100 Years of

AGRICULTURAL SCIENCES IN INDIA

Editor
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New Delhi

100 *Years of* | AGRICULTURAL SCIENCES IN INDIA

This book is a science roadmap for food and agriculture system to render India hunger free, more equitable, prosperous and evergreen. Underpinning the centrality of agriculture in achieving comprehensive and sustained livelihood security in India, it is envisioned that science and technology couched in effective policy regimes will render India zero hunger and less unequal. Internalizing these profound pronouncements, the book is a saga of generation, growth, development and application of agricultural sciences, technologies and innovations during the past 100 years for dynamically transforming Indian Agriculture towards meeting the changing societal needs and priorities and to address ever-evolving and intensifying challenges of comprehensive food, nutrition, ecological and livelihood security.

The eight chapters of the book: Crop Sciences, Horticultural Sciences, Animal Sciences, Fisheries Sciences, Natural Resource Management Sciences, Plant Protection Sciences, Agricultural Engineering and Energy, and Social Sciences, give a lucid account of science-led ushering in of the Green (crops), Golden (horticulture), White (milk), and Blue (fisheries) Revolutions. The major scientific breakthroughs have been highlighted in the areas of genetics, genetic improvement and genetic resources of crops, livestock and fisheries; physiology and biochemistry; molecular biology, biotechnology and 'omics'; conservation and productivity of soil and water, and ecosystems management; pests and diseases, biotic and abiotic stress management; prevention of losses, value-addition and farmer-market linkage; mechanization and energy; and climate smart agriculture. Each chapter has analysed the gaps critically and suggested research priorities, well-thought-out paths and ways forward to develop science-informed policy options and actions to meet challenges.

It is hoped that the comprehension of the experiences of the past one century, detailed in the book, will be an inspiration and important resource not only for agricultural science students, scientists and academicians, but also for all stakeholders and partners, science managers, policy makers and farmers to capture new uncommon opportunities to meet complex challenges of developing an evergreen agriculture for green economy.

Foreword by: S. Ayyappan, President, NAAS, New Delhi

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CHAPTER 4

Fisheries Sciences

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Historical Perspective and Research Trends

The history of fisheries research in India goes back to the early 19th century, when dried or preserved material was sent to the Museums of Natural History in England and other European countries for identification and cataloguing (Silas, 2003). Some of the earliest scientific observations on fisheries in pre-independent India were the works of Francis Hamilton-Buchanan (1822) and Francis Day, whose initial work on 'The Fishes of Malabar' (1865), was followed by a monograph on 'The Fishes of India' (1875-78); and two more volumes on 'Fishes' in 'The Fauna of British India, including Ceylon and Burma' (1889).

The enactment of Indian Fisheries Act of 1897 was a major landmark in the development of fisheries in pre-independent India. In the latter half of 19th century, emphasis on coastal and deep-water surveys in the Bay of Bengal and Andaman Sea led to possession of valuable information on new deepwater fauna of fishes and crustaceans, hydrology and plankton. The initial work by the Zoological Survey of India on fisheries and marine biology through eminent leadership of its Directors, viz. Nelsen Annandale, Stanley Kemp, Seymour Sewell, Baini Prasad and S. L. Hora during first half of the 20th century led to generation of several first hand information on the taxonomy, bionomics, eco-biology, hydrology, and fish and fisheries of upland lakes, rivers and coastal waters. The emphasis shifted from coastal and deep-water surveys in the Bay of Bengal and Andaman Sea to upland lakes, rivers and coastal waters in the beginning of the 20th century. With the establishment of the Bureau of Fisheries in 1907, the Madras Presidency became the pioneer for fisheries development in India. Establishment of the Marine Biological Station at Krusadai Island in 1924 and subsequently at West Hill and Ennore led to organized research programmes on pearl and chank fisheries in the Gulf of Mannar.

The realization of the necessity of strengthening research in different aspects covering all sectors led to establishment of several specialised fisheries research institutions during the post independence period. The Central Marine Fisheries Research Station (renamed the Central Marine Fisheries Research Institute (CMFRI)) was established in 1947 at Madras University, which subsequently shifted to Mandapam Camp, Tamil Nadu in 1949 and in 1972 to Cochin. The Central Inland Fisheries Research Station was set up in 1947, elevated to the status of an Institute in 1959 and renamed as the Central Inland Fisheries Research Institute (CIFRI). In 1949, CIFRI established the Pond Culture Unit at Cuttack.

In 1977, CIFRI, in collaboration with the FAO, established the Freshwater Aquaculture Research and Training Centre (FARTC) at Kausalyaganga (Bhubaneswar) and merged the Pond Culture Division. The FARTC was given the status of an independent institute, the Central Institute of Freshwater Aquaculture (CIFA), in 1987. The Central Institute of Fisheries Education (CIFE), Mumbai (1961); Central Institute of Fisheries Technology (CIFT), Kochi (1967); National Bureau of Fish Genetics Resources (NBFGR), Lucknow (1983); Central Institute of Brackishwater Aquaculture (CIBA), Chennai and National Research Centre in Coldwater Fisheries Research, Haldwani (presently Directorate of Coldwater Fisheries Research (DCFR), Bhimtal (1987) are the other Fisheries Research Institutes under the Indian Council of Agricultural Research. In addition, several other institutions such as the Fishery Survey of India (FSI), Central Institute of Fisheries on Nautical and Engineering Training (CIFNET), Integrated Fisheries Project (IFP), presently National Institute of Fisheries on Post Harvest Technology and Training (NIFPHATT), Kochi, under the administrative control of the Government of India; in addition to the Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavanagar and the National Institute of Oceanography (NIO), Goa, under the Council of Scientific and Industrial Research (CSIR); and, the Centre for Marine Living Resources and Ecology (CMLRE) and Rajiv Gandhi Centre for Aquaculture (RGCA), under the Ministry of Commerce, Government of India; besides the State and Central Agricultural Universities (SAUs and CAUs) as well as the traditional universities, both State and Central, have also been contributing to the fisheries research in the country.

Six decades of Independent India have seen the fisheries sector to evolve from primarily being capture-based to one having almost equal contributions from aquaculture and capture fisheries. Indian fisheries now occupy second position in global fish production with an annual growth rate of 4.7% (3.2% in marine fisheries and 6.2% in the inland sector), thereby contributing 1.1% of the total GDP and 5.3% of the agricultural GDP of the nation (Ayyappan *et al*., 2011).

