubation take place in freshwater, the newly hatched larvae need brackishwater of salinity of 10-12 ppt for *M. rosenbergii*, 18-20 ppt for *M. malcolmsonii* and 10-18 ppt for *M. gangeticum* for their survival and growth. The three species have 11 zoeal stages but the larval cycle takes 40-60 days in *M. malcolmsonii* while it is much shorter (22-32 days) in both *M. rosenbergii* and *M. gangeticum*.

Two-stage clear water technology has been found to be the best for larval rearing resulting in high rates of survival. Daily water exchange (60%) and artemia nauplii and wet feed comprising egg custard and minced fish or mollusc meat constitute the feed.

Prawn males exhibit heterogeneous individual growth (HIG), hence multiple harvesting strategy is adopted to cull the larger ones from the fifth month of stocking followed every 3-4 weeks. It is better to culture prawns with carps as monoculture is expensive and risky. About 200 million seed of *M. rosenbergii* alone is available from 71 hatcheries besides those of other species. Prawn aquaculture has a great future as it is a dollar earner but it is necessary to be cautious about diseases.

CAGE AND PEN CULTURE

Systems that originated in Asia and have become highly popular and lucrative in Europe and the Americas are now making inroads in India though some sort of crude 'pen enclosure' system existed in West Bengal. Cages of various shapes – square, rectangular, circular and spherical, the latter to be found only in Kiel fjord in the Baltic Sea – and sizes from 45 m^2 to 75 m^2 are commonly used. Cage aquaculture has twin advantages in that it (i) makes use of existing water bodies and is complimentary to existing activities, and (ii) permits good water exchange allowing high stocking densities that can be easily managed in terms of feeding, grading and disease identification and treatment and ease of harvesting, *vis-à-vis* a pond, making the system cost-effective. There are other additional advantages in that they can be easily moved to another location either within the same water body or to a different one to provide protection from pollutants, predation, etc.

However, there are limitations too in that there should be adequate water exchange through the cages to remove metabolites and maintain oxygen levels.

Cages and carps are not made for each other hence the idea of raising marketable carps should be given up till such time that a specific acceptable feed for each of the three major carps is developed along with an appropriate delivery system. However, cages have been/are being used for raising carp fingerlings for stocking the seed-hungry reservoirs whose insatiable appetite is hard to meet by any means at the present point of time. The huge reservoir resource of 3.15 million ha produces only 82 kg/ha/an despite a potential ranging from100 kg to 450 kg/ha/an from small to large reservoirs. The production can be augmented only if the seed of cultivated varieties, Indian major carps, of an appropriate size is stocked, the annual requirement being 3,000 million fingerlings (at least 100 mm in size). This is a very tall order, especially when the seed requirement even for culture activities is not fully met with. However, the results of a dozen experiments conducted at half-a-dozen sites in different States raising spawn to fry and fry to fingerlings has shown (i) poor rate of survival, (ii) highly variable growth, and (iii) duration of culture being longer than in ponds. Perhaps, in the face of no alternatives, the system is accepted for adoption.

Cage culture of the exotic, *Pangasiodon hypophthalmus*, has gained wide acceptance in India – Jharkhand taking the lead in terms of installing about 3,000 cages in various reservoirs – within the last three years owing to very high rates of production exceeding 50 kg/m^2 or approximately 500 t/ha. The fish prices are already going down and the booming industry may face a sudden fall as in Vietnam. Diseases could be another menace.

Pen Culture

Comparatively, pens are a cheaper system and far more effective. While the so-called *jano* from Chilka Lake could be considered a precursor of *pen* in India, about 5 ha of modern pens were once functional in Tungbhadra reservoir for raising the seed of Indian major carps to be supplied to the farmers of Andhra Pradesh besides meeting the requirements of Karnataka. Unlike the cage which is closed on all sides, the pen does not have a bottom as it uses the productive bed of the water body itself. Again, it could be of any size (0.1 to 1.0 ha, preferably not exceeding 0.5 ha) and shape (rectangular, square, horse-shoe shaped) depending on the nature of the shore. The site should have a gentle gradient from the shore towards the centre and a depth not exceeding 2 m. Stake poles of bamboo/casuarina and synthetic nets as screen materials are used, the deposits on the screen need to be cleaned periodically for free water exchange and aeration.

The pens are ‘net ponds’, and have to be prepared and managed the same way as the nursery or rearing ponds for stocking spawn or fry and for raising the marketable fish. Pens are functional in a number of wetlands in Assam, Bihar and West Bengal and yielding 3,500 – 5,000 kg of fish/ha.

Whether cages or pens – its numbers have to be kept restricted within the carrying capacity of the water body where it is installed – there can be no better lessons on environmental hazards to be learnt than the examples of Laguna de Bay or Seven Lakes in the Philippines!

AQUAPONICS

While addressing the scientists on the occasion of 86th ICAR Foundation Day on 29 July 2014, Prime Minister Modi gave a *mantra* for rural transformation through agriculture: “more crop per drop”. Here is a system known as ‘Aquaponics’ that follows every alphabet of the PM’s dictum. It uses only 1/10th of the water required for soil-based plant production and even less than hydroponics or recirculating aquaculture.

Aquaponics is an integrated system that grows fish and plants together where fish wastes provide an organic food source for the growing plants and the plants provide a natural filter for the water where the fish live in. The third component in the system are the microbes (nitrifying bacteria) and composting red worms that thrive in the growing media and convert the ammonia from the fish waste first into nitrites, then into nitrates and the solids into vermicompost that are food for the plants. The water in the system is reused indefinitely and will need to be replaced only when it is lost through transpiration and evaporation. Another advantage is that it could be set up on any soil that is not worth any purpose. Backyard and commercial aquaponics systems are highly popular in the West as well as Japan and Australia.

The system has arrived in India only recently and about a dozen farms are established in Kerala, the Nanniode Aquaponics Research and Development Centre (NARDC) in Palakad district being the hub for training and demonstration. Besides fish, amaranthus, okra, pig weed (punarnava, *Boerhavia diffusa*), drumstick (*Moringa oleifera*) besides ash gourd, snake gourd (*Trichosanthes cucumerina*) and Kani vellari (golden cucumber) – a fruit that has a premium price during Vishu festival are being produced. Notable amongst these is Punarjani Resorts which is promoting and practicing natural organic production and is targetting an annual output of 5000 kg fish and 7500 kg of high value vegetables. This besides, the world's first *Seabass Aquaponics Nursery* has been installed at Nanniode, where demonstration programmes are being organized by MPEDA, which is procuring and supplying the fry from its hatchery (Rajiv Gandhi Centre for Aquaculture, RGCA) located at Thoduvai, Tamilnadu, and also the pelleted feed.

India is gifted with solar energy and its use in the Aquaponics system would solve the problem of energy. It is high time that India adopts this system on a large scale in view of its chronic shortage of water and also land. Should it not surprise us that one of the world's largest aquaponics farm is being set up in the UAE at Baniyas, Abu Dhabi, that is targeting to produce 40 t of veggies and 12 t of fish meeting its energy requirements using solar and wind power? Perhaps, NFDB and NABARD could help!

CHALLENGES AND OPPORTUNITIES

Challenges

There are umpteen challenges to aquaculture development: Floods and drought; Non- availability of seed; High cost of feed; Impact of climate change:

Floods and Drought: In recent years, frequency of natural disasters has increased and floods are often not only washing out the nurseries and brood fish pond but also damaging the infrastructure by way of silting and breaching the dykes. Drought is another hazard that prohibits both the culture activity as well as seed production.

Non-availability of seed: Seed of desired species and of appropriate size is in short supply in certain areas. It is equally true that large quantities of fingerlings produced in Tripura and elsewhere are sold as consumption fish in the market. This needs to change and the States should collaborate with each other in its proper utilization for culture.

High cost of feed: Short supply of nutritive feed in remote areas and its high cost prevents many a farmer from using it.

Impact of climate change: It is a slow process and perhaps too much is being made of it**.** Climate has been changing over the years and plants and animals are gradually adjusting to it. It is only a sudden change that causes the damage. This would impact the coldwater fish culture activities of trout and other species that cannot tolerate temperatures higher than $20^{o}C$ rather than warm water fishes which will move further north and have additional area for culture in cages and pens in lakes and reservoirs.

Opportunities

Total utilization of available area: Presently, only 40% of the total available area of 2.36 million ha of ponds and tanks is being utilized, thus almost half the available resource (0.94 million ha) is available for utilization. Presuming the rate of production from these waters to be increasing progressively, from 500 kg/ha in the first year to 1,000 kg in the second year and 2,000 kg in the third year, they would give us a production of 3.23 million t at the end of the third year. Switching over to intensive system by the end of five years, this alone would provide about 5 million tonnes of fish.

Breeding and Seed production: Breeding technology is now available for a large number of species including the high value regional ones as well. It is necessary that those who practised the technique are invited and suggested to take it up on scientific lines for which they could also be provided one or two day's training.

The dry *bundhs* that were once the source of seed supply and played an important role should be revived, infrastructure improved, quality broodstock developed in its vicinity to undertake breeding operations. Portable hatching pools may be provided to obtain high rates of survival. Spawn diet developed at CIFA may be used to wean the spawn as soon as its mouth opens to make good use of the artificial feed when stocked in nurseries.

One-stop Aqua Shop (OAS): The best way to help the farmers is to establish an OAS at a place near a cluster of ponds which should supply almost all aquaculture requirements like ovaprim, fertilizers, feed, literature, seed, and also help the farmer take advantage of government schemes and bank loans.

Aquaponics system needs to be promoted in a big way through research and farmer to farmer interaction and visits to established centres. It would help produce fish, fruits and vegetables even in Bhuj and Bikaner where solar energy is available in plenty.

Skill development is crucial at this stage when we need to double the production and raise the farmer's income. A brigade of young and intelligent rural youth, particularly from fisher community, needs to be trained in distinguishing fully mature males and females, the art of bundh breeding, deciding the dosages and injecting the fish for controlled breeding, hatchery operation techniques, seed packing and its transport, etc.

There is no denying the fact that a host of technologies are available that need to be sincerely used and applied wherever possible. Funds are no problem, the government departments are being supported by NFDB and NABARD and the farmer can also obtain a loan under the schemes that are launched by the present Government to set up a small business.

We need to have faith in ourselves and work with the zeal that "I can do it".

4

Marine Fisheries at Cross-roads – What is in store for the future?

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Many a malady surrounds the Indian fisheries sector impacting increase in production from the fresh water, brackishwater and marine segments. Notable amongst them are the indiscriminate, destructive and overfishing, pollution of water bodies, environmental degradation and fragmentation, ecosystem devastation, developmental activities encroaching on water bodies, human interference, global warming and climate change. Unless these negative effects are mitigated or at least abated, chances of increasing fish production through whatever means appear rather bleak and remote. Fish are highly sensitive to their intimate environment that is water. Therefore, the basic requirement for achieving future targets of increasing production revolves round ensuring a healthy ecosystem for fish to thrive, regenerate and replenish.

World-over, there is concern for overfishing and degradation of fish habitats, leading to mass disappearance of fish and sea food species in several parts of the globe. Enough warning signals have been sounded, if the trend is not reversed, there may not be sea food to eat by the year 2048 (Science, Nov. 3, 2006). Consequently, there have been several reactions to this alert, positive and negative, from different parts of the world but significantly none from this country. This does not mean we are not affected. We have all these effects and more in our fisheries sector in some measure or the other. Truly, we seem to be at cross-roads for the sustainability of inland fisheries, aquaculture and marine fisheries on various accounts. Cross-roads are turning points with a possibility to take the right path and recover if we wake up early, but beyond that point, it would be anybody's guess and imagination. A quick introspection would reveal the present status of our fisheries sector as a whole.

In this context, we need to be reminded that we are dealing with a living, self-generating and replenishing resource which requires careful management to retain these properties. Else, beyond a certain point of intense exploitation over the years, it may not retain these properties but succumb. This would necessitate imposition of certain regulatory measures to maintain its sustainability. Equal concern should also be shown for the protection and preservation of the ecosystem in which the resource thrives.

The present article briefly reviews the current status of the marine fisheries sector and highlights the possible ways to deal with the emerging scenario.

The Assets

Physical

The country is bestowed with a long coastline of about 8118 km, including that of the oceanic islands, offering an extensive seaboard for access to the sea. However, it is sad, we have not been fully making use of the same, especially that of the islands. The Exclusive Economic Zone (EEZ), declared in 1976, extends over 2.02 million sq km and a continental shelf area of 0.53 million sq km, providing opportunities for easy access and exploitation of fisheries resources. The brackishwaters, estuaries, backwaters, lakes, bheries and the lagoons which are contiguous with the seas cover about 2 million hectares affording capture and culture of marine organisms.

The coastal fisheries sector is backed-up by a massive infrastructure, consisting of 32888 marine fishing villages, 1511 marine fish landing places, about 4 million marine fishrfolk, 72559 mechanised, 71313 motorised and 50618 non-motorised fishing craft, using a vide variety of fishing nets. Other facilities include 195 freezing plants, 409 cold storages, 189 processing plants, 1227 ice plants, 85 fish meal plants, 317 prawn pealing sheds, 405 boat building yards, and 44 extraction plants. There are 839364 members in fisheries and other cooperatives in 11 maritime States (Marine Fisheries Census, 2010, Min.of Agr., Govt. Of India & CMFRI, Kochi). According to earlier information, there are 33 minor and 6 major fishing harbours in the country.

Biological

The marine fisheries resources are composed of finfishes, crustaceans and molluscs, belonging to over a thousand species of which, about 200 are commercially important. The finfish species are broadly grouped into the pelagic and demersal categories, some migratory and others more or less sedentary. Several species enter the columnar region. The species are both short-lived and long-lived, the pelagic species laying more eggs and the demersal less. There are wide variations in spawning seasons, frequency and fecundity. The species inhabit a variety of marine ecosystems, which often come under intense human pressure for various purposes. Some species like the oil sardine and the mackerel exhibit wide fluctuations in catch from year to year. In addition, regional, spatial and seasonal variations in occurrence of species are noticed, requiring continuous monitoring for fishing and management purposes. Over the years, the scientific community built up a fund of knowledge on the occurrence, distribution, abundance and biological characteristics of the species.

Character of the Fishery

The coastal marine fishery, which is multispecies, multigear oriented, has been operating on the open access system for over six decades, a free-for-all situation, without meaningful controls, lacking periodic reviews on its reflection on the sustainability of the resources except for some scientific appraisals which mostly go unheeded. The fishing gears include selective and non-selective types, affecting the resources in multiple ways. The trawls and ring-seiners are considered destructive, not species- and environment-friendly. The target for fishing has all along been the high value shrimp through coastal trawling because of its high foreign exchange value. The result has been hardly any diversification of fishing although there were several crustaceans, finfish and molluscan resources. The boom for shrimp capture triggered intense fishing and incessant trawling with small meshed trawls (less than 15mm. cod ends) in coastal waters by pressing in additional trawlers, all to the detriment to coastal ecology. Further increase in fishing pressure will not only be uneconomical but yields would not increase from the present fishing grounds. Studies indicated the sea bottom in the inshore area has been badly scrapped, destroying the bottom fauna and flora. Great damage had been wrought on the shallow nursery grounds, landing tonnes of by- catch, mostly consisting of about 200 species of which, 50 are commercially important finfishes, crustaceans, molluscs and other biota. Despite all restrictions prohibiting usage of small meshed trawlnets, the rules are blatantly violated and even today, this devastation of juvenile populations is rampant under the nose of the authorities even at major fishing harbours like Mangalore and Tuticorin as revealed by personal observations of the author very recently. Earlier studies indicated about 34% by weight of low value by-catch (LVE) of trawlers at Mangalore Fishing Harbour consisted of 45 commercially important species. The same may hold good at other fishing harbours. It appears, demand for fishmeal for poultry industry and aquaculture is encouraging this destruction. This is one significant example of disaster to marine fisheries, in the long run. The open access system hinders effective conservation of fisheries resources as seen in the massacre of juvenile fishes. The endangered marine animals are protected by law but hardly any steps are taken to propagate them or review increase or decrease of the resources, the lack of which in some cases, affecting the dependent livelihoods of fishermen.

Exploitation of the Resources

Until the 1950's, marine fishing remained artisanal and traditional with non-mechanized crafts and simple types of gear like hooks and lines, traps, cast nets, dragnets and small shore seines, resulting in uncertain and meagre catches, mostly at sustenance level, from the inshore regions. The coastal zone is highly productive and profitable because of the availability of the high value shrimp resources besides abundance of other quality table fishes and shell fishes. This knowledge prompted introduction of mechanized boats with trawl nets and motorized boats with improvised gears like the ring-seines and mini-trawls in the 1950's and 1960's for speedy fishing operations, wider coverage, extended areas and increased efficiency. This development was quickly followed in the 1970's through introduction of purse-seines along the south--west coast to harvest the abundant pelagic fishes like the oil sardine and the mackerel. This increased further, the operational range and production but in its wake, brought in socio-economic complications with the coastal artisanal fishermen alleging that such fishing operations in the coastal region are depriving them of their usual produce. At times, purse-seine operations also resulted in glut, necessitating disposal of surplus catches for fish meal and even fertilizer by burying in the coastal areas. In course of time, purse-seine operations in coastal areas were gradually discouraged in view of the socio-economic conflicts, non-selective nature of the gear and high investments in infrastructure development. A few trials were conducted along the south-east coast also but were given up ultimately due to poor economic viability. Operation of such large, non-selective, sweeping gear would only be economical in offshore and oceanic regions for fishes like the schooling tuna. This is linked with precise knowledge on the distribution and occurrence of schooling fish in the high seas.

With these efforts and further additions to fishing fleets and simultaneous innovations in fishing techniques, use of electronic fish finders, synthetic fibers for nets, modifications to indigenous fishing gear to increase their efficiency, sweep and coverage, reduction in mesh size of trawl nets, remote sensing to locate fish schools, usage of GIS and GPS, better communication facilities, multiday fishing, etc. increased production initially but soon it tended to attain a plateau in annual catch in the 1990's, decrease in per-capita area per-fisherman per-boat, decrease in catch-per-unit of effort (CPUE), decrease in total catch and size of fish and growing imbalance in the socio-economic status of different categories of users of the same resource. Such a situation lead to conflicts between the artisanal and small mechanise boat fishing sectors. A sort of stagnation of catches prevailed for about a decade till 2004. However, no serious complications arose except in the socio-economic and food security front NOR THE SITUATION ATTRACTED CONTROLS OR REGULATIONS. Fortunately for the country, the massive contribution by pelagic fishes like the oil sardine and mackerel, though with their natural fluctuations year after year, has been sustaining marine fish production. However, intensive and in-discriminate fishing resulted in declining trends in various stocks, stagnation of fish production, near-optimum or over exploitation of resources through introduction of non-selective and small meshed nets (purse-seines, ring-seines and mini-trawls). The contribution of the artisanal sector was significant only upto the 1960's. In later years, it gradually dwindled to 3% as against the mechanized (75%) and motorized (22%) by 2015. Nearly, 80% of the fish landings are contributed by trawl-nets, gill nets and ring seines (CMFRI Booklet No. 3/2016). This reversal of relative importance of artisanal and mechanized fishing sectors was reflected in high disparity in the income between the sectors, which could be a major reason for conflicts in the marine fisheries sector. The fishery is now diagnosed to be suffering from overfishing, overcapacity and overcapitalization, though it is considered the back bone of production and lifeline of fishermen and other weaker sections of people in the coastal region.

The fisheries sector has been playing a crucial role ensuring rapid food and nutritional security to the growing human population, livelihood security to the fishermen and weaker sections of people in the coastal area, enhanced income, employment generation and earning valuable foreign exchange for the country. Foreign exchange earnings were Rs. 33,440 crore in the year 2015. The estimated marine fish landings from the mainland coast of India in 2015 (CMFRI Booklet No. 3/2016) were 3.40 million tonnes, the potential of Indian EEZ being 4.40 million tonnes. Region wise, south-eastern region produced 31.8%, north-western region 31.4%, south-western region 29.2%, and the north-eastern region 7.6% of the total catch. Production-wise, the south-eastern region produced a maximum of 10.8 lakh tonnes the north-west 10.7 lakh tonnes, south west 9.9 lakh tonnes and north-east 2.7 lakh tonnes. Statewise, Gujarat ranked first (7.22 lakh tonnes), Tamil Nadu ranked second (7.09 lakh tonnes) and Kerala ranked third (4.82 lakh tonnes). The major exploited resources during the year 2015 are mentioned below:

It is significant to note from the above that Tamil Nadu contributed to maximum landings of the oil sardine (an unusual situation) and lesser sardines, Gujarat contributed to greater part of the landings of cephalopods, ribbon-fishes, croackers and non-penaeid prawns, Kerala to the Indian mackerel, penaeid prawns and threadfin breams and Karnataka to the scads.

Increased pace of developmental activities along the coast and the islands greatly impacted the water bodies by reclamation, encroachment, habitat degradation and the ecology of the coastal area reflecting on the well-being of coastal resources and coastal communities. Added to these, industrial development along the coast, tourism, pollution of air, water and land have been severely damaging the coastal ecology and pristine purity of the coast, thus interfering with the very life processes. The brunt of these humans interferences are borne by marine species like turtles (considered endangered) which visit several places along the coast for nesting on the beaches year after year in counts of lakhs in numbers and fall victims to depredation on eggs, young ones, disturbances to nesting sites and even adult mortality due to trawling in coastal waters at the season. Similarly, the coastal coral reefs (especially in the

Table: Major exploited marine fisheries resources-2015*

Resource	Landings (lakh tonnes)	Major Contributing State	% Contribution from the State
Oil Sardine	2.66	Tamil Nadu	33
Lesser sardines	2.56	Tamil Nadu	26
Indian mackerel	2.38	Kerala	29
Cephalopods	2.13	Gujarat	30
Penaeid prawns	1.99	Kerala	19
Ribbon-fishes	1.77	Gujarat	50
Threadfin breams	1.63	Kerala	26
Croackers	1.55	Gujarat	37
Non-penaeid prawns	1.49	Gujarat	71
Scads	1.12	Karnataka	38

*Source: CMFRI Booklet No. 3/2016

islands), the seagrass beds and other sensitive areas like mangroves, mudflats and lagoons also suffer from human encroachment of the coastal areas by way of pollution, cutting off mangroves and other vegetation, all of which not only act as nurseries for fish and other organisms, thus continuously replenishing stocks and maintaining ecological balance. This is fundamental science, not known to policy makers, politicians and administrators. The author's strong conviction is, the existing coastal zone regulations (CRZ) are too complicated and difficult to implement. The present developmental activities, further plans and industrial corridors along the coast would be another possible disaster for marine fisheries development and restoration of marine eco-systems for the sustainability of marine resources. I would reiterate here, my suggestion that all ill-advised, money making, destructive plans in the coastal area should be abandoned forthwith by banning all such activities up to 500 m, from high water level. It should not be difficult to implement this throughout the coast. Till recently, there was no encroachment of any sort in the coastal area and the life processes were going on very peacefully. Just because we want development, we are not justified to interfere with nature and upset ecological balance. Scientific advice on matters like this is of paramount importance and if not heeded, could constitute another disaster in the offing.

Of late, coupled with over fishing and climate change, significant changes are observed in the distribution and availability of certain species like the oil sardine appearing in greater abundance along the coasts of Odisha, Andhra Pradesh and Tamil Nadu. Catches of cat fish, white-fish and other demersal fishes indicated decline along the west coast in earlier years. Under-exploited and unexplored resources like the threadfin breams, Indian drift-fish, Bull's eye, several other obscure fishes and medusae are being caught in increasing quantities. These instances are considered indicative of stress on certain quality resources due to high fishing intensity, their place being taken by new, virgin and uneconomical species as mentioned above. The reasons for such untoward happenings could be due to fishery-dependent (excess fishing intensity) as well as fishery-independent (environmental and oceanographic factors, especially the marked fluctuations in sea water temperature.) causes. The current year's unusual warming of sea water is suspected to be the result of the El Nino phenomenon disturbing the normal distribution and catch rates of species like the oil sardine decline in catch as well as abundance along east coast (CMFRI Booklet No. 3/2016). Wide variation in the biology of the constituent species and the dynamic environmental changes in the ocean including ocean health may also be responsible for changes in species composition and quantities landed.