Initial research efforts in post-independence India were largely confined to study on biology of commercially important species, both in inland and marine waters, which included food and feeding habits, age and growth, migration and aspects of reproduction; productivity of natural ecosystems; biodiversity; data generation pertaining to fish catches in different systems; exploratory surveys and stock assessment; mapping of productive fishing grounds; and environmental studies relating to fisheries. As increase in production from the marine waters was the main focus, improvement of harvest technologies received greater importance, which included improvement and modernization of boats - motorization of traditional fishing crafts and mechanization of propulsion; introduction of different fishing gears; use of synthetic gear materials; acoustic fish detection and satellite-based remote sensing techniques. Studies on ocean current pattern on fisheries, primary and secondary productivity, nutrient cycling and other ecological studies also received adequate attention. Considering the fact that the fish catch in coastal zone up to 50 m depth reached almost potential level, studies on resource assessment (finfishes and shellfishes) in oceanic and deep sea waters and their exploitation received greater attention in recent past.

Researches on stock enhancement through provision of fish aggregation devices (FADs) and sea ranching have been some of the recent attempts. These multidimensional research efforts over these years have been instrumental in providing knowledge base, not only towards achieving steady increase in production, but also for management of these complex multi-species and multi-gear fishery resource. Aspects of impact of climate change on fisheries, disaster management, ecosystem modeling and forecasting etc., in recent past, have also received due importance among the researchers.

The post-independence period also witnessed parallel studies in different inland waters, viz. rivers, estuaries, lakes, reservoirs and wetlands, on different aspects of fisheries and ecosystem dynamics including impact of pollution, water abstraction, entry of exotics, biodiversity loss, habitat degradation etc. Adequate research thrust was also given on study in upland coldwater resources and effective management of species like mahseers, trouts and other coldwater species as approach towards sustainable management of these fragile ecosystems and sport fisheries development. Scientific management interventions through culture based fisheries in small and medium sized reservoirs have resulted improved yields of 100-300 kg/ha in different reservoirs across the country. Research outputs in cage and pen culture could provide feasible approach for ensuring *in situ* production of fingerlings/juveniles of desired species for reservoir stocking.

Increased fish demand in the country led to early realization of the necessity of pond aquaculture to complement the capture fisheries production. In this endeavour the ‘Pond Culture Division’ at Cuttack took the lead in conducting research on different aspects of freshwater aquaculture. Development of induced breeding techniques; introduction of exotic carps, viz. silver carp, grass carp and common carp into the carp polyculture system; development of different hatchery systems for mass-scale seed production; technology of nursery rearing and fingerlings production; and technology of carp polyculture are some of the epoch-making technologies developed during 1950s to 1970s, which practically led to the freshwater aquaculture development in India. Subsequently, research on development of hormone formulations; breeding and mass-scale seed production of commercially important catfishes, medium and minor carps, freshwater prawn and other commercially-important species; management of nutrient status of pond soil and water quality parameters including fertilization; management of nutrition and feed development for different culture species for varied life stages; fish genetics including hybridization and selective breeding for growth improvement and disease resistance; and fish health management including disease diagnosis and control measures, development of diagnostic kits and therapeutic/prophylactic formulations, and disease surveillance led freshwater aquaculture to a greater fillip. Recently considerable thrust has also been given on the areas of water budgeting for different culture systems and hatcheries operations, and development of tools and gadgets, as an approach towards farm mechanization.

Research on intensification and system diversification led to development of host of technologies with varied production potential, which could be adopted by the farmers and entrepreneurs of the country depending on their investment capacity and resource possession. Packages of practices pertaining to the development of culture systems like sewage-fed fish culture, integrated farming, cage culture and flow-through culture made the freshwater aquaculture an accepted practice in different parts of the country. Higher market demand, consumer preference and economic advantages for certain catfishes, few other commercially-important finfishes and freshwater prawns received adequate attention by researchers for development of packages of practices for their culture.

It was only during 1970s that the research on brackishwater aquaculture received due attention. Although initiation of All India Coordinated Project on Brackishwater Fish Farming by ICAR in 1973 intended for development of technologies for both finfishes and shellfishes, subsequent research programmes pertaining to the sector largely confined around shrimps by virtue of its excellent export value and greater demand of the industry. Hatchery production of shrimp seed of *Penaeus monodon* and *Fenneropenaeus indicus* and development of semi-intensive farming technology with packages of practices of water management, aeration, supplementary feeding, waste disposal and disease management took the centre stage of research. With the white spot syndrome virus resulting huge production loss, significant attention in last two decades has been on its control and management. Introduction of another exotic shrimp species, *Litopenaeus vannamei* in recent years has gained higher attention by the industry, as a substitute of *P. monodon,* due to higher production potential and availability of SPF broodstocks. Although there have been considerable research efforts on development of technology of breeding and farming of several commercially important finfish species over the years, recent success in development of technology of breeding, seed production and grow-out farming of seabass has provided an opportunity for its commercial farming in coming years. High export prices of crabs have made fattening of species like *Scylla serrata* a remunerative farming practice.

With technologies developed for mariculture of mussels, oysters, pearl oyster, seaweeds and more recently the cage culture of marine finfishes and shellfishes, these are providing additional avenues for utilization of coastal resources and gainful employment of fishers. Demonstration of research success of sea cage culture of seabass, groupers, snappers and cobia in recent years has provided greater hope for selective intensification and scaling up of these culture systems leading to substantial increase in the production of marine fish.

Although traditional methods of fish preservation like drying, salting and smoking were in vogue in coastal areas, in order to enhance the keeping quality and maintain hygiene, intensified scientific dimensions were given to all these preservation methods. Further, technologies of freezing and canning were perfected for high valued species for prolonged preservation and higher value realization. Thrust was also given to develop battered and breaded products from low-valued species, ready-to-cook and ready-to-eat fish products. Several industrial products, viz. fishmeal and oil; chitin and chitosan from the exoskeleton of shrimp, lobster, crab or squilla; shark fin rays; fish maws from fish bladder; etc. were developed from low-valued fishes or other fisheries byproducts. Substantial efforts were also made on development of technology of packaging and improvements in processing machinery.