Some Implications

1. Open access system indefinitely, leads to depletion of resources, encourages economic wastage and generates conflicts. Damage can be stopped by creation of exclusive rights where possible.
2. Imposition of taxes, fees or giving areas on lease may also contain free access to the resources
3. Subsidies leads to over capitalization but when fish catches decline, subsidies become a burden, though the aim is to protect important sources of jobs in the fishing, ship building and allied industries and encourage consumption of cheap protein.
4. Credit to small scale fishermen leads to over fishing and conflicts. Motorisation of craft makes fishing faster, easier and increases coverage but reduces employment and displaces labour.
5. Intrusion of large trawlers and mechanized boats (in search of shrimp) into traditional fishing grounds of artisanal fishermen leads to conflicts periodically.
6. Restrictions on fishing grounds, demarcation of zones, ban on fishing are difficult to implement and often do not yield results. A strong socio-economic approach is needed.

7. When thre is lack of respect for the sustainability of the resource on the part of users, the solution should be to allocate exclusive rights. Otherwise, conflicts arise since resources are not unlimited and open to all on high seas as well as in national jurisdictions.
8. Granting exclusive rights has advantages but there are drawbacks to implement because fish migrate, data on resources would be difficult to collect, would create controversies as it would eliminate some existing users and displaces people from their jobs.
9. Exclusive rights can be easily operated on sedentary resources and in well defined ecosystems like the lagoons, estuaries, backwaters, sea grass beds, coral reefs and mudflats. So also, in cage culture in specified areas, for trap fishing, in artificial reefs and in fishing for crabs and lobsters.
10. Community structure of fishermen, where exists, promotes exclusive rights.

Legacy of Irresponsible and Over-fishing

The present trend of exploitation, though steadily increasing production, has serious repercussions on the resources and fish habitats. Having attained maximum sustainable yields in respect of a number of major resources and have even crossed this limit, any further increase in fishing intensity would have to be regulated. Destruction of eggs and young fish, if not halted, future stocks would be at peril. This can be facilitated by stringent rules to prohibit operation of small meshed nets, especially, the cod ends of trawl nets. Usage of by-catch reduction devices (BRDs) called the juvenile fish excluder-shrimp sorting devices, aimed at eliminating by-catch of juveniles and young fish by about 20-40% should be promoted. Other alternatives would be to declare a fishing holiday for fishing by such nets for varying periods of time, if not total ban for some years. The success of these methods depends and rests on the State governments to formulate suitable measures. Encouraging sea fishing with environment-friendly fishing gear like large meshed gill nets, hooks and lines, longlines and traps which would not only totally eliminate juvenile fishes but also harvest several groups of large fishes not harvested at present from columnar regions in the seas around India. In April-May 2016, the author had an opportunity to observe fish catches in the UAE where only large fishes where seen. Not a single juvenile fish was found at any fish landing centre or fish market in the region. It is sad, there is not even a semblance of responsible fishing in marine fishing operations in India as enunciated in the FAO Code of Conduct for Responsible Fisheries (CCRF).

The situation is no better in case of the fish habitats. Since trawl fishing is confined to and has been intensive for several decades, the coastal area bottom ecology is considered to be seriously damaged by destroying the benthic fauna. Tonnes of by-catch composed of several groups of biota are landed day in and day out at several landing places. Pollution of coastal water bodies is not a healthy sign for the growth and survival of species. Land reclamation, coral mining, oil spills, navigation and shipping, all contribute to damage of coastal ecology. Damage to coral reefs, sea grass beds and mangroves would be disastrous to several species of flora and fauna supported by these highly productive marine ecosystems. While it is essential to protect and preserve all these eco systems for well-being of marine fisheries, these efforts have to be supplemented by enlarging the chain of marine protected areas (MPAs) and marine bioreserves in the country for maintaining biodiversity. If fishing has to continue as a source of livelihood for fishermen, fisheries resources have to be sustainable.

Demand for Fish

It is a paradox that even as fish production is increasing, the present supply does not seem to meet the demand. Evidently, the percentage of fish eating population is rising at a faster rate than the fish production. Wholesome fish is still not available to the consumer in the nooks and corners of the country. The trade is almost entirely in the hands of middleman. It is time to encourage cooperative system, self-help groups and NGOs to do the business. If the fish eating population goes up to 50%, total fish eating population is expected to be 650 million by the year 2020. At present, the per capita availability of fish is estimated to be 11 kg/year. On this basis, the total quantity required for domestic consumption would be 7.2 million tonnes, of which, approximately 4.3 million tonnes would be from the marine sector. Since the present production (2015) from the marine sector is 3.40 million tonnes, approximately one million tonnes more of marine fish would be required to meet the internal demand, which incidentally coincides with the total potential of the EEZ (4.4 million tonnes). If approximately another one million tonnes would be required for export of marine products the author feels it possible by harvesting the underexploited fisheries resources of the Andaman and Nicobar and the Lakshadweep Islands with environment-friendly gear mentioned earlier.

The Future

Coastal Sector

The maritime States have the jurisdiction over coastal fisheries resources, their exploitation, management and conservation up to 12 nautical miles from the shore. Therefore, all fisheries developmental activities are under their control in this zone. The States implement their own policy, rules and regulations for fishing in coastal waters. Thus, they discharge a great responsibility and also cooperate with neighbouring States and the Centre for overall development of fisheries.

In the light of the background of the present state of exploited marine fisheries, which are essentially coastal, the following suggestions are offered for the future:

1. The exploited fisheries resources have to be carefully managed for increasing fish production.
2. The proven, viable technologies for mariculture have to be taken advantage of to establish suitable hatcheries, produce seed, farm in specified and legally preserved areas, sea-ranch and replenish stocks for speedy development of sea-farming in the country.
3. Artisanal fishermen should have control over demarcated areas for fishing, their livelihoods and rights protected.
4. Limit fishing effort as per scientific recommendations, divert excess effort by suitable modifications as done earlier by the Indo-Danish Project along Karnataka coast, and fish the column dwelling fishes with environment-friendly fishing gear.
5. Get the maximum sustainable yields fixed State-wise by scientific advice and allow fishing accordingly.
6. Gradually switch over to a regulated fishing regime, wherever possible.
7. Make mandatory the use of by-catch reduction devices (BRDs).
8. Establish more artificial reefs in aid of artisanal fishermen
9. Institute broad based management of marine ecosystems and establish more marine protected areas (MPAs).
10. Prevent damage to marine biodiversity
11. Stringent steps have to be taken for curbing pollution of coastal waters and contiguous water bodies.
12. The complicated CRZ rules lacking strict implementation need be simplified by banning all developmental and other encroaching activities and restricted beyond 500 m from the coast. If necessary, separate classification may be made anew for such other activities beyond 500 m from the coast.
13. Activities that violently disrupt economic, social and the community fabric of coastal communities have to be controlled so as not to

disturb the coast, coastal ecosystems and marine fisheries resources.

14. Integrated coastal fisheries management as suggested by the FAO, taking into account the varied economic activities of the coastal area dealing also with nature, biodiversity and conservation has to be given serious consideration for adoption.
15. Steps have to be taken towards ushering in the responsible fishing as suggested by the FAO.
16. Extension education of fishermen, industry and end-users needs to be intensified on matters of responsible fishing, conservation and protection of fisheries resources.
17. Instill confidence in fishermen with full measures to mitigate impact of natural calamities like floods, cyclones, tidal waves, tsunamis and coastal erosion. Rescue, revive and rehabilitate coastal communities from such natural disasters.
18. Fish distribution and marketing should be organized under cooperatives, NGOs and self-help groups to eliminate middlemen in the trade.
19. Scientific advice and recommendations on all matters of fisheries development have to be given due credence.

The Deep Sea Sector

Rest of the EEZ, beyond 12 nautical miles from the coast falls under the jurisdiction of the Centre for exploitation and development of deep sea fisheries and other living and non-living resources, besides coordinating with the States and other nations. For the exploitation and development of deep sea fisheries, the following suggestions are made:

1. A viable and effective deep sea fishing policy has to be developed
2. The Indian EEZ should be fully and optimally exploited by indigenous efforts to the exclusion of entry for foreign fishing vessels to have full sovereignty over fisheries resources and protection of the interests of the local fishermen
3. Lack of effective deep sea fishing appears to be exerting additional fishing pressure in the coastal area. This requires quick development of own skill, fleet and related infrastructure for deep sea fishing.
4. The available large fishing vessels (15-23 m OAL) may be suitably modified and converted for fishing the identified tuna, cephalopods, lobsters and deep sea shrimp resources.
5. Construct indigenously, multi-purpose fishing vessels (23-27 m OAL) in Indian ship yards, for which they may suitably be equipped.
6. Subsidies to Indian shipyards may be continued
7. Additional and exclusive fishing harbours and other infrastructural facilities have to be built and those existing modernized.
8. The underexploited fisheries resources around the Andaman and Nicobar and the Lakswadweep Islands have to be intensively exploited and utilised, lest they die of old age. This should be linked to on-board processing and export of products.
9. The deep sea fishing policy needs to be linked to the upgradation of infrastructure, onboard processing facilities and products.
10. Develop a national policy of investment and management of Indian enterprises for deep sea fishing.
11. Ensure an exclusive financial arrangement for deep sea fishing in the country, since conventional banking system would not be suitable, for harvesting deep sea resources.
12. Aim at sustainable utilization of transnational fisheries resources around the Indian sub-continent through regional management mechanisms by a common strategy to be evolved between India, Pakistan, Bangaladesh, Myanmar and Sri Lanka through SAARC or

other multilateral arrangements for exploiting shared, straddling and migratory stocks.

13. The recurring and frequently occurring skirmishes between India and neighbouring countries pertaining to fishing have to be speedily, permanently and amicably resolved in the interests of fishermen of the concerned countries.

Summary and Conclusions

From a relatively small beginning with artisanal craft and gear, the marine fisheries sector in the country developed into a sophisticated and technologically advanced industry through excellent scientific innovations and infrastructure. However, this bright scenario is accompanied by numerous negative attributes of diminishing resources and environmental degradation. Though, world over, there is apprehension of scarcity of sea food species in the years to come, fortunately, the country has species like the oil sardine and mackerel which have been substantially contributing to the fish catch for decades, not withstanding violent fluctuations from year to year. In the interest of sustainability of fisheries resources, the rampant pollution of the aquatic realm and human encroachment on to the water bodies need to be rooted out.

The progress of marine fisheries over the past few decades had witnessed near annihilation of the artisanal sector, now dominated by the mechanized and motorized sectors, unduly concentrating in the shallow but highly productive coastal region in pursuit of the high value shrimp, fetching lucrative returns and earning major portion of foreign exchange by export of marine products. In the process, the wonton destruction of young fish needs to be curbed by mandatory use of bycatch reduction devices and strict observance of prescribed mesh sizes for nets.

The present free-for-all open access system created frequent socio economic and livelihood controversies as well as habitat degradation with hardly any diversification of fishing to the detriment of the resources. Fishing has been largely irresponsible concentrating mainly on trawling in coastal waters leading to over fishing and damage to coastal ecology with utter disregard for conservation of resources. Grossly, there has been no respect for scientific advice on sensitive matters relating to fishing.

Rules and regulations on fishing exist but often violated, necessitating imposing bans and other restrictions which widely vary between the coastal States. Uniform seasonal ban on fishing along West Coast (May-July) and East Coast (Nov-Dec) is recommended. The coastal fisheries are now in the dire need of management and attention to other methods of increasing production like sea farming, sea ranching, artificial reefs, etc. Earlier attempts to develop deep sea fishing were mostly futile. Permitting foreign fishing vessels to fish in the EEZ was vehemently resisted by local fishermen alleging destruction of national wealth but of no avail. By all means, this should be put an end to. In recent times, some indigenous efforts proved successful to augment some deep sea resources which deserve encouragement. Better political support to the sector, coordination between the Centre and States, focus on solving inter-state, national and international fisheries problems and inter-ministerial coordination at the Centre is the key for development of fisheries in the country.

Piecemeal approach at a Blue Revolution may not yield tangible results. The country is vast, the resources aplenty, problems galore but solutions few. Hence a comprehensive plan for Blue Revolution as envisaged and suggested by the author on June 4, 2009 to the Central Government for creating an exclusive Ministry of Fisheries and Oceans, and executing programmes through a National Fisheries Mission appears to be the best option under the circumstances.

5

Fish Health and Aquaculture: Key Concerns and Approaches

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Aquaculture, a major contributor to food and nutrition security

The importance of fish and fishery products in combating food and nutrition insecurity cannot be over-emphasised. While it is well recognized that fish is an important source of proteins and polyunsaturated omega-3 fatty acids, the importance of fish as source of micronutrients and minerals is not widely known. It is generally believed that polyunsaturated omega-3 fatty acids come mainly from marine fatty fish. But, it needs to be highlighted that even fresh water carps that are widely consumed in Asia contain significant amounts of omega-3 fatty acids. According to FAO estimates, fish accounts for about 17% of animal protein supply to the global population and 6.5% of all protein (FAO, 2014). Thus fish plays an important role in meeting the nutrition security of the global population. However, fish supply is not uniform across the globe. In industrialised countries, the per capita food fish supply is 27.4 kg per year, while in low income food deficit countries (LIFDC), it is 10.9 kg, in least developed countries, 11.5 kg.

Global fish production by capture fisheries has been stagnating for nearly two decades and most of the increase in fish production is coming from aquaculture. The global fish production was 158.00 million tonnes in 2012, of which, 91.3 million tonnes came from capture and 66.6 million tonnes came from aquaculture. In addition to food fish, 23.8 million tonnes of aquatic algae were produced in 2012 and the value of aquaculture production in 2012 has been estimated to be 144.4 billion US$. World fish supply reached 19.2 kg per capita in 2012 (FAO, 2014). Farmed fish accounted for 42.2% of global fish production and if only food fish are considered, the contribution of aquaculture goes up to 49%. It is estimated that by 2030, the contribution of aquaculture to global fish supply will increase to 60% (World Bank, 2013).

According to FAO global statistics, India is the second largest aquaculture producer after China. During 2012, India produced 4.2 million tonnes of aquatic products, of which fresh water finfish accounted for 3.8 million tonnes and marine crustaceans accounted for 0.3 million tonnes. According to data from MPEDA, shrimp production crossed 0.4 million tonnes in 2014.

Disease problems in aquaculture

However, aquaculture has been facing serious problems due to diseases. Finfish culture in Asia suffered seriously from epizootic ulcerative sysndrome (EUS). After the first report from Japan in 1971, the disease has been reported from over 25 countries affecting over 90 fish species. Economic loss due to this disease has been estimated to be several million dollars. Black tiger shrimp (*Penaeus monodon*) is indigenous to Asia and this was the principal shrimp species cultured in this continent in the 90's. Around 1992-93, white spot syndrome struck black tiger shrimp culture, which was first noticed in China and this spread rapidly in Asia and arrived in India in 1994. Mortalities due to whitespot syndrome virus (WSSV) is said to have caused losses to the tune of over $10 billion in Asia. This disease has led to shifting of shrimp species cultured in Asia from *P. monodon* to white Pacific shrimp, *Litopenaeus vannaemei*, mainly because Specific Pathogen Free (SPF) stocks of latter were available. But this has not reduced the problem. Once SPF seeds are stocked in open ponds, they are exposed to pathogens that are endemic in aquaculture environment. Some of the recently observed disease problems in shrimp aquaculture include Acute Hepatopanceatic Necrosis Disease (AHPND) and growth retardation associated with infection by the microsporidian parasite *Enterocytozoan hepatopenaei* (EHP). AHPND was first noticed in China in 2009 and spread to Vietnam, Thailand, Malaysia, Philippines, and Mexico. This disease has led to nearly 50% reduction in shrimp production in Vietnam and Thailand.

Issues and concerns

Some of the major points to be considered about disease problems are:

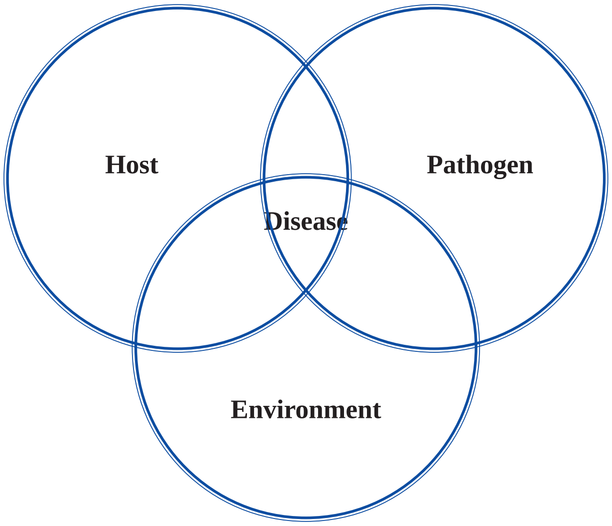

Fig. 1. Illustration to show that disease is a failure of the delicate balance between the host, pathogen and environment.

1. Disease is most often the result of breakdown of the delicate balance between the host, pathogen and environment (Fig.1). Pathogens like WSSV are endemic in many countries practicing aquaculture. This virus has a very broad host range and is present in crabs and other crustaceans that can easily get into the aquaculture system. Though biosecurity is a good practice for prevention of diseases, total exclusion of pathogens such as WSSV is impossible even when SPF seeds are stocked. Such seeds are SPF only in a SPF production facility. Once they are out in the environment, they are exposed to pathogens. Thus, even after farmers in Asia switched over to stocking SPF *L. vannamei*, WSSV continues to cause mortalities in ponds.

2. Infection may not always result in disease. Presence of a pathogen in a host is infection. But this may not always lead a disease, which is manifested when there is the presence of pathology induced by the pathogen. There are farms, where shrimps are carrying WSSV detectable by sensitive molecular tests like the Polymerase Chain Reaction (PCR), but animals are growing normally. This is because the environment is favourable for the host. But when there is deterioration of environment, eg, sudden rains and drop in salinity or low temperatures, it could result in a disease. In many parts of India, WSSV is a common cause of mortality in winter, when temperatures are lower than normal.

3. Aquaculture environment may favour selection of newly emerging pathogens. In 2009, mass mortalities of both *P. monodon* and *L. vannamei* were noticed in China and the disease spread to Vietnam and Thailand quickly. The causative agent could be identified only in 2013. The disease was initially called Early Mortality Syndrome (EMS), but later, it has been renamed as Acute Hepatopancreatic Necrosis Disease (AHPND). The causative agent happens to be a special strain of *Vibrio parahaemolyticus*, which is a common organism found in coastal and estuarine environments globally. Not all strains of *V. parahaemolyticus* are pathogenic. The AHPND causing strains carry a mobile genetic element, a plasmid, which carries two genes producing toxins very similar to those produced by some strains of *Photorhabdus*. It is now well established that AHPND causing

V. parahaemolyticus can be found in aquaculture environments and the disease is favoured by poor husbandry practices. Thus, it is possible that deterioration of aquculture environment selects some specific pathogenic strains.

4. Movement of live animals and live feeds could lead to transboundary movement of diseases. It is very well established that transboundary movement of live animals and feeds has lead to global spread of pathogens of aquatic animals. Fig. 2 illustrates examples of shrimp pathogens that have spread between Asia and Latin America and this can be mainly attributed to movement of broodstock, larvae or live feeds. WSSV was first detected in Asia and subsequently migrated to Latin America. The virus can replicate in several decapod crustaceans and presence of virus in non-decapod crustaceans such as *Artemia salina*, copepods as well as other aquatic animals such as bivalves, polychaete worms, aquatic arthropods including insect larvae has been observed.

Taura syndrome virus (TSV) outbreaks in *L. vannamei* were first reported in Ecuador in 1992, but it is suspected by the farmers in this region to have been present since mid-80's. Natural and experimental infections have been demonstrated in several species of penaeid prawns. Transmission is mainly by horizontal route and most often, the disease occurs at nursery or grow-out phase during 14-40 days of stocking. TSV has been reported to have been introduced into Taipei, Taiwan (Republic of China) in 1999 through infected *L. vannamei* and has spread with the movement of broodstock and larvae into China, Thailand, Malaysia and Indonesia, where epizootics with high mortality rates have been reported. The economic loss due to TSV in Americas during 1991/1992 is estimated to be $1-2 billion and the outbreak in Asia in 1999 has been estimated to cause losses of about $0.5-1 billion. Similarly, import of *L. vannamei* to Asia brought Infectious Myonecrosis Virus (IMNV) to Asia.

The virus Infectious Hypodermal Hepatopancreatic Necrosis Virus (IHHNV) is prevalent in *P. monodon* in Asia and is detectable by molecular techniques like PCR. The virus was reported from *P. stylirostris* and *L. vannamei* in the Americas during the early 80's and is believed to have been introduced through importation of live experimental stocks of *P. monodon* from Asia.

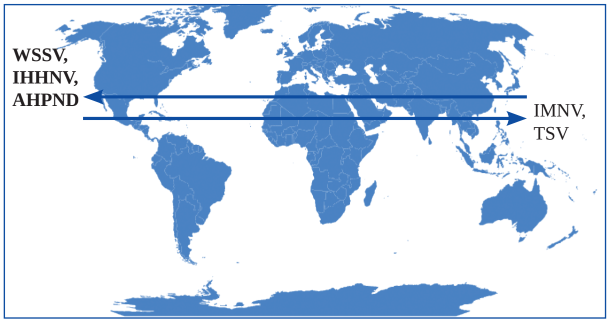

Fig. 2. Examples of shrimp pathogens that have spread between Asia and Latin America.

5. Pathogens may also spread across continents through oceanic currents. There may be lessons to learn from experience of spread of human pathogens. Certain strains of *V. parahaemolyticus* can cause human disease and and have spread across continents. Molecular studies combined with study of sea surface temperatures show that the strain of *V. parahaemolyticus* that caused large number of human cases in Peru might have migrated from Asia due to El Nino warm water currents. More recently, strains of *V. parahaemolyticus* causing human cases in Pacific coast of US have been found in cases in Europe. *V. parahaemolyticus* may be associated with zooplankton like copeods and cnidarians. This planktonic association may be responsible for glogal spread through oceanic currents.

6. Use of antibiotics and veterinary drugs has caused more problems than solved any. Diseases in aquaculture have led to indiscriminate use of antibiotics. Till early 2000's, even antibiotics like chloramphenicol and nitrofurans have been used, but their use has come down due to very strict regulations and rejections from European and US markets. Most shrimp pathogens are viruses and antibiotics are ineffective against viruses. The recently discovered cause of AHPND is a bacterial pathogen, but even in this case, antibiotic use is not warranted since the disease can be managed with good aquaculture practices. Thus indiscriminate use of antibiotics has created a very poor image of the prevailing regulations and enforcement in most aquaculture producing countries in Asia. Significant improvements have been made in recent years, but the problem still persists and more work is needed to raise awareness. It needs to be emphasized that one of the most important adverse effects of antibiotic use is the seletion and spread of antibiotic resistant bacteria through products of aquaculture and the producing countries need to make more efforts to minimize the use of antibiotics in aquaculture.

7. There is no alternative to adopting good aquaculture practices. Presently, there are no effective vaccines available for prevention of disease in aquaculture. Experiences in many countries, including India have shown that disease problems can be minimized by the adoption of good aquaculture practices (GAP). If aquaculture has to be sustainable, GAP is to be widely adopted by the farmers.

8. Disease problems have impacted international trade, but there is no definitive evidence show that diseases have spread due to import of commodity shrimp. There have been several instances of trade bans due to outbreak of diseases in aquaculture. But there is no clear scientific evidence to demonstrate that import of frozen commodity shrimp can lead to spread of diseases. There is clear evidence to show that most cases of spread are attributable either to import of broodstock or larve from disease affected regions, or live animals were fed with caracass of infected shrimp. In case of AHPND, it has been shown that frozen infected shrimp was unable to transmit disease. Therefore, countries need to do a scientific import risk analysis before taking measures like import bans. Guidelines for performing import risk analysis are available from OIE.

9. Aquaculture certification is important, but proliferation of private certifications has negatively impacted the industry. A notable development in international markets is the growing importance of large retailers and supermarket chains in fish trade. In their effort to differentiate their products from that of competitors, they are coming up with strategies like selling only fish that has certain private certifications. Certifications for an environmental standard or ecolabel provide retailers and brand owners insurance against negative media coverage or boycotts from environmental groups. This will also help them tap into and meet consumer demand for ethical products. A number of private standard setting bodies have come up with their own certification standards and criteria. In the fisheries sector, private certifications first started with organisations like Marine Stewardship Council (MSC) certifying for sustainability of the fisheries and this has been promoted by policies of large retailers like Walmart. Reliance on third party certification for implementation of standards and for managing auditing of compliance minimises cost and responsibility to the retailers, while the certificates provide the “burden of proof” that the meet the required standards. The certificates and labels help to reassure the consumers, respond to NGO pressures while shifting the costs involved in achieving these to the producers. This has led to a situation wherein there has been a proliferation of private standard setting organisations and organisations certifying compliance with private standards. Some examples of private aquaculture certifications include Aquaculture Stewardship Council (ASC), Global GAP, Best Aquaculture Practice (BAP) and certification of Global Aquaculture Alliance (GAA). These private aquaculture certifications cover a range of issues like aquaculture practices, environmental aspects, food safety and aquaculture inputs like feed and chemicals.

6 Conservation of Biodiversity in Aquatic Ecosystems, specially the Fish Genetic Resources of the Eastern Himalayas

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International Day for Biological Diversity was observed on May 22, 2016 with the theme: Mainstreaming Biodiversity, Sustaining People and their Livelihoods. Biodiversity is considered as a bio-resource and is always linked with human welfare and sustainability of the resource. Emphasis has been given on the development of Agriculture, Fisheries, Forestry and Tourism. Freshwater has become a vulnerable commodity and thus, conservation of this commodity its bioresource and the ecosystem has become matters of great concern these days.

Freshwater which constitutes only 0.01% of the whole world's water (Dudgeon et al, 2006) supports several species. However, this precious ecosystem is facing five interactive categories of threats, viz., overexploitation, water pollution, flow modification, habitat degradation and invasive species. In addition, global climate change has adverse impacts on the cold blooded aquatic animals.

Eastern Himalaya is the region extending from the Kali Gandaki River in Central Nepal to Myanmar through Southern Tibet in China, North Bengal and Northeast India. Conservation International identifies the region as a Biodiversity Hotspot. The glacier-fed rivers originating in the Himalaya Mountains comprise the largest river run-off from any location in the world. The rivers provide livelihood and transport to millions of people. The rivers and their basins sustain ecosystems that are vital to biodiversity. However, these are impacted by several factors, including population increase, water abstraction, pollution and ecosystem modification.

Of global map of 426 freshwater ecoregions based on the distributions and compositions of freshwater fish species, presented by Abell et al (2008), the Eastern Himalaya region comprises of six regions, viz., the Ganga Delta and Plain, Ganga Himalaya Foothills, Upper Brahmaputra, Middle Brahmaputra, Chin Hills-Arakan Coast and the Sittaung-Irrawaddy ecoregions (Fig.1). This represents valuable resource for regional assessment and conservation planning efforts. The region has a richness consisting of around 500 freshwater fish species.

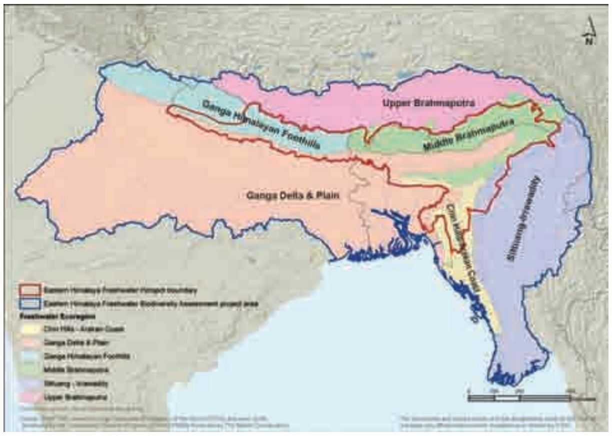


Fig. 1. Map of Eastern Himalaya Region (redrawn after IUCN, 2010)

The region is drained (Fig. 2) by the Ganga-Brahmaputra-Surma-Meghna (Ganga Himalayan Foothills, Ganga Delta Plains, Upper and Middle Brahmaputra ecoregions); the Chindwin-Irrawaddy (Sittaung-Irrawaddy ecoregion) and the Kaladan (Chin Arakan-Hills ecoregion) River drainages. Kottelat & Whitten (1996) estimated The Ganga River drainage to contain 350 fish species and the

Brahmaputra and Irrawaddy, 200 species and also presented a 'freshwater biodiversity hotspot' map which covered major parts of Northeastern India and Myanmar (Fig.3).

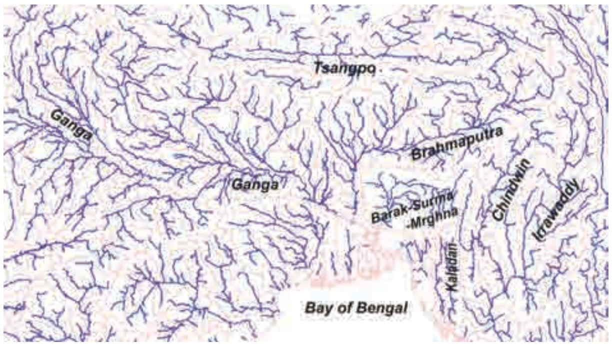


Fig. 2. Map showing River Drainages of Eastern Himalaya

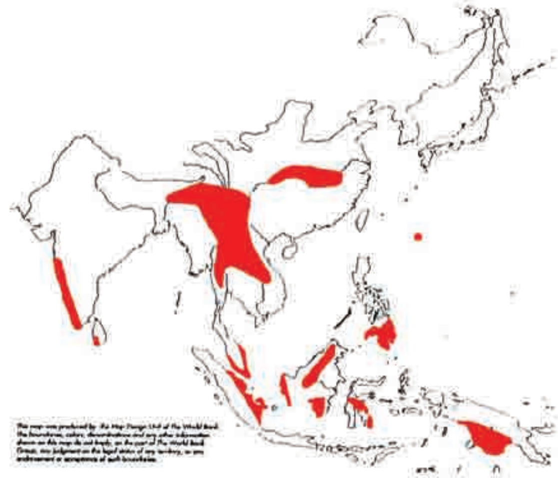


Fig. 3. Freshwater Biodiversity Hotspot Map (after Kottelat & Whitten, 1996)

Freshwater Fish Diversity

The Eastern Himalaya region is very rich in freshwater fish diversity and contains 596 species under 123 genera and 37 families (Table 1). Family Cyprinidae includes highest numbers of species (169) and genera (38), followed by family Nemacheilidae, Sisoridae, Mastacembelidae, Erethistidae, Badidae and Channidae which are highly valued as ornamental fishes also show species richness. There may be slight changes in the numbers of species with further taxonomic studies. However, the table shows the diversity and richness.

Threats to Freshwater Fish Diversity

Dudgeon et al (2006) reported that freshwater, which supports several species makes up only 0.01% of the World's water. The freshwater biodiversity is facing multiple threats: overexploitation, water pollution, flow modification, destruction or degradation of habitat and invasion by exotic species (Fig.4). Their combined and interacting influences have resulted in population declines and range reduction in freshwater biodiversity worldwide.

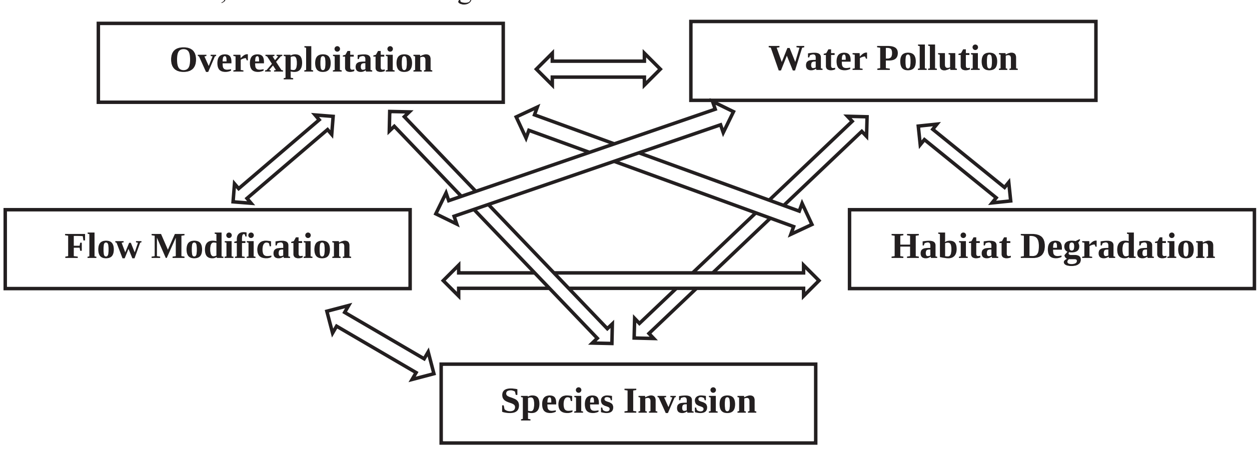


Fig. 4. Five interactive threats to freshwater biodiversity after Dudgeon *et al* (2006)

Table 1. Freshwater Fish Families, number of Genera and Species of the Eeastern Himalayas [based on Nelson et al, 2016]

Sl. No.	Family	Genera	Species	Sl. No.	Family	Genera	Species
1	Anguillidae	1	2	20	Erethistidae	7	38
2	Notopteridae	2	2	21	Clariidae	1	1
3	Clupeidae	4	5	22	Heteropneustidae	1	1
4	Cyprinidae	38	169	23	Ambassidae	3	7
5	Psilorhynchidae	1	26	24	Mugilidae	2	2
6	Botiidae	2	6	25	Belonidae	2	2
7	Cobitidae	5	14	26	Aplocheilidae	1	1
8	Balitoridae	2	4	27	Synbranchidae	2	4
9	Nemacheilidae	8	63	28	Chaudhuriidae	4	6
10	Siluridae	3	9	29	Mastacembelidae	2	14
11	Pangasiidae	1	2	30	Anabantidae	1	2
12	Chacidae	1	2	31	Osphronemidae	3	6
13	Ritidae	1	2	32	Channidae	1	16
14	Ailiidae	6	13	33	Nandidae	1	2
15	Horobagridae	1	2	34	Badidae	2	20
16	Bagridae	7	34	35	Syngnathidae	1	3
17	Akysidae	1	3	36	Indostomidae	1	1
18	Amblycipitidae	1	9	37	Tetraodontidae	1	1
19	Sisoridae	12	52				

Climate Change

In addition, global warming is another challenge to the aquatic environment. Fishes are cold blooded animals and their metabolism depends on the temperature of the surrounding medium. Warming increases metabolism, energy requirement, oxygen demand, feeding intensity resulting in the early maturity, low fecundity and premature breeding. However, higher temperature is inversely proportional to the oxygen content in water and there is no excess food in the medium. So there is great pressure on fish life.

What do we do?

Here we may remember IUCN's (International Union for Conservation of Nature) Vision and Mission. The vision is: a just world that values and conserves nature. The mission is: (1) to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and (2) to ensure that any use of natural resources is equitable and ecologically sustainable.

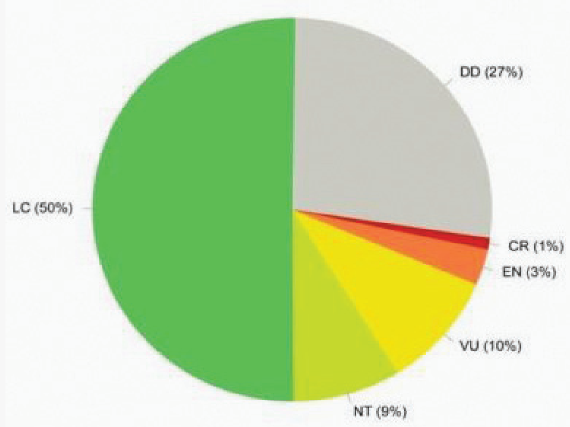
Vishwanath *et al* (2010) while reporting on the Eastern Himalayas Freshwater Fish Assessment and Evaluation for Red-listing, state that 70% fish species of the Eastern Himalayas are threatened, 46% near threatened mostly due to anthropogenic pressures. While 5 species are declared Critically Endangered, 15 are Endangered and 40 Vulnerable. 27% species are considered Data Deficient, which does not mean that the fishes are not under threat (Fig. 5). Thus, more data need to be generated so as to enable assessment.

There is need for taking necessary steps to conserve fish genetic resources and their habitats on one hand and to develop rational and efficient utilization and management of fish stocks on the other. Since a large number of species are endemic in the Eastern Himalaya, there is urgent need for conservation which requires both funding and political will. The following conservation measures are essential:

Afforestation: A practical means for reducing soil erosion in the catchments. Extensive social forestry programme will reduce habitat degradation, loss of forest cover and silt burden on the water body.

Pollution: Water quality of the rivers and lakes needs improvement if it is to be used for fisheries purposes. The discharge of untreated municipal sewages and the use of agrochemicals in river catchments should be controlled and reduced.

Dams: The restoration of flow regimes of rivers and lakes are required to maintain water quality and to restore the migratory routes of the fishes.



CR=Critically Endangered 1%
EN=Endangered 3%
VU=Vulnerable 10%
NT=Near Threatened 9%
LC=Least Concern 50%
DD=Data Deficient 27%

Fig. 5. Conservation Status of the Eastern Himalayas Freshwater Fishes based on IUCN, 2010

The Government and all authorities concerned should strictly monitor introduction, culture and sale of invasive alien species. Effective implementation of fishery legislation is required to control harvesting of brooders, illegal fishing devices.

It is easier said than done. The effective conservation of species will be possible only when people are educated and made aware of the value of nature and the integrity of the environment. Local communities will participate in the conservation of fishes and their habitats. To educate the people, we need to provide materials for identification of threatened species, their habitat and habits.

In order to conserve endemic species, extensive research is required to know their habits: breeding, feeding and culture techniques so that aquaculture is diversified based on these species. Diversification of Aquaculture through Locally Available Fish is a new initiative to conserve native species.

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7

Sea Cage Farming – a means to enhance Marine Fish Production in India – a holistic approach

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The current marine fish production in India is about 4 million tonnes. Among this the current production of high value fishes is approximately 2 lakh tonnes and the demand for high quality fish is even increasing. There is no fishing for about two months along the East Coast and West Coast in different periods due to seasonal bans. This accelerates the domestic demand for high valued fish. The projected marine fish production with all management measures by 2050 is about 6 million tons and cannot meet the requirement of about 160 crore population in India. The increased requirement has to come from Sea Cage Farming which is in the initial stages in India. The advantage of Sea Cage Farming in Indian tropical condition is the fast growth, compared to slow growth under temperate conditions. Coupled with this, the availability of low valued fish in sufficient quantity will help to address the feed requirement in the early stages.

Thus the Indian coast offer immense scope to culture high valued marine fish to marketable size in about 6-9 months. The cages in the inshore area also will act as nursery grounds like artificial reefs, thus enhancing the capture fisheries potential. It is suggested to introduce at least 1000 cages along both the coasts initially and expand further gradually improving their efficiency with experience.

The world capture and aquaculture production of fish was about 148 million tonnes in 2010 with a total value of US$ 217.5 billion. The capture fisheries production continues to remain stable at about 90 million tonnes although there have been some marked changes in catch trends by country, fishing area and species, of which 70–80 million tonnes is currently used for human consumption. With sustained growth in fish production and improved distribution channels, world food fish supply has grown significantly in the last five decades, with an average growth rate of 3.2% per year in the period 1961–2009, outpacing the increase of 1.7% per year in the world's population. World per capita food fish supply has increased from an average of 9.9 kg in the 1960s to 18.6 kg in 2010. According to the UN, 30% of fish stocks have already collapsed, meaning they yield less than 10% of their former potential, while virtually all fisheries will run out of commercially viable catches by 2050. Based on FAO projections, it is estimated that in order to maintain the current level of per capita consumption, global aquaculture production have to reach 80 million tonnes by 2050. Aquaculture must bridge the gap between fisheries production and demand and it must do so in a sustainable way, with sustainable feed raw materials and minimal environmental impact, and it must be recognized and accepted as a valid provider of excellent food.

The global demographics show us that the world population will continue to grow and the population of seven billion today will reach nine billion by 2050 rendering shrinkage of arable land. Therefore, package of practices followed in the agrarian sector is for vertical expansion of productivity. Various studies point out that, globally people will have to look to the seas for food in the years to come. Rising incomes lead to a shift in dietary patterns as the consumers choose to eat more protein rich meals comprising of meat and fish. Another factor driving up the demand for fish is its increasing recognition a source of excellent nutrition, providing highly digestible proteins, essential vitamins and minerals in an easily available form. In many species there is the additional benefit of health promoting Omega-3 fatty acids. The requirement of fish by 2050 for food and livelihood, vis-à-vis the population, at current level of management and restrictions, seems to be much more dependent on marine fisheries sector.

During the last two decades global demand for sea food has increased substantially and currently aquaculture accounts for half of all seafood consumed directly by people. With many global fisheries exploited at or beyond capacity, aquaculture will be the source of all additional seafood consumed. Given the production efficiency of some aquaculture species it is predicted that "white fish" from aquaculture will equal chicken production by 2050, then surpass it. On a global scale aquaculture is responsible annually for around 68 million tons of fin fish such as carp and Atlantic salmon, molluscs, aquatic plants and crustaceans such as shrimp. A total of over 300 species are raised through aquaculture, but only about 40 are economically significant.

India is one of the biggest marine fisheries hubs in the world. Marine fisheries management in India followed the global trends despite the fact that there were no instances of a collapsed fishery here unlike the temperate waters where operational fisheries collapsed several times due to various factors. The marine resources off Indian shores have been exhibiting thorough heterogeneity and complex interrelationships over the years. The major issues that were addressed in the past but with no practical solutions are:

a) Stock assessment models devised for marine fisheries management fails at operational level;
b) Ecosystem based management of marine fisheries requires complex data as inputs thus making the entire process complicated;
c) As Fisheries management is a State (regional) subject, it lacks coherence in implementing uniform regulations;
d) Limitation on scientific estimation of harvestable yield of marine fisheries of India;
e) Lack of integration of database of individual species into a multi species management scenario;
f) Mesh size of gear – recommendations *vs*. implementation issues;
g) Fleet strength greed overruling diminution of fleet size;
h) Ban on fishing and protected areas are logically assumed regulations without a deterministic model.

Hence, any fisheries management measures in the country must address the protection of the nursery areas of fishes during spawning season and habitats during maturation phase for sustaining fisheries and mariculture for future. Since there are limitations in the existing marine fisheries management measures, novel methods should be invoked to reduce fishing pressure, and at the same time enhance production through mariculture.

Since the demand for marine fish was not much in India before 1990s, the domestic production through capture fisheries was more than sufficient to cater to the population needs. Hence the mariculture R&D efforts were on lower scale and mostly confined to shellfishes. Meanwhile, globally mariculture has leaped miles ahead, leaving India far behind. In India, due to general awareness of marine fish as health food, the demand for marine fish has been increased during the past two decades. Now the demand for high valued marine fishes is so high that most of them are out of export basket and the exports are mainly of those that have no domestic market. High valued fishes command a price well above Rs.400 at the farm gate and they include pomfrets, seer fish, sea bass, mullets, groupers, cobia, pompano, red snapper, *etc*. The current capture fishery production for the above fishes is only about 2 lakh tons leaving a wide gap between supply and demand. The national trawl ban for about 2 months also accelerates the demand and price for marine fishes. All the above factors points to the necessity of India to emerge as a leading mariculture nation in the coming years, as it is endowed with all resources and a huge domestic demand.

Potential Areas

Cage Culture requires favorable conditions both in terms of environment topography as well as human resources. It is very difficult to implement Sea Cage Farming in areas having the following characteristics:

1. Thickly populated areas
2. Intensely fished areas
3. Areas having pollution or otherwise close to metropolitan cities
4. Intensely navigated areas
5. Defense areas, navigation areas, ports and river mouths.

Seed Requirement

The availability of the seed is one of the key factors in the success of the Sea Cage farming. Based on the availability of the hatchery technology, hatchery facilities and availability of wild seeds, it is envisaged that 35% of the cages will be stocked with cobia, 35% with sea bass, 10% with snappers/ groupers/lobsters, 10% with mullets and 10% with pompano.

The availability of hatchery produced fin fish seed at present is very limited, and may take years to produce sufficient seed to cater to the needs of culture industry. Same is the case worldwide except for salmon. Although natural seed is available for many species, that cannot be depended upon permanently as seed stock, due to depleting stock, biodiversity impacts, and impact on environment etc. Natural seeds should be used only partially for stocking in cages if it becomes essential till the hatchery production is sufficient or accomplished.

Fig.1, Pomfret juveniles, like many more juveniles are exploited from inshore areas (<10m), which can meet the demand of seed for cage culture in India.

For any seed production in the hatchery, quality brood stock is essential. Unlike freshwater fishes, brood stock development and management of marine fin fish are highly technical, expensive and risky. Under these circumstances, private entrepreneurs are not coming forward to establish brood stock and operate hatcheries. Hence it is proposed that R&D institute shall supply the brood stock/ fertilized eggs/ early larvae to the hatcheries for further rearing and seed production. This needs the establishment of brood banks on similar lines of National Marine Fish Brood Bank at Mandapam.

Since, seed after rearing in the hatchery for about a month or so cannot be stocked directly in the cages, it has to be reared for nearly two months to make them ready to be stocked in cages for grow-out, and reduce the risk of mortality in cages. This can be done with farmers' participation in operating nursery/rearing ponds/ FRP/concrete tanks.

Feed

a) **Natural Feed**: The total marine fish landing in India is 4 million tonnes, 20% of which is constituted by low value catch with good nutritional profile. A part of this, about 4-5 lakh tones, can be safely and effectively utilized for feeding caged fish till we can acquire an indigenous production of good quality and standard formulated feed for grow-out cage culture. Majority of the cage culture in the world depend on naturally occurring low value fishes as feed.

b) **Pellet Feed:** Potentially 3000 to 5000 tonnes of fish is expected to be produced from 1000 cages per annum in the next three years. The feed requirement is about 7500 tonnes (FCR of 1:1.5 or 2) for this much production. If demand is ensured, there are well established feed manufacturing units in the country which can produce feeds of required standard at reasonable price.

Marketing

Marketing is an essential component of any enterprise in general and the open sea cage farming provides a sustained supply of fish round the year to meet the domestic demand. Due to the increased awareness of the nutritive value of fish and increasing affordability, the demand for premium fish varieties is increasing especially in metros like Delhi, Mumbai, Kolkata, Bangalore, Hyderabad, Pune, Ahmadabad, etc. Production from cages could meet such demand.

As there would be a steady and sustained supply of fish from the cages (including lean season), there is good scope for cage farmed products. The formation of marketing cooperatives will bring economies of scale in marketing operation. The fish farmer is in advantage because he can sell his produce at his will anticipating good profits in future, since the fish stock are held in cages from which they can be marketed as per demand in live condition.

It is also to be noted here that India is the largest market for marine fish in the world. The prices of all premium marine fish are above export prices and are thus out of export basket. If we look at exported fish, etc., they are mostly not preferred in the domestic market. Another important reason for high domestic demand for marine fish is that traditionally they don't prefer shellfish and seaweeds like in China and Southeast Asian countries.

Training Programmes

To develop a successful open sea cage culture industry we need to have trained manpower in the following areas:

(i) Cage fabrication

(ii) Cage installation including mooring

(iii) Hatchery technology

(iv) Nursery rearing

(v) Cage farming

A number of persons in each category have already been trained in the country. However, training is to be imparted to more fishermen, farmers and entrepreneurs so as to implement the Cage Culture Scheme successfully.

Public Private Partnership in Cage Faming

Although Cage farming may not be having the public private partnership or private investment in the beginning, it is envisaged that once these 1000 cages are successfully installed and demonstrated PPP model can be in the following areas:

(i) Hatchery technology

(ii) Feed production

(iii) Cage fabrication

(iv) Cage farming.

India is endowed with one of the best and abundant scientific and technical manpower in marine fisheries sector and does not require any foreign collaborators in any area of cage culture. Our experience indicates that knowledge about Indian marine fisheries is very poor for those experts coming from outside.

Artificial Reefs for enhancing Natural Fish Stocks and protecting Sea Cages

Sustaining/ rebuilding the marine ecosystems: Protecting tidal mudflats, wet-lands, mangroves, marshes, estuaries, beaches, lagoons and coral reefs, has also become a prime responsibility in marine fisheries management. Along with the fishing pressure there is a concern on habitat degradation also. Artificial Reefs (ARs) will automatically reduce unwanted fishing, as crafts like trawlers cannot operate in those areas. Trawling operations in such areas will result in severe damage to fishing gear. Such area would also render protection to Sea Cage installations.