The basic study on fish physiology, largely confined to different universities, provided valuable information on different physiological processes and endocrine regulation essential for reproduction that helped in developing breeding protocols for several finfish and shellfish species; understanding the osmoregulatory mechanisms, especially in migratory species; excretory mechanism; and digestion and absorption process giving cues to develop artificial feed for different life stages of fish and shellfish species. Studies on pollution of water bodies, bioassay trials with different pesticides and other toxicants, bioremediation, and several other fundamental aspects also received significant attention. Of late, biotechnology received greater focus by the researchers all over the country, which aimed at development and use of biotechnological tools for enhancing productivity including genetic engineering and transgenics, cell line development, development of vaccines, cryopreservation of fish gametes, biofertilization, stem-cell culture, genomics, surrogate fish development, etc.; improvement of product quality and safety; and management of genetic diversity and conservation including development of molecular markers for understanding genetic variation, DNA barcoding, etc.

Although the necessity of fisheries extension for dissemination of technological knowhow pertaining to fisheries and aquaculture was realized since the beginning, the importance of research in other aspects of social sciences was realized much later. However, over the years, substantial information has been generated on different aspects, viz. economic evaluation of the technologies, research on market and trade, fisheries co-operatives, gender issues, fisheries policy and legislation, information and communication, etc., which have played significant role in development of fisheries in the country.

The text description given hereunder is an attempt to outline the important research programmes undertaken on different aspects of fisheries and aquaculture, and the significant achievements those helped to make the fisheries a vibrant agricultural sector in the country.

Fish Biodiversity

Fish occupy an important position in the context of aquatic biodiversity. Blessed with rich and diverse natural water resources and ranking ninth in terms of mega-biodiversity (Mittermeier and Mittermeier, 1997), India harbours 2,508 finfishes, including 877 freshwater species, 113 brackishwater species and 1,518 marine species, besides 291 exotic species (NBFGR, 2012). In addition, 2,934 species of crustaceans (2,430 marine and 504 freshwater species), about 5,070 species of molluscs (3,370 marine and 1,700 freshwater) and 844 species of seaweeds also contribute to aquatic germplasm resources of the country.

Studies on fish diversity in the country started in the early nineteenth century (Hamilton-Buchanan, 1822), with notable contributions on distribution and taxonomic status of fishes in India in the last century (Hornell, 1914; Hora, 1921, 1923, 1934, 1937, 1942; Pillay, 1929; Jayaram, 1981; Talwar and Jhingran, 1991; Kowtal, 1994; Ponniah and Gopalakrishnan, 2000; Payne *et al*., 2004; Sarkar *et al*., 2012).). The River Ganga harbours about 250 fish species, of which 150 are freshwater ones and in a study carried out from 2007-09 in the river Ganga, 143 species were recorded, of which 29 are listed under threatened category (Sarkar *et al*., 2012). Rich species diversity has also been observed in several other important rivers, viz., Brahmaputra (167 species), Mahanadi (99), Cauvery (90), Narmada (95) and Tapti (57), several of which are common to different river systems. During a prolonged study period from 1987 to 2000, Biswas and Sugunan (2008) reported rich fish biodiversity of 151 species from Brahmaputra river system in Asom. Viswanath *et al*. (2007) reported as many as 296 species belonging to 110 genera and 35 families from North-East, much higher than 172 species reported by Ghosh and Lipton (1998) and 266 species by Sen (2000). Information on fish biodiversity, endemism, threatened status of different species and the associated risk factors in all important water bodies has enabled habitat-specific conservation strategies. Consolidated lists of 287 freshwater fishes of the Western Ghats showed as many as 192 endemic species (67% endemicity), of which 47 species have aquaculture potential (Gopalakrishnan and Ponniah, 2000).

Study on biodiversity being directly linked to sound knowledge on taxonomy and considering the fact that the country known to possess the large number of endemic fish species, it is imperative that this science receives its due importance. Despite the important role biodiversity plays in our lives, all species that together comprise biodiversity face risk and it is important to differentiate between different types of risks to biodiversity. The threats could be man-made or natural, or in combination with cascading and interlinked impacts. Pollution, increased sedimentation, flow alteration and water diversion, over-exploitation and introduction of exotics are identified as the main causes for reduced ichthyo-faunal diversity (Sivakami *et al*., 2003; Nguyen and De Silva, 2006; Singh and Lakra, 2011). Besides measures on ecosystem restoration, reduction of anthropogenic stressors and increased efforts on *in situ* conservation, several *ex situ* conservation approaches *viz*., establishment of live gene banks, stock-specific ranching of threatened species and cryopreservation of gametes, and above all controlled breeding of regionally-important endemic species and bringing them into the fold of aquaculture, have been suggested as practical and viable approaches towards management of the fish biodiversity. Information on fish biodiversity, endemism, threatened status of different species and the associated risk factors in all important water bodies would also be required for drawing habitat-specific conservation strategies.