Under conditions prevailing along Indian coast, it is best to deploy the Artificial Reefs in inshore areas along 10-20 m depth contours. Artificial Reefs are triangular concrete structures/modules deployed on the bottom of the sea bed. They provide shelter to brooder fish and juveniles. They also offer surface areas for attachment of eggs after spawning. The major seed resources of fishes like seer fish, mackerel, tuna, etc. are available only at shallow depth of less than 10 m. Thus, we can protect the nursery grounds of these fishes by installing Artificial Reefs and thereby enhance recruitment to the fishery along the entire Indian EEZ. Artificial Reef deployed areas become unsuitable for trawling and purse seine operations rendering such an area a natural "Marine Protected Area" (MPA) thus protecting the biodiversity, habitat and brood-stocks. Healthy brood stock of fishes will be a spawning stock biomass for supplying young fish to the fishing grounds in a sustainable manner (recruitment). It is emphasized here that the major aim of marine fisheries management is mainly to sustain the fisheries with a limited scope to increase production by at least 1% cumulatively in the next 35 years (by 2050).

CMFRI in association the Government of Tamil Nadu has deployed the Artificial Reefs in coastal waters off 50 villages resulting in the enhancement of traditional fisheries by 2 to 5 times over the last ten years. Consequently there is an increased in demand from the traditional fisher folk to install more Artificial Reefs in Tamil Nadu. This example can be taken as a national model for creating more awareness among the fisher folk in other States and for conducting awareness training programmes. Each cluster of modules may cost about Rs 30 lakh and is sufficient for about one km^2. If the entire coastal line is provided the same impetus over a period of next 10 years at a cost of Rs 10,000 crore, the marine fish catch is likely to reach at least 6 million tons by 2050.

Future Projection

The introduction of 1000 Sea Cages along the coastline of India will initiate a sea change in the mariculture scenario of the country. After earmarking considerable areas for fishing, navigation, defense purpose etc., it is visualized that 5 lakh Cages can be installed in the Indian seas in a phased manner. With the proposed introduction of 5 lakh Sea Cages, the marine fish production from Cages can be increased by 2 million tonnes by 2050.

Sea Cage Farming for reducing fishing pressure, improving livelihood in coastal areas and increasing fish production

The country has undertaken large-scale demonstration of sea as well as backwater cage culture in most of the maritime states of India. The technology is purely indigenous and highly economical and sustainable. It is very easy to adopt. Capital investment for a 6 m diameter circular cage in the sea is about Rs 3 lakh initially, including the cost of cage-frame, nets, mooring, seed and feed.

Fig.2. Three types of modules, 70 each form a cluster, occupying 1000 m^2 area, with about 500 m^3 volume and provide about 3000 m^2 surface area for attachment of marine organisms

By adopting culture of high valued species the production of 3-5 tonnes/ cage can be attained over a period of 6-9 months with an economic return of 6 to 10 lakhs per harvest, depending on the species. The life of cage-frame is above 5 years. Since the Ministry of Agriculture/ National Fisheries Development Board have recognized this as a government scheme eligible for 40% subsidy, the technology is gaining lot of popularity. The inputs are abundantly available along the coast and fisher folks are skilled in garnering them. Feasibility of several species emerging as candidate species for cage culture due to the ongoing breeding programmes, the possible collection from the sea may deem to be sustainable in the long run. Similarly there are about 5 large feed mills in Andhra Pradesh with high production potential for manufacturing suitable feed for marine fish. Hence, feed is not a limiting factor. Similarly there are millions of hectares of low-lying saline areas which are not utilized and can be brought under mariculture with suitable incentives from the Government/ NFDB. CMFRI has established the first Recirculation Aquaculture System (RAS) laboratory in India and the National Marine Fish Brood Bank at Mandapam. This will serve as a model for establishing some more brood banks in public sector to maintain the quality and quantity for sustainable seed production. The approach is to produce fertilized eggs/ day-old larvae and supply them to the hatcheries at a nominal cost, so that private hatcheries can raise them further and deliver them to the needy Sea Cage Farmers at a price. Marine fish brood stock maintenance is complicated and risky. Hence, private entrepreneurs may not be enthusiastic in marine fish seed production. Further, a regulation of fish seed production under public sector also ensures quality seed production.

Fig.3. Low-cost Brackishwater Cages in Andhra Pradesh, which can safely be adapted to even freshwater systems

Conclusion

Under the existing challenges of filling the gap between growing demand and supply, capture fisheries and mariculture production has to satisfy the needs of the time in terms of nutritional security and optimum production. Significant progress is being made by CMFRI in this area through cage culture as evidenced by both in scientific achievements and production trends. The economic analysis of the Sea Cage Culture has also been worked out in certain cases with higher net operating income and net income in a crop period of seven to nine months. Cage culture has attained wide publicity through audio, video and print media, research publications, training and exhibitions organized. It has to be noted that once the practice is further expanded as a commercial venture, the cost will reduce considerably due to the economies of scale of operation. Sea Cage Farming is a viable alternative that is an economically and financially feasible aquaculture operation for the stakeholders. However, for further development of Sea Cage Farming it must be sustained in future by research and development in genetics, nutrition, health management, production economy, product handling, etc. Future project assessments should involve not only technological and socio-economic considerations, but also its environmental efficiency especially in terms of carrying capacity in a water body. The role of developmental agencies as partners is a prerequisite and very essential for transfer of technology to every farmer/fisher through massive demonstrations.

Further Reading

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8 Improving Water Sharing Through Fostering Institutional Creativity: Lessons from Multi-Use Water Bodies Management*

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India is endowed with extensive Multi-Use Water Bodies (MUWBs) or multiple use water systems in the form of small water storage bodies, village ponds, irrigation and multipurpose tanks. MUWBs constitute an important component of community assets in India. These water bodies have been used as traditional commons by village communities since centuries to meet their domestic needs, irrigating crops and practicing fish farming in many Indian States. Landscape of Chhattisgarh is dotted by age old numerous MUWBs. Construction of ponds and tanks was traditionally undertaken by kings, jagirdars, religious bodies, rich and affluent in Chhattisgarh to create community water assets and management of these resources governed through well defined informal codes for different uses and stakeholders, repair and rejuvenation. Control over water bodies was with the owner. In each village MUWBs have traditionally been allotted for different uses like tending cattle, washing clothes, irrigation, fish culture, nutrient rich soils, fodder grass collection and brick making, micro biodiversity resource base, social and cultural rituals (funeral, worship, temple or sacred ponds), and for social groups and women. After 1952 most of the ponds and tanks were transferred to Panchayat, municipal bodies, and irrigation department depending on size, water spread areas and location of water bodies. New technical and institutional arrangements, entitlements and multiple authority systems governed usufruct rights for different users and non-users.

MUWBs are being administered and controlled under different property rights regimes or level of institutional hierarchy, namely, Panchayat Raj Institution at Village, Janpad and District levels, State Department of Water Resource Development (SDWRD) / State Departments of Irrigation/Public Works Departments, Soil and Water Conservation Wings of State Department of Agriculture, State Departments of Fisheries (SDF) and private owners. These resources can be managed sustainably under State or common or private property regimes and are subject to being degraded. There are many overlaps and combinations of State (public), community and private management systems or governance structures in managing MUWBs. In other words these resources are managed at the interface of different property regimes. Enough evidences are available in India when MUWBs managed under common property regime degraded into open access due to weak property rights regimes, inadequate or poorly conceived institutional arrangements and breakdown of local authority system. Examples are also available when these resources degraded under open access system brought under a State or private or community management regime through appropriate changes in institutional arrangements. The issues related to management of MUWBs are complex due to different categories and characteristics of these *de-facto* common water bodies, scale, size and coverage of fisheries, agriculture, domestic, socio-cultural-religious activities and multiple agencies involved in governing the water resource. In many

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cases competition and conflicts over MUWBs have been observed at different levels i.e. within users, across the user groups, inter-institutions and between stakeholders. Taking an example from Chhattisgarh the extent of competition and conflicts over MUWBs and mechanism to resolve conflicts can be understood. This study makes an effort to sketch paths of technical and institutional arrangements evolved over three decades to govern different categories of MUWBs administered under different property rights regimes in Chhattisgarh (some of the institutional interventions inherited from undivided Madhya Pradesh. Chhattisgarh was part of Madhya Pradesh till Nov 1, 2000). The study has documented workable institutional arrangements for minimizing water conflicts across users and sustainable management of MUWBs.

MUWBs Status in CG

The MUWBs in the form of village ponds, irrigation and multipurpose tanks are extensively distributed in all the villages of the State. MUWBs cover 52211 village ponds and 1616 irrigation tanks with 70,000 ha and 83,873 ha water spread area, respectively, in the State. Of the total water spread area (15,3873 ha) available in the State, 79% and 87% area has

Table 1: Multi-Use Water Bodies (MUWBs) Availability in Chhattisgarh

S. No.	Category of MUWBs	Available Water Area		Area under fish farming	
		Tank/ Reservoir (No.)	Water area (ha)	Tank/ Reservoir (No.)	Water area (ha)
A.	**Village Ponds/Tank**				
1.	Village Panchayat	32060	41958	26122	35929
		(59.56)	(27.27)	(61.57)	(26.91)
2.	Janpad Panchayat	227	2394	141	1873
		(0.42)	(1.56)	(0.33)	(1.40)
3.	Others	19924	25648	14704	17433
		(37.01)	(16.67)	(34.66)	(13.06)
	Sub Total	**52211**	**70000**	**40967**	**55235**
		(97.00)	(45.49)	(96.55)	(41.36)
B.	**Irrigation Resrvoir**				
1.	Village Panchayat	723	4232	645	3510
		(1.34)	(2.75)	(1.52)	(2.63)
2.	Janpad Panchayat	825	20123	751	17989
		(1.53)	(13.08)	(1.77)	(13.47)
3.	District Panchayat	34	20719	32	18002
		(0.06)	(13.47)	(0.08)	(13.48)
4.	Fisheries Mahasangh	15	35350	15	35350
		(0.03)	(22.97)	(0.04)	(26.47)
5.	Departmental	19	3449	19	3449
		(0.04)	(2.24)	(0.04)	(2.58)
	Sub Total	**1616**	**83873**	**1462**	**78300**
		(3.00)	(54.51)	(3.45)	(58.64)
C.	**Grand Total**	**53827**	**153873**	**42429**	**133535**
		(100.00)	(100.00)	(100.00)	(100.00)

Note: Figures in parenthesis are percent to respective attributes been developed under 40,967 village ponds and 1,462 irrigation tanks, respectively, for fish culture (Table-1).

Data Base and Coverage

Data used in this study have largely been taken from my earlier published and unpublished work pertaining to multi-use village ponds and tanks in different parts of Chhattisgarh (between 1988 and 2014, see references). Management of four categories of MUWBs, based on physical and technical attributes, ownership/tenure arrangements, multi-use and multifunctional and multiple stakeholders, have been critically examined in this paper. First category deals with Village irrigation tanks (VITs). These were constructed in Chhattisgarh during erstwhile Madhya Pradesh under micro-minor irrigation tanks (MMITs) Scheme or *Dabri Yojna* through its soil conservation wing in 1977-78 to provide life saving irrigation facilities with provision for fish culture. State had transferred these tanks to Panchayats for management. For the purpose of this study 10 and 8 perennial VITs and seasonal VITs were selected. Under second category of MUWBs, 7 canalfed perennial and 9 seasonal ponds and tanks (adequate water year round in perennial and up to December-January in seasonal ponds and tanks) were chosen to understand water sharing mechanism among farmers, fishers and villagers for household uses. Water Users Associations (WUAs), Krishi Samittiees, Fisheries Cooperative Societies (FCSs) Panchayat and SDWRs are collectively responsible for allocation of water. The third categories of MUWBs have 11 seasonal/rainfed ponds and tanks and primary users are fishers and village households. These are managed by village Panchayat. In the fourth category 5 privately owned rainfed ponds are also selected to compare their performance with ponds under MUWBs category. Water of these ponds is shared between fisher and owner for family use (Table-2).

Institutional Arrangements for Water Sharing

From the viewpoint of water sharing mechanism in MUWBs, based on author's earlier studies, this synthesis provides some meaningful lessons. Competition and conflicts over ponds/tanks water have been observed at different levels i.e. within user groups (irrigators), across the user groups (irrigators ,fisherman and villagers), inter-institutions (FCSs, WUAs, Panchayat, Irrigation Department, Fisheries Department), and between stakeholders and institutions (irrigators Vs SDWRD, fishers Vs WUA or Panchayat). Outcomes of major categories, mentioned above, are briefly summarized inTable-3.

The MMIT programme was introduced with the assumption that contributions of farmers in different types of resources – labour, materials and capital will be forthcoming, once it is determined that the MMITs are useful to farmers and Panchayats. This assumption has largely been proved wrong. Due to lack of legislative and administrative powers, Panchayats could not manage the MMITs under common property regime. MMITs had extremely poor excludability i.e. it was difficult to exclude non-contributors in labour or capital resources from taking advantage of the water use in absence of well defined structure of rights and duties for users. The Panchayats could not evolve rules for the use of water, collection of fees and enforce its authority; as a result the common property MMITs ultimately degenerated into open access. After the formation of Chhattisgarh the State government has empowered Panchayats as legitimate local authority and MMITs are managed now with well defined institutional mechanism for water sharing between/ among different users.

Perennial canal fed MUWBs are primarily for irrigation. Due to adequate water availability throughout the year, conflict between fishers and

Table 2: General Attributes and Institutional Hierarchy in managing different Categories of Multi-Use Water Bodies (MUWBs)

Sl. No.	Category of MUWBs	Classification based on Seasonal/ Perennial/ Rainfed water bodies	Source of water	Availability of water	Major uses of water in order of priority	Local Institutions involved in water uses	Administrative Ownership and authority for water allocation	Leasing authority for fish culture	Lease rent (Rs./ HWSA)	Restriction/ Conditions to use water for fish culture
A	Village Ponds under MMIT Scheme	Seasonal (5 ha)	Rainfed 40 ha*	Up to December	Domestic use, fish culture, Irrigation,	Village Panchayat, FGs/ Fish contractor	Village Panchayat	Village Panchayat	2600.00	Limited restrictions
		Perennial (4.90 ha.)	Rain/ Canalfed 48 ha*	Up to Feb.-March	Irrigation, fish culture, domestic use	Village Panchayat FGs/ Fish contractor	Panchayat	Village panchayat	857.00	Restriction on feed and manure
B	Irrigation Tanks	Perennial irrigation tank (101.05ha.)	Rain/ Canalfed 836.50ha*	Adequate, year round	Irrigation, domestic use, fish culture	FCS, WUAs, Panchayat	SDWRD	Janpad Panchyat	240.00	Feed and manure can't be used by FCS, other users can't be excluded to use water
		Seasonal (28.52 ha.)	Rain/ Canalfed 161.10ha*	Up to Feb-March	Irrigation, fisheries and domestic use	Panchayat, Krishi Samitee, FCS	SDWRD	Janpad Panchayat	243.00	Feed and manure can't be used by FCS, other users can't be excluded to use water
C	Panchayat owned Village Ponds for fish culture	Seasonal (1.256 ha)	Rainfed	Up to December	Domestic use, fish culture	SHG,FG and Village Panchayat	Village Panchayat	Village Panchayat	2229.00	No restriction
D	Privately Owned Ponds for fish culture	Perennial (1.60 ha.)	Rainfed	Adequate water for fish culture upto February.	Fish production	Private	Private	Privat (Lease out to fishermane)	5625.00	No restriction

Note: Figures in brackets indicate water spread area of respective tanks. Irrigation Charges for Kharif and Rabi crops are Rs230 and Rs 600 respectively.

HWSA = Water Spread Area in hectare. * Command Area

Table 3: Institutional Interventions Designed/ Initiated/Strengthened for water sharing of Multi-Use Water Bodies (MUWBs)

Sl. N0.	Categories of MUWBs	Potential competition within users and across users over Water sharing	Potential Conflicts between inter-institutions and multi-users	Institutional Mechanism to resolve competition and conflicts
A	**Village Ponds under MMIT Scheme**	Conflict within farmers located at Head, Middle and Tail end, between farmers and fisher group or fish contractor	Panchayat-farmers-fisher group/ contractor	Panchayat designed institutional arrangements for irrigation scheduling for farmers and ensured minimum water availability for fish culture and domestic uses. Used irrigation fee and fish leasing amount to maintain MUWBs
B	**Irrigation Tanks**	Between Farmers and fishers	WUA/SDWRD-FCS-Panchayat-Krishi Samittiees	Due to protective nature of irrigation system and field to field method of irrigation there were some case of conflicts observed among head, middle and tail end farmers during low rainfall years. Since SDWRD and panchayat ensures minimum level of water required for fish culture there is no conflict between fisherman community (FCS) and farmers. In case of decline of water level in the tank which may affect fish culture, FCS collectively forces to village and Janpad panchayat, and SDWRD to release additional water. With the additional release of water, fish growth period continuous up to month of June. The FCS can't use fish feed and manure in the tank, panchayat resolves conflicts if any, between domestic users of tank water and FCS. Panchayat ensures minimum level of water required for fish culture and coordinate between Krishi Samitee (responsible for maintaining irrigation water use) and FCS. With lease money panchayat repairs bunds of the ponds to stop outflow of fish. In case of water stress condition in rainfed ponds, FCS transfer fishes to perennial ponds
C	**Panchayat owned Village Ponds for fish culture**	Between village households using water and fisher groups	Panchayat and Fisher group	These MUWBs leased in largely by SHGs and since there is no restriction on application of fish feed and manure some time water users for domestic uses have serious conflict with SHGs. Panchayats now keeps a few ponds exclusively for domestic use to minimize conflicts.
D	**Privately Owned Ponds for fish culture**	No conflict between owner and fisher	Well defined leasing arrangement	Well designed institutional arrangements for use of water for fish rearing and use of water by owner.

irrigators has not been observed. However, conflict between head, middle and tail end farmers due to field-to-field and protective irrigation system (irrigation is provided at critical crop growth stages) is quite common. Occasionally conflicts also have surfaced between SDWRD and farmers/WUA. For fish culture minimum water level is ensured by SDWRD. Even in canal fed seasonal MUWBs irrigation is invariably the first priority. In case of inadequate water supply during critical crop growth stages in Kharif season (in some cases one irrigation is provided in Rabi season) farmers put collective pressure on Panchayat through Krishi Samittiees to release water. If fish growth is affected due to lower level of water, lease amount get exempted by Panchayat. FCS gets desirable support from SDF to settle the issue. In case of water stress condition, FCSs transfer fish from rainfed/ seasonal to perennial ponds/tanks. The conflict is more common in rainfed/perennial ponds which are located in/near villages and cater to domestic, fish culture and irrigation needs. Therefore FCSs prefer to lease in ponds located 2 to 3 km away from the main village periphery and water is basically shared between irrigators and fisherman communities.

It was observed in the study area that productivity levels, investment, and net benefits per hectare of fisheries under MUWSB were much lower than private ponds. Two reasons are evident. First, while private ponds are used solely for fish production, MUWBs are not. Different users cannot exclude each other-this affects the viability of MUWBs, particularly seasonal ponds/tanks for fish production, which declines as other uses ascend. Second, villagers often complain about health problems associated with feed and manure used for intensive fish culture. As a result, fisherman are constrained from applying profit-maximizing levels of inputs even in individually leased in ponds owned by Panchayat, particularly in the dry season when water for cattle and human population is most needed. These constraints have created inequalities of income, yield, and employment distribution in the management of MUWSs. Owners of private ponds also some time impose certain restrictions on input use that reduces productivity.

It is essential to note that in almost every village of Chhattisgarh, MUWBs have traditionally been allotted by local Panchayats for different uses like tending cattle, washing cloths and baths, irrigation, fish culture, social rituals (funeral, worship, etc.), These water bodies were managed through collective labour work under common property regime. There is invariably one or two temple or sacred ponds/tanks in most of the villages. In almost every village, ponds/tanks were separately allotted for women and social groups. Taking a leaf from the traditional property rights arrangements, a few ponds may be left out for domestic uses and social rituals in a village and rest of the ponds can be exclusively used for culture fisheries without any restrictions on application of growth promoting inputs to achieve potential yield. Fortunately, in several villages a good number of community ponds still exist. Close-by ponds can be reserved for common use and distant ponds for fish culture. Such simple re-orientation in property rights arrangements can substantially reduce the inter-community conflicts. Similarly irrigation ponds/ tanks can be exclusively used for irrigation and fish culture, if some ponds can be kept aside for catering the needs of villagers. Further, a feasible solution can be worked out between fishers – irrigation groups and SDWRD for de-silting the tanks, as one of the major concerns of the SDWRD is increasing silt load and reducing water intake capacity of a tank due to use of fish feed and manure. Such institutional arrangements can increase fish yield and the total productivity of MUWBs by many folds besides minimizing social conflicts. It has been observed in some parts of the State that FCSs have tendency to lease in all the common ponds/irrigation tanks within eight km periphery (a norm prescribed in Leasing Policy of Fisheries) in a particular village to strategically eliminate fishermen groups and individual fisher chance to lease in these common water resources.

Further, in some cases all the leased out ponds/ tanks have not been used for fish culture. Similarly in many cases the lessee has to be from fisherman community to lease in Panchayat owned ponds. This puts restrictions on other poor of the village.

Way Forward

MUWBs are multipurpose and multi-use in nature with technical socio-economic-cultural-political and environmental interdependencies. Management of MUWSs is intricate because it increases level of conflicts among a range of stakeholders and can create disproportionate spatial and temporal externalities. Issues regarding the role of traditional authorities, user groups, stakeholder committees, different departments of the State and Panchayat and the relationships among multiple authorities with overlapping working zones are highly complex. Given such a complexity, a pluralistic and polycentric or distributed governance approach is advocated to manage MUWSs. It is also suggested that the policies of different Departments of the State and Panchayat need to be examined critically in view of the fact that many departments are loosely linked and intensely compete for water of MUWSs. It is also equally important to learn from the traditional property rights arrangements/soft institutional arrangements how to substantially reduce the inter-community and multi-departments conflicts. A synthesis between traditional institutional mechanism and components of current policies can appropriately put into operation the concept of distributed or polycentric governance for MUWBs.

Recognizing the importance of common pool resources (CPR) in general and water bodies in particular, Honourable Supreme Court of India on January 28, 2011 passed a landmark judgment regarding restoration of these resources. The Supreme Court noted in its ruling: "Our ancestors were not fools. They knew that in certain years there may be droughts or water shortages and water was also required for cattle to drink and bathe .Hence they built a pond attached to every village, a tank to every temple". The apex court directed all State Governments to prepare schemes for the eviction of those occupying water bodies and other village commons and restore them to the community. In the State of Chhattisgarh, an overarching policy direction on commons, exemplified by MUWBs, recognizing the various social-cultural-economic-ecological functions of CPRs, clarifying rights of access, use and management of these resources, and devolving and decentralizing governance of CPRs would be crucial towards ecological security and total welfare of the society.

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9

Artificial Reefs and their possible role in Ecosystem Restoration and Enhancement of Marine Fish Production

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Various developmental activities, pollutants, excessive bottom trawling, inappropriate, illegal, unethical fishing practices and absence of proper management and conservation measures are attributed to impact adversely on the coastal and marine ecosystems leading to continued decline in biological resources and biodiversity (Devaraj and Vivekanandan, 1999). Continued reduction in the stock size of many fishery resources which may adversely affect the food security has lead the Government and Non Government Agencies to find ways and means to improve the ecosystem health and abundance of fishery resources (FIMSUL, 2011). One such intervention is the improvement of the age old indigenous traditional knowledge on artificial reefs (Sanjeeviraj 1989; Vivekanandan, *et al.*, 2006; Kasim, 2009; Kasim *et al.*, 2013). Artificial reef is a man made structure, mostly in hard materials like concrete, ceramic etc., in different shapes and designs so as to suit the required purposes and aims to serve various needs ranging from conservation, production, protection, mitigation, adverse impact reduction, reconstruction of natural habitats and ecosystems, sometimes serving more than one purpose. The concept is very ancient developed simultaneously in different parts of the world with the indigenous knowledge of the people as initial input. Now it is being practiced all over the world at different scales according to the needs.