Marine Fisheries

A coastline of 8,129 km with 0.53 million km^2 of continental shelf and 2.02 million km^2 of Exclusive Economic Zone (EEZ) has played a pivotal role in meeting the demand of fish over the years. About one million people work directly in this sector, producing 3.34 million metric tonnes (mmt) annually (Vivekanandan and Mohamed, 2009). It is a multi-species, multi-gear and multi-seasonal fishery, which is exploited through an open-access regime. Important marine fisheries resources of the country are: (i) pelagic resources [oil sardine (*Sardinella longiceps*), mackerel (*Rastrelliger kanagurta*), seerfishes (*Scomberomorus* spp.), tunas (*Euthynnus affinis, Katsuwonus pelamis, Sarda orientalis, Thunnus* spp., *Auxis* spp.), lesser sardines (*Sardinella* spp.) and anchovies (*Coilia* spp., *Setipinna* spp., *Stolephorus* spp., *Thryssa* spp.)]; (ii) demersal resources [perches (*Epinephelus* spp., *Lutjanus* spp., *Nemipterus* spp., etc.), sciaenids (*Johnius, Otolithes, Nibea, etc.*), catfishes (*Trachysurus* spp., *Arius* spp.), polynemids (*Polynemus* spp.), flatfishes (*Cynoglossus* spp.), pomfrets (*Pampus* spp.), sharks (*Rhincodon* spp., *Carcharhinus* spp., *Sphyrna* spp., *Scoliodon* spp., *Alopias* spp. etc.), rays (*Rhinoptera* spp., *Gymmura* spp., *Himantura* spp.) and skates (*Rhynchobatus* spp.),which are mainly caught by trawls)]; (iii) mid-water resources [Bombay duck (*Harpodon nehereus*), silver-bellies (*Leiognathus* spp., *Gazza* spp., *Secutor* spp.), ribbon fishes (*Trichiurus* spp., *Eupleurogrammus* spp.)and horse mackerel (*Megalaspis cordyla*)]; (iv) crustacean resources [shrimps (*Penaeus* spp., *Fenneropenaeus* sp., *Metapenaeus* spp. and *Parapenaeopsis* spp., *Solenocera* spp.), lobsters (*Panulirus*, spp., *Thenus* spp.) and crabs (*Portunus* spp. and *Charybdis* spp.)]; (v) molluscan resources [oysters (*Crassostrea madrasensis, Saccostrea cucullata*), mussels (*Perna virididis, P. indica*), clams*(Meretrix* spp., *Villorita cyprinoides),* chank (*Xancus pyrum*), squid (*Loligo* spp., *Sepioteuthis* sp., etc.), cuttlefishes (*Sepia* spp., *Sepiella* sp.) and octopus (*Octopus* spp.)] and ; (vi) seaweed resources (*Gracilaria* spp., *Gelidiella* spp., *Sargassum* spp., etc).

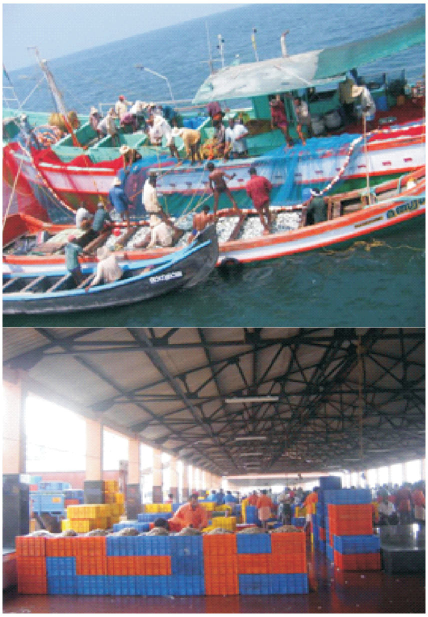
Resource Assessment/Management

During the past six decades, the production from marine fisheries has shown a spectacular increase from 0.5 mmt in 1950 to the current level of 3.34 mmt, contributing 3.5% of the total world marine fish production.

Exploratory surveys intended for biodiversity documentation and detailed studies on taxonomy and fish biology dominated the five decades prior to independence. Further, research thrust was given on taxonomy and fishery biology of major commercial species, which at that point of time were oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*) and to some extent penaeid prawns. Many of the classic works on the fisheries biology of Indian fishes published between 1950 to 1970 (Bapat and Bal, 1952; Bapat *et al*., 1952; Bapat, 1955; Panikkar and Menon, 1955; Sekharan, 1955; Jones and Pantulu, 1958; Jones and Silas, 1960; Kuthalingam, 1960, 1963; George, 1962, Balan, 1964; Jones and Kumaran, 1962; Rao, 1962a, b; Pradhan and Reddy, 1962; James, 1967; Rao, 1968; Antony Raja, 1969; Qasim, 1972, 1973a, b) still remain models emulated in fishery biology. The sixties and the following decade also witnessed a boom in oceanographic expeditions, most notable being the International Indian Ocean Expedition (IOE) resulting in a repository in the form of Indian Ocean Biological Data Centre, Kochi, which later became the Regional Centre of the National Institute of Oceanography (NIO), Goa (Nair and Subrahmanyan, 1955; La Fond, 1957; Rao *et al*., 1973). The Indo-Norwegian Project and the UNDP/ FAO aided Pelagic Fisheries Project carried out extensive acoustic and aerial surveys for pelagic fish resources along the south west coast of India (James, 1986). Dense concentrations of white baits, scads, horse mackerel, ribbon fishes and catfishes were located and estimates made of their standing stocks (Rao *et al*., 1977). The Indo-Polish Industrial Fishery Survey in 1977 for pelagic resources along the northwest coast yielded valuable information on the distribution and abundance of pomfrets as well as the existence of horse mackerel (*Megalaspis cordyla*) and ribbon fish stocks at depths of 50-360 m (Bapat *et al*., 1982). Several long and short term studies in the Lakshadweep Island ecosystem brought out information on the fishery, distribution, abundance, biology and stock structure of tuna resources (Silas and Pillai, 1982; Silas, 1985).

Mechanisation with new fishing crafts and gears during the post-independence era led to a substantial increase in landings of various resources, that propelled research initiatives on estimation of resource-wise marine fish landings. Recognizing the need for a statistically sound database on catch and effort for stock assessment exercises, pilot studies were conducted by CMFRI (Banerji and Chakraborty, 1973) from the early 1950s to 1970s, which led to the development of Multistage Stratified Random Sampling Design for building up a time-series database on season-wise, gear-wise and species-wise marine fish production (Devaraj and Vivekanandan, 1999; Mohan Joseph and Jayaprakash, 2003; Srinath *et al*., 2006). A time-series database was created, consisting of gear-wise, seasonal and spatial fish catch data for each resource supplemented with abundance data from real-time fishery surveys conducted by the Fishery Survey of India (FSI) (Pillai and Katiha, 2004; Pillai *et al*., 2007; Srinath and Jayasankar, 2007). Applying length-based methods, stock assessments of more than 40 commercially important resources of the Indian EEZ were carried out (Alagaraja, 1984; Srinath, 1991, 1998a, b, c). Besides these, the first Marine Fisheries Census carried out by CMFRI during 1957-58 was a paradigm to be followed in the subsequent decades and is presently continued as a quinquennial effort (Qasim, 1973c; Devaraj and Vivekanandan, 1999; Srinath and Jayasankar, 2007).