In India concerted effort was made to develop the age old indigenous traditional knowledge on artificial reefs called "*Mullam*" (Sanjeevaraj, 1996) by improving its longevity and ecosystem services to suit the modern requirements so that it will serve not only as biological, biodiversity enhancement tool but also a technology to improve livelihood options and socio economic conditions of the poor traditional coastal fishers. One such practice advocated is the deployment of artificial reefs all along the near shore coastal waters, to reconstruct the coastal ecosystem (Adams *et al.*, 2011) in general and in particular the biodiversity and fishery resources through an execution process where the community participation is blended with the technology transfer to reap the sustained benefit from nature.

Historical Development

There is evidence that as early as three millennia ago reefs were being used in the Mediterranean Sea, when discarded anchors from the *tonnare*, the Italian traditional tuna traps (net chambers), accumulated over time and were recognized as fish attraction structures (Riggio *et al*, 2000). It is likely that similar age old technique was used by similar artisanal fisheries worldwide at the same time (Simard, 1995). During the 1600s Japanese used reefs of buildings-rubble and rocks to grow kelp. However, the modern "Artificial Reef" concept seems to have come into existence from 18^{th} century onwards in Japan. This concept spread to the USA in the 1830s, where initially the logs from huts were used along the coast of South Carolina to improve fishing activities and this subsequently spread to many different areas of the world (Stone *et al*, 1991). In recent times, reefs are being used as a tool to protect marine living resources from illegal and improper fishing activities also (Jensen *et al*, 2000).

Traditional Artificial Fish Habitats

As early as in 1924, Hornell first described the traditional artificial fish habitats on the Coromandel coast followed by Bergstrom (1983), who reviewed the fish aggregating devices of India and Southeast Asia. Traditional practices of dumping the branches of trees weighted with rocks as anchors referred to as *Mullam* in Tamil, and the coconut fronds tied at 1 m intervals along a rope, like a bottle-brush, suspended from a float and anchored to the sea bed with a weight, called *Kambi* in Tamil are still in vogue in some parts of the coasts of Tamil Nadu, where hooks and line fishery is prevalent. They serve as a Fish Aggregating Device (FAD) and fishing is done using a square lift-net (bag net) *Mada valai* or *Ida valai* in Tamil from four catamarans at the four corners (Sanjeeva Raj, 1996).

The reef material extensively used are the trees and branches of the Tiger bean *Delonix elata* (Family Ceasalpinaceae) called *Konnu maram* or *Vadanaaraayana maram* in Tamil. The bark of this tree emits a sour stench as it soak and rots in the seawater and this odour acts as a fish-attractant. This observation is supported by Hariharan's (1969) report wherein the chemical analysis of this bark yielded amino acid L-asparagine, aspartic acid and sucrose acetate, which are known to be fish-attractants.

Definition of Artificial Reef

Artificial Reef (AR) is defined variously by different workers in different parts of the world. As per the London Convention and Protocol/UNEP (2009) "An artificial reef is a submerged structure deliberately constructed or placed on the seabed to emulate some functions of a natural reef such as protecting, regenerating, concentrating, and/or enhancing populations of living marine resources. Objectives of an artificial reef may also include the protection, restoration and regeneration of aquatic habitats, and the promotion of research, recreational opportunities, and educational use of the area. The term does not include submerged structures deliberately placed to perform functions not related to those of a natural reef - such as breakwaters, mooring, cables, pipelines, marine research devices or platforms - even if they incidentally imitate some functions of a natural reef".

Global Scenario of Artificial Reefs

The objective of establishing artificial fish habitats in the marine environment is mostly to improve the biological resources with an additional aim to sustain the conventional commercial, recreational fishing and to increase the marine biodiversity. Over 40 countries worldwide have deployed artificial reefs (ARs), with different objectives. Structural designs vary according to the objectives and in some cases the design was species specific taking into consideration the behavior of the species concerned and also the type of marine organisms to be attracted for the resource enhancement. The designs vary from improvement of the existing indigenous structures spread across extensive areas to sophisticated concrete structures. Japan (17^{th} Century), America (19^{th} Century), Thailand, Philippines, India, Singapore, Malaysia, Australia, Honkong (20^{th} Century) used modern methods, by designing the artificial reefs according to the behaviour of different species. Artificial fish habitats are being used at present to increase tuna catches in the tropical Pacific, to augment demersal fish catches in the SE Asian waters, to provide recreational fishing in the USA and to culture shellfish in European waters.

Indian Scenario of Artificial Reefs

In India artificial reefs are in use over the last decade close to artisanal fishing villages along the districts of Thiruvananthapuram in Kerala and Kanyakumari and Chengalput in Tamil Nadu. Important organization engaged in the fabrication of different designs of artificial reef structures include: (1) The Fisheries Cell of the Programme for Community Development, Thiruvananthapuram, (2) The South Indian Federation of Fishermen Societies (SIFFS), Thiruvananthapuram (D'Cruz, 1995), (3) The

Waves, Chennai (Raja, 1986) and (4) The Centre for Research on New International Economic Order, Chennai. The Central Marine Fisheries Research Institute installed artificial reefs comprising of 100 concrete modules at a shallow area of 10 m depth off Chellanam in Ernakulam District in Kerala and with different concrete and HDPE modules off Chinnandikuppam in Chennai and other places. MS Swaminathan Research Foundation (MSSRF) in Thirespuram near Tuticorin, Tamil Nadu Fisheries Department at 11 sites along 6 districts and further more structures all along the Tamil Nadu coast, National Institute of Ocean Technology in Orissa and Participatory Learning Action Network (PLANT) in Pulicat are the important organizations actively involved in promoting artificial reefs in India.

Types of Artificial Reefs

Artificial Reefs may be grouped into the following five categories:

1) Environmental Conservation Purposes

Under Coastal Management, one of the primary objectives is to prevent the degradation of ecosystems, natural habitats and the related biodiversity. Where ever such degradation occurs, the first and foremost mitigative interventions are to reduce the pressures causing the degradations so as to enable the system to recover naturally from the adverse impacts. Even after such actions, where the systems still continue to suffer the adverse impacts, then deployment of artificial reefs is recommended as an active solution.

***Biodiversity and biological resource enhancement*:** In some of the instances artificial reefs are fabricated with an aim either to increase or alter the **biodiversity** of a region concerned, for example: (a) Reefs are constructed underwater on sandy bottom have been observed to provide hard substrata which support the prolific settlement of epibiota of benthic origin to the areas where such biota were totally absent or very sparse in nature. However, in a few instances the beneficiary stakeholders may not considered this as an enhancement of biodiversity, as this may tend to eradicate the native species associated with sandy ecosystem while paving the way for the settlement of entirely new species associated with rocky terrain. However, as the sandy bottom is considered comparatively to be less productive than the rocky or muddy bottom, this intervention is always treated as favourble action in enhancing the biological resources. (b) Reefs are being fabricated specially with a view to promote the enhancement of varieties of epibiotic colonisation by accommodating a large number and diversity of niche sizes. The biomass increase in the epibiotic colonies have been observed to be higher in shaded protected inner surfaces than the outer exposed unprotected surfaces which are prone for grazing by the free swimming fishes and other invertebrate predators. c) Reefs can also be designed to take advantage of the 'edge effect' (increased diversity of organisms). Many sedentary filter-feeders like the barnacles require at least feeble water current to provide them the required food organisms and hence these species prefer the exposed surfaces of reefs more.

Restoration: The materials used for the construction of reef meant for **restoration** of specific marine habitats, should be as far as possible, similar to the original natural materials and need to be very carefully considered, especially where complex and sensitive habitats such as the coral reefs are concerned (Edwards and Gomez, 2007). Materials used for coral reef restoration include limestone boulders, or modules made of concrete with lime coasting to facilitate the settlement of polyps (eg. Reef Balls) or ceramic materials as this is considered almost sterile material devoid of pathogens which may be adverse to the corals polyps (eg. Eco Reefs).

Protection: Reefs with deterrent raw materials have also been fabricated with an aim to reduce or eliminate the pressures on damaged ecosystems – such as illegal, improper and in appropriate fishing activities – thereby providing them an opportunity to recover naturally. For example, a number of antitrawling reefs deployed in the western Mediterranean have led to recovery of meadows of the seagrass *Posidonia oceanic* (Guillen et al., 1994). Similarly a series of artificial reefs deployed in Palk Bay at Eripurakkari, Kollukkadu and Vallavanpattinam in Thanjavur district, Gopalanpattinam and Kodimunai in Pudukottai district, Thiruppalakkudi and Villindi in Ramanathapuram districts have shown an increase in the seagrass beds and associated flora and fauna in and around these reefs as they have totally prevented bottom trawling by the mechanized wooden trawlers of the respective districts and served as 'micro marine protected areas' in these regions (Kasim, 2009).

Mitigation: Reefs are normally considered where the adverse impacts on the coastal ecosystems are inevitable by the overwhelming development or operation of a province, state or country. For example, an artificial reef established by the Chennai Water Desalination Ltd., in coastal waters nearby a fishing village in Pulicat, Tamil Nadu, to compensate the loss of marine living organisms owing to the intake of 200 MLD of seawater from that area, is observed to be very effective as a mitigative intervention in Tamil Nadu (Kasim, 2009). Further a 61 hectare artificial reef was proposed in Southern California to compensate for the loss of kelp beds as a result of the operations of the San Onofre Nuclear Generating Station, and to date an experimental reef of 9 hectares has been established (London Convention and Protocol/UNEP, 2009).

Water Quality: In countries like Hong Kong, China, Poland, Finland, Israel, Chile and Canada artificial reefs have also been used in the management of **water quality** in the vicinity of aquaculture facilities, in particular in the finfish farming industry, where large amounts of organic material get accumulated below the net cages. The settlement of benthic fauna and flora on the reef structures deployed below the cages provide the required substrate for these organisms which act as bio-filters. These interventions include "extensive bio-filters" – which utilize natural communities – as well as "intensive bio-filters", where the reefs are seeded with species of commercial value, and it is also advisable that these commercial species should not be harvested, as they are anticipated to provide filtration rates. This co-cultivation of species of different trophic levels is known as integrated, multi-trophic aquaculture (London Convention and Protocol/UNEP, 2009). Along the Tamil Nadu coast prawn farming is carried out extensively along the coastal belt of Palk Bay and the fishermen of Thanjavur district have complained the effluent waters from the prawn farms have a very high organic load with added antibiotic residues also. Further, open sea cage culture is being promoted by CMFRI and NIOT all along the Indian coast as a viable maricultue practice and once there is a boom in open sea cage culture India may also have similar environmental problem like in the countries mentioned above. Hence it is recommended to consider artificial reefs of different sizes and shapes for mitigating this problem as done in those countries.

2) Living Marine Resources: attraction, enhancement, production and protection

Artificial reefs can be used for a variety of purposes in relation to the utilisation of living marine resources including concentrating them in particular areas, increasing biological productivity, production of target species, and protection against illegal fishing activities. The overall objective of such reefs should be to promote sustainable utilisation of the resource.

Artificial reefs have been reported to **increase the biomass** especially the production of specific commercial fish species, by enhancing their survival, growth and reproduction. This is achieved by increasing their preferred habitat/s, including spawning grounds, feeding grounds, hiding and resting places, and should cater for the requirements of both adults and juveniles. Such reefs are obviously of greatest benefit when applied to species that use hard substrates for shelters or spawning sites, and/or which feed on reef epibiota (or associated species).

Structures used for this purpose have become highly sophisticated, particularly in the context of aquaculture. They comprise a variety of designs and can be constructed with a number of different materials, depending on the habitat that is required. Reefs can be designed to accommodate several species (by incorporating a diversity of niches in terms of shape and size) or they can be species specific, focusing on the habitat required by the targeted species. Design options include cell or alveolar, mixed, matrix, or lattice structures. Artificial reefs can also be used to **concentrate** certain fish in a particular location. Although such reefs do not generally contribute significantly to the biological productivity of the ecosystem, since they do also attract other species – benthic and planktonic – they do increase biological richness. However, attraction reefs act as fishing traps, making it easier for fishermen to catch them. Their indiscriminate use can, therefore, contribute to the over-exploitation of the resource, and they should only be promoted within the framework of an appropriate fisheries management system (Pickering and Whitmarsh, 1997). Such attraction reefs are commonly used for recreational purposes, but also play an important role in artisanal fisheries in that (i) known harvesting locations contribute to assured harvest and (ii) locations close to the coast improve the safety of fishers using small craft.

Fishermen in Kerala along the south-west coast of India, use ferro-cement concrete tents as fish attracting devices. In general, in these areas, fishing techniques are inefficient and do not endanger commercial stocks. Modular structures built of concrete, weighing up to 8 tons, and with elements designed to prevent trawl nets have been deployed in some areas to act as a **deterrent** to illegal trawling activities within the areas earmarked for the fishing by traditional fishers. Tamil Nadu Fisheries Department has taken up installation of artificial reefs on a war footing all along its coast with sole aim to enhance the fishery resources and also to prevent the illegal fishing by the mechanized trawlers in these areas.

3) Promotion of Eco-tourism (angling, SCUBA-diving, surfing, boating etc)

Deployment of artificial reef exclusively for the promotion of eco-tourisms in India is very rare and yet to develop. Many artificial reefs have been developed in western countries with an aim to attract SCUBA divers and recreational anglers. To ensure maximum benefit, diving reefs should be visually attractive and interesting and should preferably support as most divers find ship wrecks interesting, but as mentioned above, many other discarded structures and materials have also been deployed for this purpose, with varying success in developed countries like USA, UK and Japan. Artificial reefs intended just to attract and concentrate fish populations do not necessarily contribute significantly to the biological productivity of the ecosystem as well. Rather they are intended to make it easier for anglers to catch the fish. They can therefore be constructed with a range of materials, provided they meet regulatory requirements, provide a suitable habitat for the fish, some substrate for the settlement of benthic organisms, and do not degrade the environment. Artificial reefs for diving or angling can also contribute to the conservation of natural reefs by providing relief from diving or fishing pressure on some of the surrounding natural reefs. This is especially important for biogenic structures such as coral reefs available in Gulf of Mannar and Palk Bay in Tamil Nadu.

It is important to note that SCUBA diving and recreational angling do not go well together as the divers are considered to disturb fish in the reef and hooks deployed among the reef may potentially hurt the divers. Artificial Reef managers should seriously consider designating specific types of reefs established at different locations for these two activities. In some of the developed countries reefs have also been especially designed with the purpose of producing ‘wave breaks’ for surfers, at a specific distance from the coast line (Bleck, 2006). This technology globally adopted to improve surfing conditions for tourists is derived from New Zealand

and Australia and may be customized to the Indian condition in and around the metropolitan cities like Chennai in Tamil Nadu.

4) Scientific research and education

Artificial reefs are also deployed to play a part in scientific research and education with the scientific objectives such as: (i) assessment of physical, chemical, biological and socio-economic impacts; (ii) assessment of the efficacy of reef unit designs; (iii) assessment of the environmental acceptability of potential reef materials; and (iv) a study of the biological, chemical or physical component(s) of the artificial reef 'system'. In most of these cases the design of the reefs constructed for such purposes depend mainly on the experimental purposes and objectives, such as the need for replication of structures to promote the collection of sound data and analysis thereafter.

5) Multi-purpose structures

In all the instances the artificial reefs, especially those constructed for specific purposes are reported to be expensive and quite costly to deploy. In order to maximise the benefits from a given budget, it is advised that the reefs may therefore be often designed to serve more than one purpose. For example, the reefs constructed as deterrents to mechanized bottom trawling may also serve the purpose of increasing the biomass of the benthic biota in the sea, either by enhancing the biological production or attracting different kinds of free living fauna. In India mostly multipurpose reefs are established to serve several purposes.

***Conflict resolving*:** Artificial reef structure can be thought of as a tool for conflict resolving in specific cases like that of the conflict in sharing the fishing ground in Palk Bay among the Tamil Nadu and Sri Lankan fishers though they belong to the same Tamil Community in both the countries. Since the artificial reefs are used as a deterrent tool to prevent mechanized bottom trawling in the near shore waters of Tamil Nadu within the 3 nautical mile limit from the sea shore which is dedicated for the use of traditional fishers, and also in Sri Lanka bottom trawling is a banned fishing method, heavy artificial reef structures of not bigger than 1 m in height (as the Palk Bay is shallow and the average depth is around 9 m) only may be deployed in a dispersed manner prefrably every 10 sq km area within the Sri Lankan trawlable areas. This will effectively and totally prevent the operation of mechanized trawling by the Indian and Sri Lankan fishers, thus solving the cross border fishing conflict. Further, this may also serve as a conservation intervention on Sri Lankan side of Palk Bay leading to increased biological production which will be beneficial to the Sri Lankan fishermen in supporting their livelihood.

Criteria for the Selection of Beneficiary Fishing Villages on the Coast

It is of paramount importance to conduct a bench mark survey of the probable beneficiary fishing village where the artificial reef is intended to be established in order to assess the suitability of the village and the attitude of the fishers in adopting the technology with willingness to participate in the fabrication, deployment and monitoring of the artificial reef. Further, it becomes necessary to collect the baseline data on various socioeconomic indices initially so that these data will be useful to assess the impact of the artificial reef during the operational phase after establishment of the reef in the nearshore waters. Multistage random sampling method/ Participatory Rural Appraisal, Focused Group Discussion and combination of such methods may be employed to collect the data on various socioeconomic indices, fishing practices and awareness on FAD and AR, need for AR/ FAD, location of AR, problems owing to AR, sale of fish, mode of sale of excess fish if caught, attitudes towards AR/ FAD and other details. These data have to be processed by appropriate statistical methods such as SPSS, regression analysis, test of significance, index of preponderance and other methods to assess the suitability of the fishing village and aptitude of the fishers towards artificial reef.

Criteria for Selection of Suitable Site for Deployment

Selection of suitable site for the establishment of an artificial reef in the nearshore water is very essential for maximising the benefit from the reef and also to avoid adverse impacts of the reef on the environment and the dependent living resources (United States Department of Commerce National Oceanic and Atmospheric Administration, 2007).

The following criteria should be taken into consideration for selecting the sites for the deployment of artificial reef structures: (i) the sea floor should be even and hard. Rocky areas of uneven terrain are not suitable; (ii) the site should not be a hindrance to navigational route and established trawling grounds or being used for shore-seining operation; (iii) sites with strong current and wave action need to be avoided, as unfavourable oceanographic conditions tend to disperse the structures to distant areas; (iv) sites of heavy silt deposition, such as river mouth, should be avoided. In areas of heavy silt deposition, the structures will sink into the seafloor quickly; (v) the structures should be installed near the villages where gears suitable for fishing around the structures such as hooks & line are available and are regularly operated by the fishermen; and (vi) the structures may be deployed at depth, not exceeding 20 m for easy accessibility, as this zone permits better sunlight penetration, better phtotsynthesis and enrichment of flora and fauna.

Bathymetry

It is very essential to study the bathymetry and geomorphology of the sea bottom while conducting the site selection. This can be done by underwater SCUBA diving by expert divers and cover the sea bottom physically by videography or one can use the side scan sonar system to study the sea bottom and its morphology. This is very much needed to compare the impact of the artificial reef after it is established at the selected site to assess whether the impact is favourable to the environment or it affects adversely.

Hydrography

The water quality parameters such as surface, column, bottom temperature and oxygen content, pH, nitrate, nitrite, phosphorus, phosphate, silicate, chlorides, micro nutrients, heavy metal contents like lead, mercury, nickel, cadmium, chromium, magnesium etc., have to be studied in detail. These baseline data will be useful to assess the change in the parameters of water quality during and after the installation of the artificial reef and to surmise the degree of the positive impact. This will also indicate whether there is any negative impact. If so what are the negative impacts and what is the level of these adverse impacts. This information will help the managers to plan appropriate mitigative measures if there is any adverse impact. However, previous experiences with the prefabricated structures with hard substratum favours the profuse settlement of filter feeders which are reported to clean the water by filtering the particulate suspended solids and other matters leading to the improvement in the quality of bottom water.

Primary and Secondary Production

Along with the above mentioned hydrological parameters, the primary production of the site will also be studies. The estimates of chlorophyll a, b and c will give an idea on the productivity of the site. The estimates on the primary and secondary production through the collection of qualitative and quantitative data on the abundance of phytoplankton and zooplankton by plankton net operation will help to decide on the productivity of the site. These data will be useful to assess the impact of artificial reef after the installation.

Biological Resources

With the help of SCUBA diving a detailed study has to be made on the available biological resources like the quality and quantity of the sessile and free living fauna and flora of proposed site. The abundance of these resources will indicate the status of site with regard to the availability of various biological resources. Very rich biological resources availability will suggest that the site may not be suitable as the deployment of artificial reef may adversely affect the available rich biodiversity and may change the composition of the species diversity which may not be favourable as the aim of reef introduction is to enhance the poorly populated area. Hence, a site comparatively poor in abundance of flora and fauna demanding an intervention like establishment of artificial reef should be selected.

Structural Design of Different Types of ARs

Connell and Glasby (2001) and Glasby et al., (2007) have studied various urban structures like the pilings, pontoons and rock reefs to serve as marine habitats exhibiting variations in the settlement composition and abundance of sub-tidal epibiota. Different materials such as the concrete, rubber and miscellaneous materials were observed to serve as the artificial reef materials (Ryder, 1981). However, designed and prefabricated artificial reef modules are reported to serve the purpose more effectively than the other materials (Sheeby, 1982; Raja, 1986). With regard to the Indian scenario it is necessary to have the types with respect to production and protection considering the fact that coastal degradation of nearshore habitats and associated living resource have been drastically affected by excessive fishing pressure, inappropriate and illegal fishing especially bottom trawling by mechanized fishing vessels, inshore trawling by the traditional push-net and dynamite fishing. In addition to these, the tsunami of 2004 has devastated the coastal ecosystem of Tamil Nadu and Puducherry beyond imagination, and escalating coastal developmental activities like port, thermal and nuclear power plants, desalination plants and various industries have also contributed to environmental degradation. It is therefore very essential to create as many micro marine protected areas as possible with the deployment of artificial reefs which may act not only in resurrecting the degraded ecosystems by preventing trawling but also will enhance the biodiversity with special reference to various fishery resources.

Materials

Materials for the fabrication of artificial reefs should be considered only if they possess characteristics that meet the established safety goals and objectives for the artificial reef project under consideration, and present no risk to the environment in which they are being placed. There is no need to conduct a detailed research on the material for AR in India as much of the experience gained by various reef programs across the United States has been well documented. The Artificial Reef Subcommittees of the Atlantic and Gulf States Marine Fisheries Commissions (Lukens, 1997; Lukens and Selberg, 2004) have developed a comprehensive manual entitled, 'Guidelines for Marine Artificial Reef Material', which is based on the experiences of reef programs throughout the United States. This document is an excellent source of information on reef materials and has been widely endorsed by researchers, fisheries managers and reef developers as an essential guide for marine artificial reef development, and should be referred to while selecting artificial reef material.

Selection of Suitable Reef Modules

The following three types of artificial reef modules are being extensively used at different sites along Tamil Nadu and Gujarat coasts:

(A) Grouper Module: This reef module is observed to be most preferred structure by different species of perches especially by the *Epinephelus spp.* rock cods, snappers, *Diagramma spp.* etc., The three cement pipes inserted inside the middle portion of the triangular structure serves the purpose of hiding place for these species as these groupers prefer to have some holes or crevices either to hide or save themselves from bigger carnivores or to hide from their prey so that they can attack in a surprise manner (Plate 1). The dimensions of the grouper module are given in Plate 1.

Plate 1. Fabrication of Grouper Module	Finished Grouper Module	GROUPER MODULE DIMENSIONS
		GROUPER MODULE Height x Breadth x Length–1.5m Weight of one module – 0.95 t Diameter of inner pipes 0.30 m No. of module in a cluster – 70

(B) Ornamental fish or Seahorse Module: This is a ring module constructed with three well rings interwoven as shown in Plate 2. It is preferred by small ornamental fishes like the blue damsels, wrasses, dumb-heads, seahorses, clown fishes etc. This module is also well known as Seahorse Module as it is very much preferred by Seahorses as they can freely hang on these module with their tails and continue to feed on their prey conveniently without any distrubances (Plate 2). The dimensions of the Ornamental Fish Module are given in Plate 2.

Plate 2. Fabrication of Ornamental Fish Module	Finished Ornamental Fish Module	ORNAMENTAL FISH MODULE DIMENSIONS
		ORNAMENTAL FISH MODULE Diameter of each ring – 0.90m Height of the ring – 0.6 m Weight of one module – 0.65 t No. of modules in a cluster – 70

(C) Reef Fish Module: This module is observed to be the best choice not only by different groups of demersal species like all kinds of perches, but also by schools of carangids, rays etc., One can see underwater that many species enter into this module thorough the side openings and use the center spacious portions as their home. Many schools of carangids of different age groups can be seen hovering in the water on top of these modules (Plate 3). The dimensions of the Reef Fish Module are given in Plate 3.

Plate 3. Fabrication of Reef Fish Module	Finished Reef Fish Moduale	REEF FISH MODULE DIMENSIONS
		REEF FISH MODULE Height x Breadth x Length-1.5m Weight of one module – 0.75 t No. of module in a cluster – 70

Spread Area of AR Modules

The substratum provided by a single artificial reef module is of paramount importance with regard to the production oriented reefs, as greater the spread area of the substratum the higher the biomass production. The substratum of a single Grouper Module is estimated to be 16.04 m^2 and 70 numbers of Grouper Modules provide a total area of 112.8 m^2 (16.04*70=112.8 m^2); one Reef Fish Module provides an area of 13.5 m^2 and 70 numbers of Reef Fish Modules provide a total area of 945 m^2 (13.5*70=945 m^2) and a Well Ring Module is estimated to provide 10.2 m^2 and 70 Well Ring Modules provide a total area of 714 m^2 (10.2*70=714 m^2). Total substratum provided by all the 210 numbers of modules worked out to be 2781.8 m^2. Total volume of these 210 artificial reef structures is estimated to be 446.25 m^3. These 210 structures of artificial reef are being deployed in one cluster in an area spread over 1000 m^2 of the sea bottom.

Process of Institution Building in the fishing village

Initially fishers of the selected fishing village are appraised on the modern artificial reef through video clippings, power point presentations and detailed lecture. Later the fishermen leaders and expert fishers are motivated to form an **"Artificial Reef Fabrication, Deployment & Monitoring Committee" (ARFDMC)** in the fishing village comprising of expert fishers and elderly leaders so that this institution will serve as an advisory and executive body in establishing and using the artificial reef effectively in order to reap the sustained benefits from the usage of artificial reef on a long term basis. The committee members themselves formulate the bylaws through mutual discussion and agreement under the guidance of the Government Official or the facilitating NGO and register the committee under Societies Act of Tamil Nadu so as to provide legal powers to the committee. The committee members are trained in formulating the rules for a customized and regulated fishing in the reef area when it is ready for fishing, to maintain an accounting on the fish catch, sale of fish proceeds and account maintenance on the income and expenditure.

Community Participation & Ownership

After the formation of the expert fishers committee in the village an MoU is signed to the effect that the artificial reef will be the property of the village and the expert committee members will be responsible for the fabrication, deployment and monitoring of the artificial reef with the guidance, technical input, financial support etc., by the facilitating organization, either Government through an intermediary organization or an NGO, working closely with the fishermen community. Then the fabrication of the artificial reef structures will start on the beach close to the village with the participation of the fishers identified by the expert committee. While the fabrication and curing of the reef structures are in progress with the active participation of a few expert fishermen, a technical team comprised of the Technology Expert to identify the suitable site, underwater SCUBA divers for exploring the sea bottom and nature of the soil and a few helpers will go into the nearshore waters and identify a few suitable sites for the deployment of the artificial reef structures. Finally the best site is selected with the advice of the expert for the deployment. The location of this site in latitude and longitude fixed by the GPS is provided to the expert committee of the village for deployment. Once the fabrication of the three types of artificial reef structures is completed the deployment of these structures is carried out on an auspicious day by loading one or two structure onto each catamaran or FRP boats and deployed at the selected site marked by floats on four corners for easy location of the site. After completion of the deployment the maturation process of the reef is monitored closely with the help of the expert committee of the village for the first 6 months. After this period of initial 6 months for maturation, the reef is declared open for fishing by hooks & line and gillnet only by the fishers.

The Process of Deployment by the Fisher Community

As pointed out already, prior to the deployment the preparatory works such as the marking of the deployment site with buoys on all the 4 directions are carried out. The necessary numbers of wooden frames to be kept on the boats are fabricated with the help of carpenter and supplied to the boat owners. Couples of mechanized wooden trawl boats are hired on rentals from the nearby fishing harbor for lowering the AR modules at the deployment site. For lifting the AR structures to the boats either a Poclain or JCB is arranged where required or the fishermen themselves get organized into small groups and are ready to carry the AR structures to the boats as shown in the above Plate 4, where the community participation in artificial reef deployment is shown. The initiation of deployment is fixed on an auspicious day and a formal puja is offered to invoke the blessings of their deity on the first day. In the presence of important dignitaries the deployment process is initiated on the 1st day by loading the AR blocks on to the series of boats kept ready for carrying the AR blocks to the deployment site. Initially a few boats are flagged off by the dignitaries with the AR blocks to the deployment site.

Plate 4: Deployment of artificial reef modules Community Participarion

Once these boats reach the deployment site, the AR modules are lifted from the boats by the mechnaised trawlers and lowered to the sea bottom one by one and this process is repeated for all the 210 blocks one by one till the last one is lowered to the sea bottom and then the deployment process comes to an end.

Plate:5 Bulk Deployment of Artificial Reef

Process of Bulk Deployment

There are instances when the required types of FRP boats/ catamarans may not be available with the fishermen of the beneficiary village and arrangements may be made from the neighboring villages. When this arrangement also becomes difficult then the AR modules have to be transported by road to the nearby fishing harbor and lifted on to the mechanized trawlers berthed there with the help of load carriers and then deployed at the selected sites. When the number of villages is more and located in the same area of the sea necessitating the fabrication and deployment in a bulk, then the AR modules are fabricated at one suitable site of a wider area. The process of deployment is carried out by loading the AR modules en mass on to a Tuticorin type of wooden cargo vessel or a steel flat bottom barge based at nearby port or a finger jetty, and carried to each preselected deployment sites located in the region. In each site the deployment area are marked with buoys on all the four directions and the AR structures are lowered manually with the help of pulleys and shackles to the bottom of the sea and placed in appropriate manner as shown in the Plate 5.

Process of Artificial Reef Maturation

The initiation of maturation process is the formation of a biofilm of marine bacteria and fungi on the concrete surface of the artificial reef structures, followed by massive settlement process of biofoulers like the barnacles, coralline algae, ascidians, tunicates, sponges, soft corals, hard corals, algae and seaweeds of different species. Cuttlefish and squids deposit voluminous egg-masses amidst these concrete modules, and crabs and lobsters crawl on their surfaces. Algae, bivalves and barnacles literally choke the hollow of these concrete rings. New food-chains are formed at this reef. The underwater SCUBA divers can even hear the snapping of the valves of the Giant Barnacle *Balanus tintinabulum* so abundant characteristically on the tropical coastal waters.

Biological Enhancement

Deployment of artificial reef structures initially adds complexity to the barren environment by increasing the surface area availability for the benthic flora and fauna to use this as the basic substratum for proliferation. It is needless to emphasize that the complexity of the environment supports a wide variety of species diversity. Artificial reef is an eco-friendly bio-resource enhancement technology. The increase in the surface area of the substratum of the environment due to the introduction of the artificial reef is approximately estimated to be 23 times more than what was available before the introduction of the artificial reefs. Ecologically, provision of a larger area of substratum induces a settlement process of a rich succession of marine life, not only as encrusting biofoulers on the concrete substratum takes place, but also a succession of fish fry, fingerlings and adult fish colonise this reef for shelter, feeding and breeding.

Succession of Species

The initial colonisation of lower invertebrates itself attracts a succession of fish species. In the beginning, first to visit the artificial reef are the different species of carangids, coral fishes like the damsels, clownfish, dumb-heads, wrasses, squirrel fish, perches like lethrinids, balistids, parrotfishes, *Diagramma* spp, *Epinephelus* spp, rays, squids and cuttlefishes. All these species may be called as the **visitors** as they visit the artificial reef temporarily for feeding purpose and may leave the reef once their need is fulfilled. The abundant availability of live food in the artificial reef area induces some of the species to stay back and continue to live in the reef area. These species are called the **residents**. Latter these species continue to live, breed in the reef area and produce their young ones which contributes to the growth of their population by continuous recruitment of young ones into their stock.

Biomass Estimation

The most common method to quantify fairly uniform fouling is by stating the average deposit surface loading, i.e., kg of deposit per m^2 of surface area (Rutecki et al., 1985). The fouling rate can be expressed in kg/m^2, and it is obtained by dividing the deposit surface loading by the effective operating time. The data analysis has been recruitment, colonization and seasonality of plant, crustacean, molluscan and fish species at natural and artificial reef sites. SCUBA divers underwater using metal scrapers shall scrape the epibenthos per unit area of the artificial reef structures covered by superficial netting so as not to allow drifting/ escaping of the scrapped material into the water and brought on board the research vessel where it shall be weighed and analysed in detail quantitatively and qualitatively. Video observations may also be recorded and this may show the intensity of algal cover and its protracted seasonal variation.

Fishery Estimation

Most of the previous observations on the reef maturation reveal that after a period of six months from the time of deployment the artificial reefs were observed to be fit for conducting fishing by hooks & line and to some extent by drift gill nets. Since it is impossible to estimate the fish catch specifically and exclusively from the artificial reef area since the fishers do not maintain fishing log as the same is not mandatory as per the existing rules in India. The data on fish landings shall be collected separately from reef area and non-reef area by enquiring the fishermen at the time of landing in the respective landing centers through recall method ie., *Multi Stratum Random Sampling Method* a standard statistical method employed by the Fishery Resource Assessment Division of CMFRI.

CO_2 Emission

Almost all the artificial reefs are located in near shore waters within 20 m depth very close to the fishing village as they are well within 5 km from the landing centers of these villages. All the boats fishing in the artificial reef area need not go in search of fish like other usual boats which go in search of fish shoals all over the sea and this results in considerable fuel saving. This fuel saving is construed to lead to some amount of reduction in CO_2 emission and also contribute in fighting the global warming and climate change in a humble way.

Benefits of Artificial Reef

Critical study of the artificial reefs established earlier along the Tamil Nadu coast during the last one decade indicate that there are number of accrued benefits in the form of ecosystem services offered by these reefs. Biological production has increased owing to the increase in the biomass production of different varieties of benthic fauna and flora coupled with fish production. Surrounding water mass has been cleansed by the biological and ecological process of the artificial reefs, pollutants have been removed to a considerable extent, CO_2 emission has been reduced, CO_2 sequestration has been increased owing to increased photosynthetic activities by the flora, ecotourism developments have been observed, a series of social benefits have accrued and above all the socio economic condition of the fishers of these villages have improved to a considerable extent as indicated by better economy of their fishery and feedback information obtained from the fishers. Robust economic benefit is recorded with a short duration of payback period coupled with gain in empowerment of the fisher community which enjoys a series of social benefits also. Hence, the earlier researchers have strongly recommended this environment friendly technology for implementation all along the Indian coastal waters to improve the inshore ecosystem and the livelihoods of traditional fishers and other coastal community. Important beneficiary services offered by artificial reef are described below.

Ecosystem Services

It is reported that over the years the artificial reefs have evolved drastically as they have been designed for specific tasks such as: species habitat, wave attenuation, oyster restoration, estuary enhancement, coral reef repair, recreational diving, fishing reefs, fishery management, barriers to protect endangered habitat, snorkeling reefs and as integral parts of pier construction. Ammar (2009) has reported that on a global scale, the value of the total economic goods and services provided by natural coral reefs have been estimated to be US$375 billion per year with most of this coming from recreation, sea defense services and food production, this equates to an average value of around US$ 6,075 per hectare of coral reef per year. By any means artificial reef can never equate the services of a natural coral reef, but it also contribute to a moderate level.

Provisioning Services

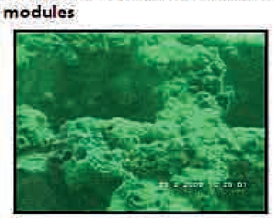
Taking the three types of AR modules described in earlier section as example and deployment of 210 numbers of the above described structures at one site is estimated to provide 1,000 sq m (31.63 x 31.63 m) primary core surface area at the sea bottom as an 'Indigenous and Community Conserved Areas' (ICCAs) for basic biomass production. Nearly 5,000 sq m (70.71 x 70.71 m) of protected secondary core area is created where secondary and tertiary producers start thriving well within a short period of 6 months. An estimated 10,000 sq m (100 x 100 m) of buffer zone is created which serves as a significant coastal ecosystem with improved conservation status and support wide variety of biodiversity including a sustainable fishery. As much as 10 ha of additional fishing ground has been developed by each cluster of artificial reef for the poor traditional fishers to carry on sustainable fishing leading to an improvement in their socio economic status and well being.

Cultural Services

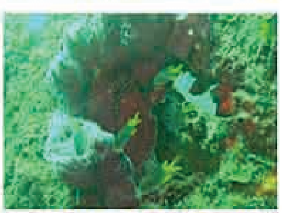
While considering the cultural services, the artificial reefs serve as an excellent ecotourism site. The people visit the coral reefs and its associated flora and fauna with the help of glass bottom boats in Gulf of Mannar operated by the Forest Department. Those who are well trained in underwater diving with SCUBA/snorkeling can go for sport fishing and sightseeing around the artificial reef sites. Qin *et al*., (2011) have report that after the artificial reef construction, the tourism service value of places other than the reef sites in Yangmeikeng artificial reef region in China decreased from 87% to 42%, food supply service value increased from 7% to 27%, and the services value of raw material supply, climatic regulation, air quality regulation, water quality regulation, harmful organism and disease regulation, and knowledge expansion had a slight increase, as compared to the surrounding coastal areas.

Plate: 6 Photos shown various stages of living resource assemblage in artificial reef modules

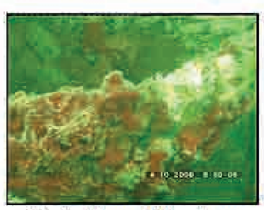
Freshly Deployed Grouper Module



Epifauna on Seahorse Module



Reef Module with Ornamental fish



Reef with coral line algae

Preserving Services

Artificial reef supported wide varieties of flora and fauna communities, which flourished luxuriously and abundantly on the reef structures and observed to be very rich in biodiversity. The biological resources eventually obvious to the naked eye comprised of seven phyla and about 38 species, with representatives of 8 polychaetous annelids, 9 crustaceans, 7 mollusks, 6 coelenterates, 2 bryozoans, and 2 others (Plate 6). Amphipod crustaceans, three caprellids and three tube-building gammatid amphipods, were the earliest and most abundant settling foulers. Polychaetes (nereids and polynoids), molluscs (sessile bivalves, pearl oysters), and other fouling organisms such as hydroids, actinians, and bryozoans, were lately represented. Algal succession on artificial reefs comprised of filamentous algae which were the primary colonizers; the fleshy brown algae, appeared soon after. Low light penetration through the water owing to the suspended solid load during certain period and selective browsing by herbivorous fishes favour the blue-greens to be the dominant algae in the climax community which, occurs within a 1-year period. This indicates that the artificial reef sites are an excellent habitat for luxurious proliferation of biodiversity and its conservation (Kasim, 2009).

Supporting Services (Water Quality Enhancement)

Generally the relevance of ecological process to common artificial reef applications are dealt under three heads: (i) Fisheries production, (ii) Water quality enhancement and (iii) Ecosystem restoration (Miller et al., 2002). The water quality enhancement deals with trophic interactions (particularly filter-feeders), biogeochemical cycling and organismal-level physiology. Coastal water quality is improved to a very great extent through extracting particles from the water by communities of filter-feeding benthic invertebrates of the artificial reefs (Newell, 1988). Especially sponges may even be able to filter and sequester other pollutants, such as heavy metals and other organic matters. Thus, artificial reefs supporting filter-feeder communities may be able to mitigate water quality degradation from organic enrichment.

Regulating Services

In addition to absorption of nutrients, removal of heavy metals and reduction of suspended solids during the water quality enhancement, artificial reef are judged to be effective in **carbon sequestration and reduction in CO_2 emission** also. As already pointed out, considerable savings is observed in fossil fuel and fishing time due to the proximity of the fishing ground in the artificial reef area. Fishers need not hunt for fish far and wide wasting their fuel as they limit the travel to and fro the fishing grounds in reef area which are almost on an average below 5km distance from the fishing village and save on an average 5 l of fossil fuel per boat per day.

Social Benefits

Artificial reefs can be established as the common village property and can be operated by the village fishermen as a whole by evolving a system of sharing the fishery resource among them by appropriate customized fishing practices. Since the whole community is expected to participate in installing the artificial reef, the entire community has the right to fish at the reefs through custom evolved fishing practice. This incidentally strengthens the community to build up the solidarity of the fishing village community, without any disparity between the richer and poorer fishermen, within the village. The fringe benefit for the traditional fishermen is that the artificial reefs may also help to prevent the operation of mechanized trawlers in the area where the artificial reef structures are deployed into the coastal waters and this will minimize the long-standing enmity between traditional fishermen and mechanized trawler operators.

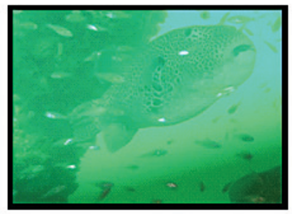
Other Benefits

Artificial reefs in due course of time evolve almost as a natural reef imitating the functions of natural coral reefs if there happen to be a coral reef island or submerged corals reefs in the nearby area adjacent to the artificial reef (Plate 7). This helps to reduce the dependence of the fishermen on the natural coral reefs and provides alternative fishing area to support the livelihood of the coastal fishermen who once originally fished in the natural coral reef areas such as the coral island of Gulf of Mannar. Further the artificial reefs have been observed to support a good population of ornamental fishes and other ornamental invertebrates. Harvesting of these ornamental fishes and invertebrates by traps and scoop nets by SCUBA diving in a sustainable manner may provide additional income for the fishermen.

Plate 7: Fish assemblage and young ones of fishes in artificial reef

Breams & perches in reef module

Fishes grazing on reef module



A grouper under reef shelter

Fish young ones in reef module

Economics of Artificial Reef

Evaluation of the socio-economic performance of artificial reefs and related aquatic habitats has been dealt in detail by Milon et al., (2000). The economics of artificial reef studied based on the data on catch, effort, revenue realized, catch rate per unit of effort and value realized per unit of effort by gillnet and hooks & line units are dealt in detail by Kasim et al., (2013). The estimates obtained at artificial reef area were higher than the estimates obtained for the same units operated in non artificial reef areas in the same village. This is possibly due to low operational expenses, better quality catch and better price due to bigger sizes of fishes and better freshness of the catch. As already mentioned the payback period is worked out to be 0.53 years which is highly suitable to promote this as a bankable project throughout the country.

National/Local Policy, Legislation and Decision-making for the Construction/ Placement of Artificial Reefs

In India the construction and placement of artificial reefs is still a relatively minor activity when compared to many developed countries like USA, UK, Australia and Japan, and there is no explicit mention on artificial reefs in the policy of either Central or State Governments. Neither the Comprehensive Fisheries Policy of Central Government nor the State level policies of Maritime States deal with the Artificial Reef except Tamil Nadu where the state policy makes a mention to the effect that "*To augment aquatic resource production in the inshore areas by conservation measures, stock enhancement,* ***establishing artificial reefs etc***., (FIMSUL, 2010). Coastal Regulation Zone Notifications, Environment Protection Act and Rules and Marine Fishing Regulation Acts and Rules of Central and State Governments do not deal with Artificial Reefs, but deal with the prevention of waste dumping and controlling of pollution of the marine environment.

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10 Marine Ornamental Fish Production and Trade Opportunities Ahead

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It is well understood that the international trade of marine ornamentals has been expanding in recent years and has grown into a multimillion dollar enterprise. Since 1990, the aquarium trade has seen a shift in consumer preference from fish only aquaria to miniature reef aquaria. Because of this, collectors now focus on full coral reef biodiversity to supply to the trade. The marine ornamental organisms are chiefly distributed in the coral reef habitats and include fishes, stony corals, soft corals, sea fans, ornamental shrimps, sebellids, giant clams, echinoderms and live rocks. The existing global marine ornamental fish trade is mainly based on wild collection and less than 1% is only traded from hatchery production. The three key words associated with the marine aquarium trade are – collection, culture and conservation. The ornamental animals are the highest valued product that can be harvested from a coral reef. The global marine ornamental trade is estimated at US$ 200-330 million. The ornamental trade is operated throughout the tropics. Philippines, Indonesia, Solomon Islands, Sri Lanka, Australia, Fiji, Maldives and Palau supplied more than 98% of the total number of marine ornamental fish exported in recent years. India is endowed with vast resource potential of marine ornamentals distributed in the coral seas and rocky coasts with patchy coral formations (Murty, 2002; Gopakumar, 2007). The major oceanic reef areas of coral reef distribution in India are the Lakshadweep Islands and the Andaman – Nicobar groups of Islands. The other areas of coral fish distribution are the coastal areas of fringing or patch reefs of Gulf of Kutch to Mumbai, areas of Central West Coast between Mumbai to Goa, certain locations of South West Coast and Gulf of Mannar and Palk Bay. In this context of the expanding global scenario, it appears very much lucrative for India to venture into this industry. But it is a multi-stakeholder industry ranging from specimen collectors, culturists, wholesalers, transhippers, retailers, hobbyists to researchers, government resource managers and conservators and hence involves a series of issues to be addressed and policies to be formulated for developing and expanding a sustainable trade.

An overview of global scenario

Based on the Global Marine Aquarium Database (GMAD) the annual global trade is between 20 - 24 million numbers for marine ornamental fish, 11-12 million numbers for corals and 9-10 million for other ornamental invertebrates. A total of 1471 species of fish are traded globally. Most of these species are associated with coral reefs although a relatively high number of species are associated with other habitats such as sea grass beds, mangroves and mud flats. According to the data provided by exporters, the Philippines, Indonesia, the Solomon Islands, Sri Lanka, Australia, Fiji, the Maldives and Palau, together supplied more than 98% of the total number of fish exported. GMAD trade records from importers for the years 1997-2002 showed that the United States, the United Kingdom, the Netherlands, France and Germany were the most important countries of destination, comprising 99% of all imports of marine ornamental fishes. (Collette *et al*., 2003).

Among the most commonly traded families of fish Pomacentridae dominate accounting for 43% of all fish traded. They are followed by species belonging to Pomacanthidae (8%), Acanthuridae (8%), Labridae (6%), Gobiidae (5%), Chaetodontidae (4%), Callionymidae (3%), Microdesmidae (2%), Serranidae (2%) and Blennidae (2%). The most traded species are the blue green damselfish (*Chromis viridis*), the clown anemone fish (*Amphiprion ocellaris*), the whitetail Dascyllus (*Dascyllus aruanus*), the sapphire devil (*Chrysiptera cyanea*) the three spot damsel (*Dascyllus trimaculatus*) *Amphiprion percula*, *Paracanthus lepturus*, *Dascyllus albisella*, *Zebrasoma flavescens,* the cleaner wrasse *Labroides dimidiatus*, the powder blue surgeon *Acanthurus leucosternon*, the sea goldie *Pseudanthias squamipinnis*, the fire goby *Nemeteleotris magnuifica,* and the dragonet *Synchiropus splendidus* were the most commonly traded species. These species together account for 36% of all fish traded from 1997 to 2002.

According to GMAD, there are 61 species of soft corals, 140 species of stony corals, eight genera of sea fans and 516 species of ornamental invertebrates in the trade. (Collette *et al*., 2003).

Trade development through hatchery production

The ultimate answer to a long term sustainable trade of marine ornamentals can be achieved only through the development of culture technologies. It is well accepted as an environmentally sound way to increase the supply of marine ornamentals by reducing the pressure on wild population and producing juveniles and market sized fish of wide variety of fish year round. In addition hatchery produced fish are hardier and fare better in captivity and survive longer. The maximum number of species reared in hatchery are from the family Pomacentridae which includes the clownfishes and damselfishes. Almost 50% of the marine ornamental fish trade on a global scale is constituted by species of the Family Pomacentridae, which is a positive factor for the development of a hatchery produced marine ornamental fish trade.

Global scenario of Marine Ornamental aquaculture

The UNEP World Conservation Monitoring Centre Report on the Global Trade in Marine Ornamental Species stated that 69 marine ornamental fish species were captive bred in sharp contrast with the Marine Fish Breeding Records (MFBR), which reported that 211 species were bred and grown to the juvenile stage and beyond. The disparity may be due to the differences between successful ornamental fish reproduction reports and commercially available species. However, to date, successful commercial rearing has been scientifically reported for only a few species and less than 1% of marine aquarium fish are commercially produced. The main families bred for aquarium purposes are Pomacentridae, Pseudochromidae, Gobiidae, Apogonidae, and Syngnathidae (Dominguez and Botella, 2014).