Investments in harvest and post-harvest sectors in Indian fisheries during the 1980s and 1990s and subsequent resource assessment studies brought out the potential dangers involved in unregulated fisheries and declining catches (Pillai *et al*., 2007; Radhakrishnan, *et al*., 2007; Vivekanandan and Sivakami, 2007). Large-scale fluctuations in abundance, population crashes and subsequent revival of oil sardine and Indian mackerel populations continue to be an enigma (Pillai *et al*., 2007), though there have been concerted efforts to explain such fluctuations, based on the upwelling indices (George *et al.,* 2012). Assessing the health of 26 major fish stocks from Indian coastal waters, Sathianandan *et al*. (2011) reported a decline in whitefish stocks, depleted flying fish stocks and a collapse in unicorn cod (*Bregmaceros macclellandi*) stocks. Fishing down the marine food web has also been detected along the Indian coasts, especially along the southeast coast at the rate of 0.04 trophic level per decade from 1950-2004 (Vivekanandan *et al*., 2005), indicating that fishing is affecting not only fish stocks, but also ecosystem structure and function in most regions of exploitation. All these triggered urgent initiatives on resource assessment and management research related to sustainable harvest (Devaraj and Vivekanandan, 1999). As a result, the Marine Fishing Regulation Acts of various maritime states of India introduced a ban on fishing by mechanized vessels during the monsoon to protect spawners and new recruits of different species (Kalawar *et al*, 1985; Pillai *et al*., 2007). In addition, for the first time, marine fisheries were analysed as an outcome of habitat which later paved way for the concept of Ecosystem Based Fisheries Management (Vivekanandan *et al*., 2003; Mohamed and Zacharia, 2009). Climate change impacts make the Indian fisheries sector vulnerable to forces other than exploitation. Phenological changes such as seasonal shift in spawning season of the threadfin breams (*Nemipterus japonicus* and *N. mesoprion*) are evident in the Indian seas, possibly due to the global warming (Vivekanandan and Rajagopalan, 2009).



Marine fishing

Concentration of fishing effort in shallow, coastal shelves (< 50 m depth) has been one of the major problems of Indian marine fisheries. Though fishing had extended to offshore areas by the late 1980s, only 20% of the landings is from the offshore areas (Pillai and Katiha, 2004; Vivekanandan *et al*., 2009a). Island (Lakshadweep and Andaman & Nicobar Islands) resource potential has been estimated to the tune of 0.2 million tonnes - mostly coastal and oceanic tunas – that indicate the potentials for enhanced harvest (Pillai *et al*., 2007). The potential yield of rich offshore resources between 120-500 m depth zones of Indian EEZ is estimated at 2.73 lakh tonnes and the harvestable quantity as 1.34 lakh tonne (Pillai *et al*., 2007; Ayyappan *et al*., 2011). These resources include oceanic tuna, sharks, myctophids and deep sea shrimps as the front runners for enhanced sustainable production in the marine sector.

Researches on marine fisheries over the years on distribution and abundance of commercial finfish and shellfish resources, stock assessment, potential fishing zone, effectiveness of different crafts and gears, productivity of coastal and deep waters, as also availability of catch statistics have provided adequate background information for developing an ecosystem-based management plan for both east and west coasts of India for sustained fisheries. Considering the current yield of coastal waters up to 50 m reaching almost the potential level, focus is being given on the regions beyond 50 m depth to tap the potential of 1.69 million tonnes from these deeper waters. Further, in order to exploit the rich crustacean resources like deep-sea shrimps and deep-sea lobsters available between 120-500 m depth zones along the southwest coast, appropriate strategies need to be drawn up. In the context of increasing anthropogenic activities of indiscriminate capture of juveniles, onboard discards of low value fishes, coastal pollution and environmental degradation, strict enforcement of policy guidelines, *viz.* restriction of fleet size, regulation of mesh size, declaration of closed season and implementation of effective code of conduct for responsible fishing are imperative.

There is also a need to understand the relationship between physical, chemical and biological oceanographic parameters, and fish distribution and abundance. Surrogate databases from satellite data sources used for numerical and time-series models have taken a priority over real time observations and revolutionised our research. But, the evident gaps in observation and assessment of fishery resources have to be nullified through regular survey, sampling and analysis. Focus on future fisheries resource research will also require orientation towards building a spatio-temporal database in GIS platform as a decision support tool. Automation of landing data estimation, geo-referencing of fish catches, local spawning ground and fishing ground delineation, better understanding of the resource vulnerability to climate change and international trade policies impacting our resources need emphasis.

Harvest Technologies

Fishing craft mechanization in India progressed through four stages, beginning with motorisation of some of the traditional crafts, followed by introduction of mechanised crafts, more specialised crafts and broadening to a full-fledged fishing fleet (Gurtner, 1958; Jacob *et al.*, 1987; Pillai *et al.*, 1992). Initial attempts to design beach landing craft as suitable replacement for traditional catamarans and canoes were done by Gurtner (1960). During the eighties, the FAO,s Bay of Bengal Programme developed beach-landing craft made of fiberglass, popularly known as Pablo, for operating from Tamil Nadu and Andhra Pradesh. Simultaneously, mechanisation of small craft was initiated through the Indo-Norwegian Project with assistance of FAO Naval Architects. FRP boats made of composite material of fibreglass and polyester resin have gained wide acceptability due to their light weight, durability and strength.

Trawling was first attempted in Indian waters during exploratory surveys conducted off the Bombay coast in 1902 (Chidambaram, 1952) and by the Ceylon Company for Pearl Fishing Survey in 1906-07 (Hornell, 1916). Trawling as a major fishing method became popular with the introduction of mechanised craft targeting shrimp (Miyamoto and Deshpande, 1959; Kurian, 1969). The double rig trawling for shrimp in the east coast was also a notable advancement (Hameed and Kurup, 1998). Initially single day fishing and later larger vessels, sufficiently powered and equipped to undertake multi-day operations in deeper waters, became popular. Introduction of mini trawls, a typical drag type gear, operated by powered country craft was an innovation along Kerala, Karnataka and Maharashtra coasts (Pillai *et al.,* 2000). Designs for multipurpose gear such as the high opening trawl, semi-pelagic trawl (CIFT-SPTS) etc., were also introduced for commercial use in Indian waters. Incorporation of large meshes in the forepart of the trawl aided reduction of drag and the off bottom operations, which is expected to reduce the impact on the benthic fauna.