Pomacentridae

These were the first marine ornamental fishes to be cultured, but considering their importance in the aquarium trade (it represents almost half of the traded species, a great amount of research is still being focused on breeding these fishes). This family includes damselfishes (which includes *Pomacentrus* spp., *Neopomacentrus* spp. *Abudefduf* spp. *Chrysiptera* spp.) and clownfi shes (*Amphiprion* spp. and *Premnas* sp.), which are perhaps the most famous species in marine aquaria. Although the reproductive behaviour of damselfishes has been described for sometime most available information is related to clownfishes. Some of the species of this family are commercially available from hatchery, such as *Amphiprion ocellaris*, *A. melanopus*, *A. frenatus*, *A. percula*, and *Premnas biaculeatus.*

Pseudochromidae

The most famous members of this family are the dottybacks (*Pseudochromis* spp.), which are colourful but relatively aggressive and territorial fish. They are generally small, being less than 10 cm in length, and some can be even less than 2 cm. Some of the species of this group are being reproduced in captivity, and are commercially available, such as the orchid dottyback (*Pseudochromis fridmani*), sunrise dottyback (*P. flavivertix*), the orange dottyback (*P.aldabraensis*) and the Lyretail dottyback (*P. steenei*). Interest in breeding and culturing these species has been increasing in the last few years.

Gobiidae

Several species have been spawned in captivity and some of them are commercially produced, such as *Elacatinus* spp., *Gobiosoma* spp. and *Gobiodon* spp.

Apogonidae

Some species are cultured in captivity, including *Apogon imberbis*, *A. notatus*, *A. cianosoma*, *Sphaeramia orbicularis* and, *P. kauderni*, and some of them are commercially produced, such as the Bangaii cardinalfish (*P. kauderni*), the ochre-striped cardinalfish (*A. compressus*) and the Pajama cardinalfish (*S. nematoptera*).

Syngnathidae

The research effort in seahorse husbandry and breeding techniques in the last 15 years led to large-scale seahorse farms in Australia, USA and New Zealand in the early 2000s. Captive breeding techniques are available only for some species, such as *Hippocampus reidi*, *H. kuda*, *H. ingens*, *H. subelongatus*, *H. fuscus*, *H. erectus*, *H. trimaculatus*, *H. hippocampus* and *H. Abdominalis* Some of these species are commercially available, such as *H. reidi*, *H. kuda*, *H. zoosterae*, *H. breviceps*, and *H. Barbouri*.

Blenniidae

Some species belonging to the genus *Meiacanthus* are bred in captivity

Pomacanthidae

There has been a great effort regarding the culture of marine angelfish species in particular, the cherub pygmy angelfish, *Centropyge argi* and the flame angelfish, *C. loricula*. These species are the subject of research, but they are still not commercially available.

Labridae

The aquarists' interest in this family is based mainly on wrasses from the genera *Thalassoma*, *Bodianus*, *Choris* and *Labroides*. Captive spawning has been reported for a number of species, such as the blue head wrasse (*Thalasoma bifasciatum*), the bluestreak cleaner wrasse (*L.dimidiatus*), the cupid wrasse (*T. cupido*), and the clown wrasse (*Halichoeres maculipinna*), but they are still not commercially available .

Status of Hatchery Production technologies in India

Clownfishes

Clownfishes are distributed throughout the Indo-West Pacific Region. Clownfishes continue to be the most demanded marine tropical fish and the technologies available at present on marine ornamental fish breeding are mainly centred around clownfishes. They are distinguished and taxonomically separated from other damselfish by their dependence on anemones for protection. They are further distinguished from other damsels by their large capsule shaped eggs and large larvae at hatch. Their swimming pattern consists of exaggerated lateral flexures and alternating paddling of their pectoral fins. The Central Marine Fisheries Research Institute (CMFRI) and CAS in Marine Biology, Annamalai Univeriosty have successfully developed and standardised breeding and hatchery technology for ten species of clownfishes which are in good demand in the ornamental fish trade. (Gopakumar *et al.*, 2001; Gopakumar *et al.*, 2008, Ignatius *et al*, 2001; Madhu and Rema 2002; Rema Madhu *et al*., 2007; Rema Madhu *et al.*, 2008 and Madhu *et al.*, 2008, Ajithkumar and Balasubramonian, 2009, Ajithkumar and Gunasundari, 2013, Dhaneesh *et.al*., 2012a, Dhaneesh *et.al*. 2012b, Swagat Ghosh *et. al*, 2012a, Swagat Ghosh *et.al.* 2012b).

Species of Clownfish for which hatchery technologies are developed and standardized in India

S.No.	Species Name	Common Name
1	*Amphiprion sebae*	Sebae clownfish
2	*A. clarkii*	Clark's anemonefish/ yellowtail clownfish
3	*A. percula*	Orange clownfish
4	*A. ocellaris*	Ocellaris clownfish/ false percula clownfish
5	*A. frenatus*	Tomato clownfish
6	*A. perideraion*	Pink skunk clownfish
7	*A. nigripes*	Maldive anemonefish/ black finned anemonefish
8	*A. ephippeum*	Red saddle anemonefish/ Fire clown
9	*A. akallopsisos*	Skunk clownfish
10	*Premnas biaculeatus*	Spine cheeked anemonefish/ maroon clownfish

Spawning of *Amphiprion percula*

Hatchery produced juveniles of *A. percula*

***A. ocellaris* pair guarding the eggs**

Hatchery produced juveniles of *A. ocellaris*

Egg laying of the maroon clown
Premnas biaculeatus

Freshly laid eggs of maroon clown under microscope

Developing embryo of maroon clown

Parental care of eggs in maroon clown

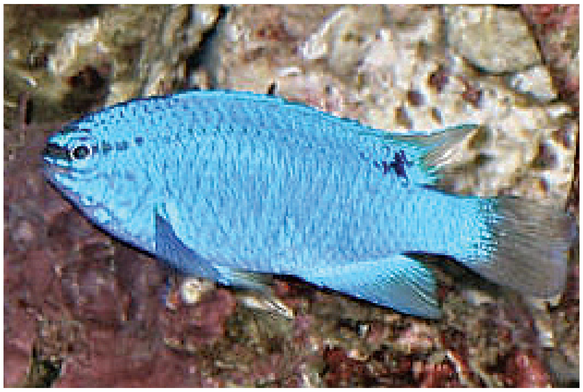
Marketable size tomato clown

Marketable size Maldive clown

Damselfishes

The damselfishes which also belongs to the Family Pomacentridae are very popular among aquarists due to their small size, bright colours, quick acclimation to captivity and interesting behaviour. The majority of species inhabit the Indo-Pacific region and about 100 species and 18 genera have been recorded from the Indian Ocean. More than 30 species belonging to the genera *Pomacentrus*, *Neopomacentrus*, *Chromis*, *Abudefduf* and *Chrysiptera* are commonly available from Indian coral seas.

Broodstock development and larval rearing were achieved in India for **eigh**t species of damselfishes *viz.* the three spot damsel (*Dascyllus trimaculatus*), striped damsel (*Dascyllus aruanus*), the blue damsel (*Pomacentrus caeruleus*), the peacock damsel *P. pavo*, the bluegreen damsel (*Chromis viridis)*, the filamentous tail damsel *Neopomacentrus cyanomos*, the yellowtail damsel (*Neopomacentrus nemurus)* and the Sapphire devil damsel (*Chrysiptera cyanea*). (Gopakumar and Santhosi, 2009; Gopakumar *et al.*, 2009; Gopakumar *et al.*, 2002; Pananghat Vijayagopal *et al.*, 2008) However the survival rates during larviculture were comparatively low and not consistent and hence further upgradation of techniques are needed prior to commercialization.



Sapphire devil damsel (*Chrysiptera cyanae*) adult

Hatchery produced *Chrysiptera cyanae*

Humbug Damsel (*Dascyllus aruanus)* adult

Hatchery produced *Dascyllus aruanus*

Others

Captive breeding was achieved in the purple firefish *Nemeleleotris decora* (Madhu and Rema Madhu, 2014) and breeding and larval rearing in *Pseudochromis dialectus* (Madhu *et. al.*, 2016)

The immediate way forward

The technologies for hatchery production of ten species of clownfishes are standardised and hence can be scaled up for commercial level production and a hatchery produced marine ornamental fish trade could be developed in the country. Hatchery production of marine ornamental fishes can be a lucrative additional source of income for the coastal fishermen below poverty line. The immediate way forward for the development of a hatchery produced marine ornamental fish trade in the country include imparting necessary training to prospective entrepreneurs, supplying of brooders/ newly hatched larvae to the trained entrepreneurs, promoting the establishment of a few small-scale hatcheries and establishing appropriate marketing channels. In this regard, a joint programme involving National Fisheries Development Board (NFDB), Central Marine Fisheries Research Institute (CMFRI), State Fisheries departments of maritime states/ Lakshadweep, Andaman-Nicobar Islands is the need of the hour.

Development of required broodfishes of the different species in broodbanks and production of larvae and early juveniles in pilot hatcheries is needed for initiating the entrepreneurship. Imparting necessary hands on training to prospective entrepreneurs and capacity building is to be taken up. Simultaneously establishment of a few small-scale hatcheries to groups of small-scale farmers has to be accomplished. Initially supplying of just metamorphosed young ones for rearing to marketable size, subsequently after the development of live feed culture providing newly hatched larvae for rearing and finally providing brooders for breeding and seed production to the small-scale hatcheries in a phased manner and hand holding till the hatcheries are able to function independently are needed. Developing appropriate marketing channels both domestic and export should also receive priority attention so that the enterprise becomes sustainable.

The roles of the different agencies envisaged under this programme are as follows:

CMFRI: (i) To produce and supply to hatcheries metamorphosed young ones/ yolk sac larvae/ broodfishes of 10 species of clownfishes for which technologies are developed. (ii) To create biosecure broodstock facilities that will serve as Broodbanks to provide broodfish to hatcheries. (iii) To establish pilot hatcheries for providing metamorphosed young ones/ yolk sac larvae to the hatcheries. (iv) To conduct trainings on broodstock development, larviculture and rearing to marketable size to entrepreneurs.

State Departments: (i) To be a connecting link between the CMFRI centres and farmers. (ii) To select farmers for hands on trainings by the CMFRI centres. (iii) To develop small-scale production units of marine ornamental fishes in the concerned States/ Union territories with NFDB support. (iv) To develop market outlets.

NFDB: (i) Funding support and (ii) Co-ordinating and monitoring the progress.

If the concerned agencies are making a co-coordinated and synchronous effort in their respective roles, the development of a lucrative hatchery produced trade of marine ornamental fishes in the country will become a reality which can improve the livelihoods of hundreds of poor coastal fishermen in the country.

Development of a Sustainable Trade from Wild Collection

A critical analysis of current global trade of the marine ornamentals from wild collections reveals many ecological concerns which require policy interventions. The major aspect that should receive topmost priority is for taking appropriate action to ensure that the development of the trade should not threaten the sustainability of the coral reef ecosystem. The following measures are suggested:

(i) Concerns of wild collected trade

Destructive collection practices, the introduction of alien species, overexploitation, the lack of scientific information on many species collected and threat of extinction of target species are the major problems of the marine ornamental fish trade. Destructive fishing techniques include the use of sodium cyanide and other chemicals to stun and catch fish. Eventhough cyanide only stuns the fishes, high post capture mortality is recorded. It may destroy the coral reef habitat by poisoning and killing non-target animals, including corals. During collection of coral pieces for the coral trade, many more colonies may be damaged or broken than are actually harvested. Corals are also broken for easy access to capture fish. This is more common with branching species of corals in which small species such as *Dascyllus* and *Chromis* often refuge (Edwards and Shepherd, 1992). Collection of live rock has been considered as potentially destructive as it may lead to increased erosion and loss of important reef habitat.

When exploitation is at a lower level in comparison to the resource available, there will not be any negative impact on reef fish populations. A study of the Cook Islands showed that the total catch per unit effort remained constant between 1990 and 1994 (Bertram, 1996). In Australia, due to the permit system, the current aquarium fishery is at sustainable level (Queensland Fisheries Management Authority, 1999). But Australia is a rare case as the Great Barrier Reef is the largest reef system in the world. It is well known that not all fish are equally available or equally attractive to the industry, and the most common fish need not be those favoured by the hobbyists. As a result, the effect of collection of ornamentals should be measured with respect to their potential to deplete particular species or locations. Several countries in Asia and South America have begun to implement collection restrictions of certain ornamental fish species (Corbin and Young, 1995; Friedlander, 2001, Ogawa and Brown, 2001). Although no marine species collected for the aquarium trade have been driven to global extinction, studies carried out in Sri Lanka, Kenya, the Philippines, Indonesia, Hawaii and Australia have reported localized depletion of a number of target aquarium species of fish like butterflyfish and angelfish due to heavy collection pressure (Lubbock and Polunin, 1975; Rubec, 1987; Vallejo, 1997; Soegiarto and Polunin, 1982, Tissot and Hallacher 1999). The only systematic study assessing the effects of harvesting fish for the aquarium trade on resource populations was carried out in Hawaii (Tissot, 1999). The study reported that eight of the ten species most targeted by collectors showed decline in abundance at exploited sites relative to control sites.

A larger part of the trade of ornamentals is centred on individual species. The vulnerability of the species to collection will depend on a number of life history parameters like growth, reproduction and recruitment (Harriott, 2003). Eventhough reef fish exhibit a wide variety of mating strategies the larvae are distributed through wave and wind driven ocean currents (Hutchings, 2002). This makes replenishment of reefs with new fish larvae highly dependent on these currents and hence the availability of fish for sustainable aquarium collection is highly variable.

The effects of fishing are significantly different for species that are hermaphroditic compared with species that do not change sex. A fishery selectively removing larger animals first will mean that animals will have to start changing sex at smaller sizes, possibly reducing the fitness of individuals and thus making hermaphroditic stocks more vulnerable to overfishing.

Trade in ornamental marine fishes is characterized by extreme selective harvesting. For many species, juveniles are preferred by aquarium fish collectors due to their distinctive coloration and ease of maintenance. Consistent harvesting of juveniles may leave only limited number of young ones to reach adult size and replenish the adult stock.

Eventhough most coral reef fishes have broad distribution, a few species are endemic. Some species are naturally rare, occurring only in very restricted locations or naturally occur in lower numbers, although they may be widely distributed (Wood, 2001). Other species may be abundant at different sites, but their distribution is limited to specific habitats. The more wide spread/ or abundant a species is, the less vulnerable to exploitation. Increased rarity often implies higher prices and hence vulnerable to overexploitation.

Males of many coral reef fishes tend to be preferred due to their distinctive colouration. Selective harvesting for males of particular populations on a regular basis may lead to reproductive failure and ultimate population collapse due to heavily biased sex ratios in remaining population.

There are many factors that lead to post harvesting mortality, such as physical damage and use of chemicals during collection, poor handling practice and disease. Even when collected in an environmentally sound manner, aquarium organisms often suffer from poor handling and transport practices resulting in stress and poor health of fishes. Research on the marine ornamental trade between Sri Lanka and the UK demonstrated that in the mid 1980s about 15% of fish died during and immediately after collection, another 10% died during transit and a further 5% in holding facilities (Wood, 1985). As a result of such mortality, more fishes are required to be collected than would be necessary to meet the market demand.

Where organisms are collected, stored and handled by adequately trained individuals and transported in suitable containers fish mortality have been very low. The post harvest conditioning facilities should include modern gadgets such as UV lighting system, protein skimmers and carbon filters.

Destructive collection practice - Blasting

Destructive collection practice – Cyanide poisoning

An analysis of the wild collected marine ornamental fish trade revealed that: (i) no species collected for the aquarium trade is yet known to be at the risk from global extinction; (ii) in some cases excessive wild collection of ornamental fishes with destructive fishing methods have led to depletion of certain species (eg. Banggai cardinal fish from Indonesia); (iii) traders in Philippines reported lower catches of some most valuable species and potential loss of varieties; (iv) excessive coral collection in Philippines altered community structure; (v) due to global concerns about overexploitation all international trade of the three aquarium taxa *viz.* sea horses, scleractinian corals and giant clams are controlled under CITES Appendix-II (Cato and Brown, 2003).

The major concerns from the global scenario of wild collected trade are (i) use of cyanide and other destructive collection methods (ii) poor handling and husbandry practices (iii) unnecessary animal mortality (iv) collection of unwanted and/or unsuitable species (v) potential for stock depletion (vi) ecosystem effect of live coral and live rock exports (vii) potential for alien species introduction (viii) lack of reliable data on the resources and the trade and (ix) limited government capacity for reef management and enforcement

(ii) Introduction of certification for wild collected species

A certification system aimed at eco-friendly collection, conditioning and trading will help in long term sustainability of the trade. In this context, Marine Aquarium Council (MAC) is a golden example. MAC developed a certification scheme that will track an animal from collector to hobbyist. Established in 1996, the goals of MAC are to develop standards for quality products and sustainable practices and a system to certify compliance with these standards, and create consumer demand for certified products with a net work of 2600 stakeholders in more than 60 countries, it is recognized as the lead organization for developing and coordinating efforts to ensure that the international trade in ornamental marine organisms is sustainable. MAC certification covers both practices and products.

In India, till date no organized trade of marine ornamentals has been initiated. But it is a fact that a great deal of indiscriminate collection of marine ornamentals is in vogue in many parts of our reef ecosystem. No data regarding the same is available and this is a matter of great concern due to the indiscriminate nature of exploitation and ecohostile methods of collection which damage the reef ecosystem. In addition to this, lack of knowledge on appropriate post harvest husbandry practices leads to large scale mortality of the collected animals. It is time to evolve a marine ornamental fisheries policy in the country for developing an organized trade of marine ornamentals. In recent years the government/ developmental agencies have taken a few steps towards promotion of marine ornamental fisheries. These include the awareness programme on marine aquarium fishes and marine aquarium gadgets through aquashow events. The training programmes organized by R&D institutions through NFDB have played a major role in creating awareness as well as in realizing the potential of marine ornamental fishes. The developmental agencies like NFDB, NABARD have also started financing programmes for the development of marine ornamental trade.

In developing a marine ornamental industry in India it is inevitable to formulate legislations on these issues which are of vital concern to the sustainability of the trade. The Central Marine Fisheries Research Institute (CMFRI) and the National Bureau of Fish Genetic Resources (NBFGR) and NFDB can jointly develop a certification system on line with the standards developed by the Marine Aquarium Council (MAC). A few entrepreneurs can be trained on eco-friendly collection methods and conditioning and maintaining of harvested species in healthy condition and they can be licensed to collect suitable species from selected areas. The Marine Products Exports Development Authority (MPEDA) can take the lead to develop a marketing channel for the certified varieties. The impact of exploitation has to be closely monitored by scientific institutions at periodic intervals and required management measures have to be implemented as and when required.

Conclusion

It is well established that the long term sustainable option for developing a marine ornamental fish trade is through hatchery production. Hence the immediate way forward is commercialization of the technologies developed for the different species of clownfishes/ damselfishes by the establishment of broodbanks, and small-scale hatcheries. However, based on the current scenario of the trade it can be reasonably predicted that the percentage of wild caught marine ornamental species will continue to dominate the sector on a global basis in the near future. Based on the current technologies it is neither possible nor economically viable to hatchery produce all the species required for the trade. Hence in the long run, the hatchery production of marine ornamental species can be complementary but may not be full replacement for the collection from the wild. The wild collection sector is important and at the same time the protection of reefs due to wild collection also is vital. It also emphasizes the accurate data base needed, the eco-friendly methods to be followed and the commitment to a certified wild caught industry for sustainable trade. The attitude towards the wild caught sector and tank reared sector of aquarium industry should be mutually supportive. In the immediate future India can emerge as one of the major source countries for a sustainable marine ornamental trade if we take appropriate steps in the light of the current global scenario by formulating suitable policies for wild collection of species and also by commercial hatchery production of concerned species.

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11

Recent Advances in Post-harvest Processing and Value Addition in the Fisheries Sector

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Consumers demand high quality processed foods with minimal changes in nutritional and sensory properties. Alternative or novel processing technologies are being explored and implemented to provide safe, fresher-tasting, nutritive foods without the use of heat or chemical preservatives. Recent developments have improved techniques in handling, product development, packaging, preservation and storage. Entrepreneurs shall be benefited with a method capable of increasing the safety and shelf life of their foods.

Taking advantage of specific potentials and opportunities of these new processes, including the understanding and control of the complex process-structure-function relationships, offers the possibility for a science-based development of tailor-made foods. To consumers, the most important attributes of a food product are its sensory characteristics (e.g. texture, flavour, aroma, shape and colour). A goal of food manufacturers is to develop and employ processing technologies that retain or create desirable sensory qualities or reduce undesirable changes in food due to processing.

Sea foods are highly perishable and usually spoil faster than other muscle foods. They are more vulnerable to post-mortem texture deterioration than other meats. Freshly caught fish undergoes quality changes as a result of autolysis and bacterial activity. Extent of these changes with time determines shelf life of the product. Proper storage conditions are essential to prevent the spoilage of fish and fishery products. Many emerging technologies have the potential to extend the shelf life and are also welcomed by seafood industries globally but some are still in the research arena waiting to be worked on.

Few of the emerging technologies that have application in fish processing are High Pressure Processing, Irradiation, Pulsed light technology, Pulsed Electric Field, Microwave Processing, Radio frequency, Ultrasound and Supercritical fluid extraction. Packaging technologies like Modified Atmosphere, Active and Intelligent packaging also plays an important role in fish preservation.

High Pressure Processing (HPP)

Hydrostatic pressure technology is a novel non-thermal food processing technology in which foods are subjected to high hydrostatic pressure in the range of 1000-8000 atm (100-800 MPa), at or around room temperature. It inactivates vegetative microorganisms, spores, enzymes and increases shelf life of foods. It can also be used for texturization of food products as it denatures protein and polysaccharides. Thus it opens up unique opportunities to the food industry for the development of novel foods of superior nutritional and sensory quality, novel texture, more convenient, higher safety and increased chilled or ambient shelf life. The main benefits of HPP in fisheries include inactivation of contaminant microorganisms, texturization of proteins, shucking of oysters and improved freezing and thawing operations. It is widely accepted that conformational changes of protein by high pressure takes place which may be the reason for the extension of shelf life. In many surimi based fish products gelling is an important function and fish muscle protein paste forms a gel upon application of high hydrostatic pressure. So the application of high pressure helps to formulate a number of products with good functional properties. Studies conducted at CIFT on Indian white prawns indicate that HP treatment can improve shelf life of prawn during chill storage. However samples treated with 100 MPa are found to have marginal difference against control during storage period. Pressure treatments of 270, 435 and 600 MPa gave an extended shelf life by reducing total viable count, total Enterobacteriaceae count and inhibiting enzymes responsible for nucleotide degradation. Based on sensory attributes, 270 MPa treated sample has shown better acceptance even though it reached microbiological limit. In case of Yellow fin tuna chunks packed in EVOH (Ethylene-Vinyl Alcohol Copolymer) Pouches, control samples had a shelf life of 20 days, 100 MPa had a shelf life of 25 days and 200 MPa had a shelf life of 30 days during chill storage. Compared to 300 MPa treated samples, tuna chunks treated with 200 MPa were superior to 300 MPa in all aspects.

High Pressure Assisted Freezing

At high pressure up to 210 MPa, water can remain in liquid state down to about -22^{o}C. This allows rapid freezing and thawing. During freezing, use of high pressure helps in supercooling and promotes uniform and rapid ice nucleation throughout the sample on pressure release, producing small ice crystals which preserves the natural texture.

In high pressure assisted freezing, samples are cooled under 200 MPa to -20^{o}C without ice formation. As the pressure is released, small ice crystals are formed which prevents cellular damage compared to conventional freezing. In this, phase transition occurs under constant pressure which is higher than atmospheric pressure leading to the formation of ice crystals. Conventional freezing techniques are known to have detrimental effects on the food depending upon the methods. Slow freezing of food results in larger ice crystal formation, which may cause extensive mechanical damage, accelerated enzyme and microbiological activities, as well as potentially increased oxidation rates, resulting from the increasing substrate concentration and the insolubility of oxygen in ice. The major advantages are pressure assisted freezing (pressure-shift freezing), pressure shift thawing and possibility for storage of food under non-frozen conditions at sub-zero temperature under pressure.