Purse seining in small-scale mechanised sector was started in India in 1974 (Mukundan and Hakkim, 1980). Large mesh purse seining was later introduced by CIFT for harvest of large pelagics of the oceanic waters and 100% adoption is reported by purse seiners at Cochin (CIFT, 2011). Further, introduction of powerblock, being adopted by fishermen in Goa, has reduced drudgery in purse seine operation considerably. A mini purse seine, known as ring seine, for operation from the traditional motorized craft, was developed in 1982-83 as an efficient alternative gear for operation from the traditional boat seine craft *Thangu Vallom* (Panicker *et al*., 1985). This gear was later optimized through proper dimensional changes and use of large meshed sections (Edwin *et al*., 2010). The ring seine operations have currently spread to almost all maritime states. Tuna long lining has become an established method and deployment of vessels under the joint venture programme begun in 1992, which has also helped in exploitation of deeper waters (Hameed and Kurup, 1998). Automated monoliners through conversion of shrimp trawlers is a new method for targeting tuna resources.

Advances in satellite-based technologies such as Global Maritime Distress Safety System (GMDSS) based rescue system have facilitated safety of fishermen. Satellite remote sensing application helped fishermen reduce search time and significantly increase catch per unit effort (Solanki *et al.*, 2003; Zainuddin *et al.*, 2004). Electronic instruments for fishing including echo sounder, sonar, aimed mid-water trawling techniques (1995-1996), global positioning system (GPS) and net-sonde (net monitoring system) have played a vital role in enhancing fish production with precision in fishing. Bycatch Reduction Devices such as rigid grid devices, fish eye, radial escapement device, Juvenile Fish Excluder-cum-Shrimp Sorting Device (JFE-SSD) and Turtle Excluder Device (CIFT-TED) were developed for the sustainability of fisheries (Boopendranath, 2009).

Future work in harvest technologies needs to focus on evolution of next generation fuel efficient fishing vessels for different fishery zones and different sectors like artisanal, small mechanized and industrial. Development of resource-specific fishing gear, incorporating principles of bycatch reduction, protection of biodiversity, minimization of environmental impacts and energy efficiency, need to be other focus area of research. Alternate fuel and renewable energy sources fishing system and fish processing system and Life Cycle Assessment (LCA) and energy audit of products and processes is also essential.

Inland Fisheries

Research on inland fishery resources, *viz.* rivers, estuaries, floodplain wetlands, backwaters and lagoons, and man-made reservoirs in India took a leap only after the establishment of the Central Inland Fisheries Research Institute at Barrackpore, West Bengal. Collection of fisheries statistics was initiated upon the recommendation of the All India Fisheries Conference held in 1948. The sector which contributed just about 0.218 million tonnes in 1951, today contributes over 0.9 million tonnes of fish annually. While much of the natural resources are exploited, majority of the man-made resources, *viz.* reservoirs and canals present potentials for fish production.

Resource Management

Rivers: The 15 major riverine systems along with the network of 45 medium and over 100 minor rivers (drainage basin <2,000 km^2) (Vass and Moza, 2011) provide diverse habitats for one of the richest freshwater fish faunal resources of the world. Being the largest and most important riverine system in the country, with a combined length of 12,500 km, draining 1,060,000 km^2 area (Welcomme, 1985), the River Ganga and its tributaries have received great attention by researchers since independence. Construction of barrages in most of its tributaries over the years has led to diversion of flow and thereby declining fish catch and loss of species diversity (Payne *et al*., 2004). In general, Indian major carps, followed by catfishes, murrels and other miscellaneous varieties, contribute to fish catches in the major riverine systems (Jhingran, 1991; Sarkar *et al*., 2012) except those in peninsular rivers, where endemic species prevail (Arunachalam, 2000; Gopalakrishnan and Ponniah, 2000; Gopi, 2000; Raghavan *et al*., 2008).

Extensive studies were carried out to document important factors such as overfishing, destruction of breeding grounds, pollution, sedimentation and water abstraction responsible for reduction of catches over the years (Ray *et al*., 1966; Ayyappan and Jena, 2005). While use of non-selective gears with smaller mesh size has been a bottleneck hindering the recruitment process of major commercial species, destructive fishing such as dynamiting and poisoning pose threats to biodiversity.

The spawn prospecting investigations conducted during 1960s had led to the establishment of a methodology of riverine spawn collection and selection of sites. Effectiveness of shooting net in spawn collection in the shallow margins of flooded rivers helped in exploitation of cultivable major carp seed resources from major riverine systems (Jhingran, 1991).

While not much research inputs have so far gone for the development of specific crafts and gears suitable for river systems in the country, it is pertinent that in the contexts of conservation need of several threatened fish species and enhancing efficiency in flowing rivers, due attention is given on the subject. While beach seine boats, plank built boats, dugout canoes and catamarans are principal non-mechanised crafts, gill netters and liners are the major mechanised craft being operated in major rivers (Jhingran and Natarajan, 1969). Fishing gear used includes a variety of nets, hooks and lines and trapping devices (Saxena, 1965; Jhingran and Natarajan, 1969; Seth and Katiha, 2003).

Estuaries, being the most dynamic ecosystems, are considered an important habitat for several euryhaline fin and shellfish species and also serve as a nursery ground for several marine species. Important estuarine systems in the country are the Hooghly-Matlah Estuary of river Ganga in West Bengal; Mahanadi in Odisha; Godavari and the Krishna in Andhra Pradesh; Cauvery in Tamil Nadu and Narmada and Tapti in Gujarat. The Chilka in Odisha, the Pulicat in Tamil Nadu and the Kerala backwater systems, which too contribute significantly to the brackishwater fisheries, have also been extensively studied with regards to their hydrobiological characteristics and fisheries (Jhingran and Natarajan, 1969; Sankaranarayanan and Qasim, 1969; Joseph and Pillai, 1975; Kurup and Samuel, 1980; Kuttyamma, 1980; Ramamritham *et al*., 1986; Kurup *et al*., 1993). Mullets, milkfish, threadfins, hilsa, seabass and prawns are the most common and commercially important species which form the fisheries in most of the estuaries. Major fisheries have dwindled due to fishing pressure and increasing anthropogenic activities (Shetty *et al*., 1961; Rao, 1964; Mitra *et al*., 1997; Nath *et al*., 2004).