Pulse Light Preservation

Pulse light technology is an emerging non-thermal processing method and involves exposure of foods to short duration pulses of intense broad spectrum light. Involves the use of intense and short duration pulses of broad spectrum “white light”, where each pulse, or flash, of light lasts a fraction of a second and the intensity of each flash is approximately 20,000 times the intensity of sunlight at sea level. The spectrum of light includes wavelengths in the ultraviolet to the near infrared region. Usually a wavelength distribution having 70% of the electromagnetic energy within the range of 170-2600 nm is used. These high intensity flashes of light pulsed several times in a second can inactivate microorganisms on food surfaces with remarkable rapidity and effectiveness. The technology can also be used to sterilize packaging material too. The material to be treated is exposed to at least one pulse light having an energy density in the range of 0.01-50 J/cm^{3} at the surface. The effectiveness of light pulse treatment depends on several factors such as intensity, treatment time, food temperature and type of microorganisms. Light pulses have the ability to inactivate enzymes in food as well. However at present, industrial implementation of light pulse technology for food has been rather slow, despite its potential to produce safe, nutritious and high quality foods. Studies conducted at McGill University, Canada show promise for pulsed light treatment for cold smoked vacuum packaged salmon to control *Listeria monocytogenes* and *Clostridium botulinum.*

Work carried out at CIFT indicates that when Pearl spot fillets were packed in polyester polythene laminate and subjected to pulse light treatment for 12 sec using Xenon pulse light equipment with a total energy of 25 J/cm^2, the samples were acceptable up to 18 days compared to 12 days in control. The chemical parameters indicated that the pulse treated sample were superior to control samples.

Pulsed Electric Field (PEF) Processing

PEF processing involves treating foods placed between electrodes by high voltage pulses in the order of 20–80 kV for a short duration (usually 10 nano second to 20 micro second). The applied high voltage results in an electric field that causes microbial inactivation. The electric field may be applied in the form of exponentially decaying, square wave, bipolar, or oscillatory pulses and at ambient, sub-ambient, or slightly above-ambient temperature. After the treatment, the food is packaged aseptically and stored under refrigeration. The pulses are so short and frequent that all of the liquid in a pipe can be treated as it flows through the treatment chamber. By using multiple treatment chambers to apply pulses to a stream of fluid, kill ratios of 5-9 log have been achieved, similar to pasteurization without any adverse impact on the taste or nutritional value of the food. PEF can be used for processing liquid and semi liquid foods and holds potential as a type of low temperature alternative pasteurization process for sterilizing food products. PEF processing offers high quality fresh-like liquid foods with excellent flavor, nutritional value, and shelf life. Since it preserves foods without using heat, foods treated this way retain their fresh aroma, taste, and appearance. Application of PEF technology has been successfully demonstrated for the pasteurization of foods, fish soups, tomato juice and liquid eggs. Application of PEF processing is restricted to food products with no air bubbles and with low electrical conductivity. PEF is a continuous processing method, which is not suitable for solid food products which are not pumpable.

Radio Frequency Thawing

Radio frequency thawing is similar to microwave ovens where fish products passing through the oven (heater), are subjected to a direct or volumetric heating process in the form of a radio frequency (RF) energy source. The RF heating process depends upon the ionic conductivity of the material being heated.

Radio frequency thawing systems are also available, where the frozen product is placed between two parallel electrodes and alternating radio frequency energy is applied to the electrodes. Temperature rise within the product is relatively uniform, the degree of uniformity being dependent on the size and composition of the product. It is suggested that 5 cm blocks of fish can be thawed rapidly. However, radio frequency treatments have more promising attributes for processing seafood. At the lower frequencies of RF, penetration of the RF energy into foods is much greater and enables the temperature of blocks to increase from –20°C to –2 or 0°C. Radio frequency systems are available in both batch and continuous methods. Batch RF systems operate from 40 to 350 kg/hour while continuous RF systems can operate from 900 to 3000 kg/hour.

Ultrasound Preservation

Ultrasound is probably the most simple and most versatile method for the disruption of cells and for the production of extracts. It is efficient safe and reliable. Ultrasound techniques are relatively low cost and robust process. Ultrasound cavitation creates shear forces that break cell walls mechanically and improves material transfer. This effect is being used in the extraction of liquid compounds from solid cells. The compound to be dissolved into a solvent is enclosed in an insoluble structure. In order to extract it, the cell membrane must be destructed. For the purpose, ultrasound is faster and more complete than maceration or stirring. The particle size reduction by the ultrasonic cavitation increases the surface area in contact between the solid and liquid phase, significantly. The mechanical activity of this technique enhances the diffusion of the solvent into the tissue; Ultrasound breaks the cell wall mechanically by the cavitation shear forces and it facilitate the transfer from the cell into the solvent. This technique has potential advantages over other techniques including freedom from radiation hazards, which may appear in some of the existing non-destructive methods. The presence of the small gas bubbles in the sample can greatly attenuate ultrasound making signal detection impossible. This can be solved by using reflection measurements rather than transmission measurement.

Supercritical Fluid Extraction (SFE)

Supercritical carbon dioxide is a fluid state of carbon dioxide where it is held at or above its critical temperature and critical pressure. Carbon dioxide usually behaves as a gas in air at STP or as a solid called dry ice when frozen. If the temperature and pressure are both increased from STP to be at or above the critical point for carbon dioxide, it can adopt properties midway between a gas and a liquid. It behaves as a supercritical fluid above its critical temperature (31.1°C) and critical pressure (72.9 atm/7.39 MPa), expanding to fill its container like a gas but with a density like that of a liquid. Supercritical CO_2 is becoming an important commercial and industrial solvent due to its role in chemical extraction in addition to its low toxicity and environmental impact. The relatively low temperature of the process and the stability of CO_2 also allow most compounds to be extracted with little damage or denaturing. The use of supercritical fluids as an extraction media provides a powerful alternative to traditional chemical extraction methods. SFE is relatively cheap, nontoxic, and nonflammable with zero ozone-depletion potential. Well known processes such as the decaffeination of coffee, or the fractionation of hops for the flavoring of beer, have been abetted by more recent processes producing an array of food-related products. These products have included spice and flavor extracts, defatted or reduced-cholesterol products, natural antioxidants, and specialized oil-derived products for the nutritional market. However, the research works done on the application of SFE in processing fish and fish products are relatively scanty. The future appears bright for further extension of the critical fluid technology platform towards the processing of fish and fishery products for the health food, and nutraceutical markets. Some additional benefits can occur when using high pressure carbon dioxide or water for processing seafood products, such as the deactivation of harmful microbes or enzymes, allowing sterilization or stabilization of the resultant end products, without resorting to the extreme temperatures and pressures required in ultra-high pressure seafood processing. CIFT has developed chemical techniques for the production of nutraceuticals from seafoods. Chemical processes involved in preparation of fish products are highly expensive in terms of chemicals and man power. Hence, an alternative technique such as SFE may be effective in the preparation of these products. Investigations by CIFT in collaboration with the private industry indicate that Supercritical Fluid Extraction is an effective method for extraction of fish oil rich in EPA and DHA.

Irradiation

Irradiation is a physical treatment that consists of exposing foods to the direct action of electronic, electromagnetic rays to assure the innocuity of foods and to prolong the shelf life. Irradiation of food can control insect infestation, reduce the numbers of pathogenic or spoilage microorganisms, and delay or eliminate natural biological processes such as ripening, germination, or sprouting in fresh food. Like all preservation methods, irradiation should supplement rather than replace good food hygiene, handling, and preparation practices.

Three types of ionizing radiation are used in commercial radiation to process products such as foods and medical and pharmaceutical devices (International Atomic Energy Agency): radiation from high-energy gamma rays, X-rays, and accelerated electrons.

- Gamma rays, which are produced by radioactive substances (called radioisotopes). The approved sources of gamma rays for food irradiation are the radionuclides cobalt-60 (^{60}Co; the most common) and cesium-137 (^{137}Cs). They contain energy levels of 1.17 and 1.33 MeV (^{60}Co) and 0.662 MeV (^{137}Cs).
- Electron beams, which are produced in accelerators, such as in a linear accelerator (linac) or a Van de Graaff generator at nearly the speed of light. Maximum quantum energy is not to exceed 10 MeV.
- X-rays or decelerating rays, which can be likewise produced in accelerators. Maximum quantum energy of the electrons is not to exceed 5 MeV

Different forms of irradiation treatment are *raduarization* (for shelf life extension), *radicidation* (for elimination of target pathogens) and *radappertization* (for sterilization). Irradiation of packaging materials - in most cases like plastics, generally leads to the formation of free radicals and ions, which eventually result either in cross-linking or in chain scission. The latter leads to the release of volatile radiolysis products that may induce off-odours in the polymers, thereby altering the migration characteristics of packaging materials. Irradiation also affects polymer additives, which change the specific migration behaviour of polymer additives and additive-related decomposition products. Both migration and sensory changes of packaging materials strongly affect the quality of packaged goods and consumer safety. Radiation processing is widely used for medical product sterilization and food irradiation. Moreover, the use of irradiation has become a standard treatment to sterilize packages in aseptic processing of foods and pharmaceuticals. Nowadays, packaging consists of natural or synthetic plastics; therefore, the effect of irradiation on these materials is crucial for packaging engineering.

Irradiation produces some chemical changes, which, although lethal to foodborne bacteria, do not affect the nutritional quality of the food but lead to the production of small amounts of radiolytic products. Gamma irradiation has been considered as an interesting method of preservation to extend the shelf life of fish and also to reduce qualitatively and quantitatively the microbial population in fish and fish products. Irradiation doses of 2–7 kGy can reduce important food pathogens such as *Salmonella*, *Listeria*, and *Vibrio* spp., as well as many fish-specific spoilers belonging to Pseudomonaceae and Enterobacteriaceae that can be significantly decreased in number. Studies on 4-day-old frozen tuna loins (*Thunnus obesus*) packed in polyethylene PE bags and irradiated by an X-ray machine at a dose of 2.2 kGy, revealed the non-irradiated control samples to be acceptable up to 15 days in comparison to 25 days observed for the irradiated samples.

Modified Atmospheric Packaging (MAP)

Modified atmosphere packaging (MAP) extends shelf-life of most fishery products by inhibiting bacterial growth and oxidative reactions. The achievable extension of shelf-life depends on species, fat content, initial microbial population, gas mixture, the ratio of gas volume to product volume, and most importantly, storage temperature. Modified atmospheric packaging is a process by which the shelf life of fish is increased by enclosing it in an atmosphere so modified that it slows down the degradation by microorganisms and development of oxidative rancidity. In practice fish/fish products are packed in an atmosphere of carbon dioxide and other gases like oxygen and nitrogen. MAP chilled fish has an extended shelf life of 10 days or more depending on the species. Packaging of fishery products under modified atmospheres increases shelf-life compared with those packaged under air, but confers little or no additional shelf-life increase compared with vacuum packaging.

However, the single most important concern with the use of modified atmosphere and Vacuum packed products is the potential for the outgrowth and toxin production by the non-proteolytic, *Clostridium botulinum* type *E* which can grow at low temperatures. In addition to this, pack collapse, increased exudates/drip loss, discoloration, and histamine production are major potential problems during the storage of fish and shellfish products in MAP.

Active Packaging

Active packaging is defined as a system of packaging that changes the condition of the package to extend the shelf life or to improve the safety or sensory properties while maintaining quality of foods. These systems can be classified into active scavenging systems (absorbers) and active releasing systems (emitters). Scavenging systems remove undesirable compounds such as oxygen, excessive water, ethylene, carbon dioxide, taints and other specific food compounds. Releasing systems actively add compounds to the packaged food such as carbon dioxide, water, antioxidants or preservatives. Most important active packaging concepts includes: O_2- and ethylene-scavenging, CO_2-scavengers and emitters, moisture regulators, anti-microbial packaging, antioxidant release, release or adsorption of flavours and odours.

Oxygen-scavenging is mainly used to prevent oxidative reactions, discolouration and mould growth. Different Oxygen scavengers are chosen dependent on the amount of Oxygen to scavenge (pack size and material) and product water activity. Oxygen scavengers for high water activity foods react faster compared to scavengers for dry foods but in general the absorption is slow and exothermic. In work carried out at CIFT using O_2-scavenger a shelf life extension of 10 days was achieved for catfish (*Pangasius sutchi*) steaks packed in EVOH pouches in chilled conditions.

Microwave Processing

Microwave heating of foods is attractive due to its instantaneous and rapid increase in temperature, controllable heat transmission, and easy clean-up opportunities. It is currently being used for a variety of domestic and industrial food processing applications.

The permitted microwave frequencies are 915, 2450, 5800 MHz. The dielectric properties of these materials are important in the design of electrical and electronics equipment and various techniques for measuring the dielectric properties of different applications have been developed. The largest use of industrial microwave processing of food has been for tempering of meat for further processing. .Microwave tempering is defined as taking a product from freezer temperature to a condition (between -4 to -2°C) in which the product is not frozen but is still firm. Tempering at low temperatures results in minimal quality deterioration and can help in saving energy. Frozen blocks of meat at -18°C are to be cut or separated into individual pieces. Conventional tempering techniques take a lot of time with considerable drip loss resulting in loss of protein and quality and economic loss. Microwaves can easily penetrate the whole frozen product, thus effectively reaching the inner regions within a short time. The microwave tempering can be performed in few minutes for a large amount of frozen products (5–10 min for 20–40 kg).). Microwaves are easily absorbed by the meat, its intensity is reduced by the penetration depth. Surface layers retain more energy and heat up faster compared to the inner regions of the product. The lower frequency (915 MHz band) has an advantage for tempering of thick products because of its deeper penetration and longer wavelength compared to the higher frequency (2450 MHz) microwave. Currently, most food industries use microwave at 915 MHz for tempering purposes. Precooking of bacon is the second-largest application of microwave heating in the food industry. Microwave heating is found to be an ideal system for cooking bacon compared to conventional grilling. The third largest application of microwave processing is in sausage cooking. The quality of the sausage patty is improved along with better yield by using the microwave process. In sausage cooking also, microwave processing is used to reduce drip loss, fat, nutrients, and flavour. Microwaveable foods in suitable packaging materials are being developed by food processers to meet the growing demand. These convenience foods are microwaveable for use at home and away. High-density polypropylene (HDPP) is a suitable for microwave process over other materials since it can withstand the high temperature.

Intelligent Packaging

Intelligent packaging, sometimes referred as smart packaging, senses some properties of the food it encloses or the environment in which it is kept and informs the manufacturer, retailer and consumer of the state of these properties. Although it is distinctly different from the active packaging concept, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems. Intelligent packaging has been defined as ‘packaging systems which monitor the condition of packaged foods to provide information about the quality of the packaged food during transport and storage

- Time temperature indicators
- Leakage indicator
- Freshness indicator

Active and intelligent packaging systems contribute to the improvement of food safety and extend the shelf-life of the packaged foods. However these are evolving technologies in the seafood area and many of these systems are in the developmental stage. Continued innovations in active and intelligent packaging are expected to lead to further improvements in food quality, safety and stability.

Value Addition in Fisheries

Value addition is the most talked about word in food processing industry, particularly in export oriented fish processing industry because of the increased realisation of valuable foreign exchange. Value addition means “any additional activity that in one way or another changes the nature of a product, adding to its value at the time of sale”. Value can be added to fish and fishery products according to the requirements of different markets. These products range from live fish and shellfish to ready to serve convenience products. There is a great demand for seafood / seafood based products in ready to eat “convenience” forms. A number of such diverse products are already available in the western markets. One of the factors responsible for such a situation is more and more women getting educated and taking up employment and not having much time for traditional cooking. Reasonably good expendable income, education, awareness and consciousness towards hygiene and health, increased emphasis on leisure pursuits, etc. are some of the other reasons.

During the financial year 2014-15, exports of marine products reached an all-time high of USD 5511.12 million. Marine product exports crossed all previous records in quantity, rupee value and USD terms. Exports aggregated to 10,51,243 MT valued at Rs. 33,441.61 crore and USD 5511.12 million. Marketing of value added products is completely different from the traditional seafood trade. It is dynamic, sensitive, complex and very expensive. Market surveys, packaging and advertising are a few of the very important areas, which ultimately determine the successful movement of a new product. Most of the market channels currently used are not suitable to trade value added products. A new appropriate channel would be the super market chains which want to procure directly from the source of supply. Appearance, packaging and display are all important factors leading to successful marketing of any new value added product. The retail pack must be clean, crisp and clear and make the contents appear attractive to the consumer. The consumer must be given confidence to experiment with a new product launched in the market. Packaging requirements change with product form, target group, market area, species used and so on. The latest packaging must also keep abreast with the latest technology.

Chilled Fish

Chilling is an effective way of reducing spoilage by cooling the fish as quickly as possible without freezing. Immediate chilling of fish ensures high quality products. Chilled fish is another important value added item of international trade. Chilled fish fetches more price than frozen fish. Indian major carps like, catla, mrigal and rohu are packed in boxes in iced condition and exported. From Andhra Pradesh different species of fish is packed in boxes, transported to Calcutta and other major cities in trucks or by rail in chilled condition. It is generally accepted that some tropical fish species can keep for longer periods in comparison to fish from temperate or colder waters. Up to 35% yield of high value products can be expected from fish processed within 5 days of storage in ice, after which a progressive decrease in the utility was observed with increase in storage days.

Vacuum Packaging

Vacuum packaging is widely used in the food industry because of its effectiveness in reducing oxidative reactions in the product at relatively low cost. This method of packaging can be a supplement to ice or refrigeration to delay spoilage, extend the shelf life, maintain a high quality, assure the safety and reduce economic loss of fish and fishery products. In vacuum packaging air inside the pack is removed completely and sealed immediately. This helps in reducing the oxidation in fatty foods and also reduces the growth of aerobic micro organisms thereby extending the shelf life considerably.

Frozen Fish Fillets

Freezing and storage of whole fish, gutted fish, fillets etc. are methods for long-term preservation of some species. Fillets of many varieties of fresh water fishes like rainbow trout, catla, rohu, tilapia can be frozen for domestic market and exported to developed countries in block frozen and IQF forms. In the importing countries these fillets are mainly used for conversion into coated products. Fish fillets can also be used for the production of ready to serve value added products such as fish in sauce and fish salads.

Individually Quick Frozen (IQF) Products

IQF products fetch better price than conventional block frozen products. However, for the production of IQF products raw-materials of very high quality needs to be used, as also the processing has to be carried out under strict hygienic conditions. The products have to be packed in attractive moisture-proof containers and stored at -30°C or below without fluctuation in storage temperature. Thermoform moulded trays have become accepted containers for IQF products in western countries. Utmost care is needed during the transportation of IQF products, as rise in temperature may cause surface melting of the individual pieces causing them to stick together forming lumps. Desiccation leading to weight loss and surface dehydration are other serious problems met with during storage of IQF products.

Some of the IQF products in demand are the following: Prawn – whole, peeled and deveined, cooked, headless shell-on, butterfly fan tail round. Fish fillets – fillets of rohu, tilapia, catla, trout and catfish

Battered and Breaded Products

The most prominent among the group of value added products is the battered and breaded products processed out of a variety of fish and shellfish. Battered and breaded seafood offers a convenience food valued widely by the consumer. Battered and breaded items are included in the value added products because the process of coating with batter and bread crumbs increases the bulk of the product thereby reducing the cost element. The pick-up of coating on any product can be increased either by adjusting the viscosity of batter or by repeating the process of battering and breading. As a convention

50% fish portion is expected in any coated product. The present day production of coated seafood items involve fully automated batter and breading lines which start from portioning and end with appropriate packaging of the product. Recent innovation in the production of coated product involves the elimination of pre-frying step which significantly reduce the oil uptake and fat content of the product.

Ready to Serve Fish Products in Retortable Pouch

Ready to serve fish products viz. curry products, in retortable pouches are a recent innovation in ready to serve fish products for local market. The most common retortable pouch consists of a 3-ply laminated material. Generally it is polyester/ aluminium/cast polypropylene. Some of the products are rohu curry, prawn curry, Mahseer fish curry, prawn korma and prawn Manchurian. These products have a shelf life of more than one year at room temperature. As there is increasing demand in national and international market for ready to serve products the retort pouch technology will have a good future. The technology for retort pouch processing of several varieties of ready to serve fish and fish products has been standardised at CIFT and this technology has been transferred successfully to four entrepreneurs in the country. The demand for these products is very good.

Extruded Products

Extrusion is a process which combines shear, pressure and temperature leading to molecular transformations in the constituents and involves denaturation of the proteins, fragmentation of the starch molecules and changes in the non-covalent bonds between proteins, lipids and carbohydrate. Fish based extruded products have very good mark potential. Formulation of appropriate types of products using fish mince, starches etc, attractive packaging for the products and market studies are needed for the popularization of such products. However, technological studies involving use of indigenously available starches like cassava starch, potato starch, corn starch and the associated problems need thorough investigation. Such products can command very high market potential particularly among the urban elite. The technology can be employed for profitable utilization of by catch and low value fish besides generating ample employment opportunities. CIFT has worked on the production of extruded products by incorporating fish mince and prawn mince with cereal flours (Fig.1).

Fig.1. "TUNA KURE"- An Extruded fish mince based snack

Emerging Products

Restructured products offer a scope for developing new products that have different textures and can also contain functional ingredients. Restructuring process allows to obtain products with high commercial value from different sources: non-commercial fish species, fishes of smaller size than commercial species (such as those caught as shrimp by-catch), and trimmings from filleting of commercial fish species. Different proteins have been used as binding agents or as additive to improve mechanical and functional properties of fish products, e.g. egg white, casein and beef plasma-thrombin casein, whey protein concentrate (WPC) and microbial transglutaminase (MTGase). Some additives such hydrocolloids have been proposed to improve mechanical and functional properties of surimi and restructured fish gels. Food hydrocolloids could modify the gelling capacity of salt to solubilise myofibrillar proteins.

Considerable interest has recently been focused on the addition of natural antioxidants and antimicrobials to foods to replace synthetic compounds, due to their potential to prolong the shelf life of food products by inhibiting and delaying lipid oxidation and microbial growth. Seafoods are highly perishable. Seafoods contain high concentrations of polyunsaturated fatty acids (PUFA) because of this high unsaturated lipid content, fish products are very susceptible to loss of quality through lipid oxidation; the development of off-flavours and rancidity in these products is the main stumbling-block in their production and commercialization.

Fishery By-products

Fishery by-products are generated during processing and comprise of heads, viscera, trimmings, skin, scales, bones & cartilage, fins, eggs, shells etc. These are upgraded into two major product categories viz., for mass exploitation and small volume exploitation for high value products. The former category includes fertilizers, feed, oil & industrial products and the latter consist of health foods, functional foods, nutraceuticals, etc. In India, the traditional fishery by-products viz. fish meal, oil, chitin & chitosan are bulk produced for large scale usage. Recent innovations in fishery by-products include the development of high value products viz., gelatin & collagen peptide from skin & scales, hydroxyapatite from fish scales, calcium from fish bones (Fig. 2), glucosamine hydrochloride from chitin, etc. The technologies for commercial production of these products are being fine-tuned and there will be a wealth of opportunities in this sector for entrepreneurs.

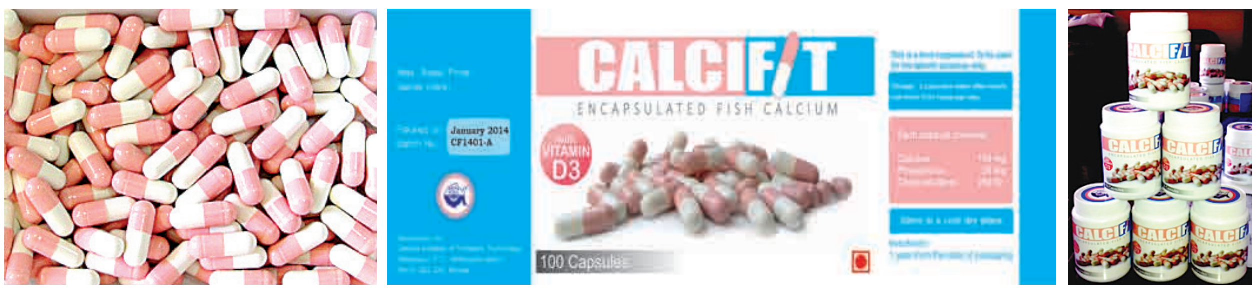

Fig. 2. "CALCIFIT" – Fish calcium capsules developed by CIFT

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