Documentation of genetic diversity and drawing inferences about population structure in commercially important finfish and shellfishes, especially those with aquaculture importance, has received increased attention in recent years. Towards this, several molecular markers, *viz.* allozymes, microsatellites, MtDNA cytochrome b, ATPase 6/8 and RAPD have been used for stock characterization (Gopalakrishnan, *et al*., 2006, 2009; Chauhan *et al*., 2007; Singh *et al*., 2010, 2012; Chaturvedi *et al*., 2011; Luhariya *et al*., 2011; Mandal *et al*., 2011; Sah *et al*., 2011; Abdul Muneer *et al.,* 2012; Das *et al*, 2012).

Sustainable riverine fisheries require effective implementation of management strategies towards habitat restoration, protection of breeding grounds, restrictions on discharge of untreated effluents and use of non-selective gears and destructive fishing, provision of effective fish passes for migratory fish species. Estuaries being the potential breeding and nursery grounds for several fish and shellfish species, require special attention on reduced fishing efforts, collection of fish/ shellfish seed and restoration and management of mangroves.

Fishing in open waters

Reservoirs, Floodplain Wetlands and Lakes: Initial research on reservoirs was largely confined to the study of hydrobiological characteristics (Rao and Govind, 1964; Sreenivasan, 1964; Palaniswamy *et al*., 2006), survey of fish breeding grounds (Gopalakrishnan *et al.,* 1966) and experimental fishing (Krishnamurthy *et al.,* 1964). Extensive studies were also conducted under the All India Coordinated Project on the Ecology and Fisheries of Freshwater Reservoirs, initiated in 1971 as a Central Sector Scheme. As an important scientific intervention, selected reservoirs were subjected to stocking of Indian major carp fingerlings since 1960s, as for example, Rana Pratap Sagar in Rajasthan was stocked with rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) fingerlings during the seventees, that enhanced the total yield from 3 tonnes to nearly 200 tonnes.

Analysing the scope and limitations of stocking silver carp in Indian reservoirs, Jhingran and Natarajan (1978) suggested stocking of the species in Gobindsagar and Nagarjunasagar reservoirs. However, introduction of silver carp in Gobindsagar reservoir and its subsequent establishment has affected the fisheries of the native catla (*Catla catla*) and mahseer (*Tor putitora*) to a great extent. Adverse impact of the common carp on several indigenous species has been documented (Ayyappan and Jena, 1999, 2005; Lakra *et al*., 2008). Prolific breeding and over-population of tilapia, *Oreochromis mossambicus* in several reservoirs and lakes in Tamil Nadu, Kerala, Karnataka and Rajasthan have resulted in great ecological imbalance with reduction of endemic fish population (Singh and Lakra, 2006; Lakra *et al*., 2008).

The 56 large, 180 medium and 19,134 small reservoirs covering an area of 3.15 million ha remain unexploited/ underexploited with regard to fisheries development. The main reservoirs on the Ganga river system have had the initial advantage of harbouring indigenous Indian major carps (Jhingran, 1991). With the average fish production in Indian reservoirs recorded as 20 kg/ha [(Sugunan (1995)], scientific interventions in culture-based fisheries have demonstrated enormous potential of these water bodies (Sugunan and Sinha, 2000; Sharma and Kaushal, 2004a,b,c). Impressive production levels of 100-300 kg/ha/yr have been demonstrated through scientific management in a few small reservoirs across the country (Sugunan and Sinha, 2000). As an array of factors, , viz. biogenic capacity of the environment, fishing condition, shallowness of the reservoirs, water retention during summer, natural recruitment, etc. are considered for decision on stocking, each reservoir necessitates proper scientific interventions (Sugunan and Sinha, 2000). In general, stocking of advanced fingerlings (10-15 cm) of Indian major carps at densities of 1,000-2,000 nos/ha are suggested for small reservoirs (Sugunan, 1997). Sourcing the seeds of Indian major carps from adjacent regions of the reservoirs in order to avoid mixing of different populations is emphasized and stocking of peninsular reservoirs with endemic Peninsular carps is suggested.

Fishery enhancement in reservoirs (cage culture)

The 0.2 million ha of floodplain wetlands or *beels* form an important open water resource in some of the eastern Indian states, viz., Asom, West Bengal, Bihar and Uttar Pradesh, which offer high potential for both culture and capture fisheries. These water bodies provide potential nursery grounds for several commercially important fish and shellfish species, especially during the period of inundation of rivers. The rich nutrient load and availability of food organisms make such water bodies ideal for culture-based fisheries, leading to higher growth of stocked species compared to the reservoirs. While the present production levels in unmanaged *beels* in most cases remain less than <100 kg/ha, with only a few recording up to 500 kg/ha (Sugunan and Sinha, 2000; Pathak *et al*., 2004), production levels of as high as 3,262 kg/ha/yr and 1,922 kg/ha/yr have been recorded in Kola and Akaipur beels of West Bengal, respectively (Sugunan *et al*., 2000). Reduction of water levels and shrinkage of water area, weed infestation, leasing and ownership, etc. are some of the issues affecting fisheries development in these waters.

Formulation of appropriate policy guidelines for long-term leasing of reservoirs and beels and requirement of adequate investments towards scientific stocking of fish seed based on the biogenic capacity of the water bodies have been the most critical issues, which require attention of both researchers and policy makers.

Coldwater Fisheries

The upland rivers/streams, high altitude lakes and reservoirs in the Himalayan region and the Western Ghats located above 914 m above sea level with temperature below 20°C comprise the coldwater fisheries resources in the country. Although the share of coldwater fish in the total inland fish production is low, the rich biodiversity has made this resource quite unique. While mahseers (*Tor tor, T. putitora, T. khudree, T. mussullah, T. malabaricus, Neolissocheilus hexagonolepis, N. wynaadensis*) and snow trout (*Schizothorax richardsonii, Schizothoraichthys curvifrons, S. esocinus, S. niger*) are the principal commercially important indigenous species; trout (brown trout, *Salmo trutta fario*; rainbow trout, *Oncorhynchus mykiss*) and common carp are the common exotic coldwater sport and food fishes. The fisheries of these coldwater species largely depend on the tolerance limits of water temperature, *viz.* 4º-20ºC for exotic trouts, and 10º-30ºC and 5º-25ºC for mahseers and snow trouts, respectively (Mahanta *et al.*, 2011). Scientific studies on coldwater fisheries in the country started only in 1960s (Sehgal, 1974; Sehgal *et al.*, 1971; Jhingran and Sehgal, 1978; Kumar *et al.*, 1979), although exotic brown trout (*Salmo trutta fario*) was introduced in the country as early as in 1863 and rainbow trout (*Onchorhynchus mykiss*) in 1909 (Jhingran, 1991). Sport fisheries being an important activity in upland states, effective management of resources with regard to enhancing the population of trout and mahseer in hill streams and lakes, including ranching programmes is emphasised for sustenance of fisheries.

Rainbow and brown trout in cold waters

Fish Biology

Extensive studies have been carried out on reproductive biology including maturity, spawning season and periodicity, sexual dimorphism and fecundity in different cultivable freshwater and brackishwater species, viz. carps (David, 1959; Chakrabarty and Murty, 1972), catfishes (Chaudhuri, 1962; Ramakrishniah, 1986); hilsa (Jones and Menon, 1950; Pillay, 1958), freshwater prawns, *Macrobrachium rosenbergii* and *M. malcolmsonii* (Ibrahim, 1962; Rao, 1967) and shrimps, *Penaeus* *monodon* and *Fenneropenaeus indicus* (Subrahmanyam, 1963; Rao, 1967) and several other species (Prabhu, 1956; Qasim and Qayyum, 1961; Vass *et al.*, 1978), which have been helpful in development of protocol of induced breeding of these species and also understanding the natural recruitment process in different open-water bodies. Substantial efforts have also gone to understand other aspects of fish biology, viz. food and feeding, age and growth and migration pattern of different commercially important species (Pillay, 1958; Ramakrishniah, 1972; Devaraj, 1973; Devaraj *et al*., 1975; Patnaik and Jena, 1976) in different inland waters. Similar information generated in several commercially important marine species, *viz.* mackerel, sardine, seerfish, silver-belly ribbon fishes, marine shrimps etc. (Chacko, 1949; Prabhu, 1955; George, 1959; Rao, 1967; Balan, 1971; Luther, 1973; Devaraj, 1983; Jayabalan, 1986) could be correlated with the fish catch in coastal waters.

Voluminous information have also been generated on reproduction, growth, and food and feeding of different bivalve molluscan species, viz. in edible oysters (Durve and Ball, 1962; Purushan *et al*., 1983; Rajapandian and Rajan, 1983), mussels (Jones, 1950; Rao *et al*., 1975; Narasimham, 1980) and clams (Rao, 1952; Alagarswami, 1966; Rao, 1988), marine gastropods, viz. *Trochus* and *Turbo* (Rao, 1936; Nair and Appukutan, 1983), cephalopods (Rao, 1954; Silas *et al*., 1985) and other commercially important invertebrates like sea cucumber (Krishnaswami and Krishnan, 1967). While the information on maturity and breeding could be utilized effectively in controlled breeding progammes of some of these commercially important bivalves, the other biological information formed the basis in initiating the seed production and grow-out experiments.

Ecological Studies

Extensive research work have been carried out on different ecological aspects, including physicochemical parameters, nutrient status of water and sediments, plankton, periphyton, benthos and aquatic macrophytes in different openwater systems, viz. rivers, estuaries (Shetty *et al*., 1961; Rao *et al*., 1975; Nandi *et al*., 1983), lakes (Sharma *et al*., 1982; Pant *et al*., 1983), reservoirs (Rao and Govind, 1964; Sreenivasan, 1964; David *et al*., 1969) and wetlands (Natarajan and Pathak, 1983; Pathak *et al*., 1986). The modification in the ecological features in most of the rivers largely found to be due to the obstruction of water flow as a resultant of construction of dams/barrages and disposal of organic pollutants. These studies not only have helped in understanding the productivity status of the systems, but also proved basis for decision making in restoration of ecosystem health. Extensive studies were also made on hydrobiological parameters and other ecological aspects in coastal and oceanic waters over these years (Subramanyam and Sarma, 1960; Pannikar and Jayaraman, 1966; Nair *et al*., 1968; Qasim, 1977), mud banks (Nair *et al*., 1984) and also in unique habitats like coral reefs (Pillai, 1971; Nair and Pillai, 1972), which could be correlated to total fish catch and also catch composition.

Climate Change and Natural Disasters on Fisheries

It has been increasingly felt that the climate over the last few decades is showing perceptible variability and changes. The observed changes include increase in air and water temperature, regional monsoon variation, frequent droughts, non-seasonal rains and increase in extreme weather incidences in coastal states and Himalayan glacier recession. There is evidence that inland waters are warming, with perceptible changes in distribution fish species (Vass, *et al.* 2009). Impact of such climate change is being felt on the temperature regime of the inland water bodies and on the breeding behavior of fishes. From analysis of 30 years' time series data on river Ganga and water bodies in the plains, Vass *et al.* (2009) reported an increase in annual mean minimum water temperature in the upper cold-water stretch of the river (Haridwar) by 1.5°C and by 0.2-1.6°C in the aquaculture farms in the lower stretches in the Gangetic plains. A number of fish species which were never reported in the upper stretch of the river and were predominantly available in the lower and middle stretches have now been recorded from the upper cold-water region. Das *et al.* (2014) has prepared a framework for assessing vulnerability of inland fisheries to climate variations in 13 districts of West Bengal. The data obtained reflected different spatial combinations of climate exposure, sensitivity and adaptive capacity among the districts. Investigation conducted on mature female *Cyprinus carpio* to study the effect of temperature on the reproductive integrity of the fish subjected to enhanced temperature of 34°C indicated a decrease in the Gonado-Somatic Index and accumulation of liver and ovarian cholesterol (Das and Saha, 2008).

Warming of waters and sea level rise are two pervasive factors, which may severely impact the marine fishery. The imminent challenges are threats faced by bleaching of corals (Krishnan *et al.*, 2010), changing spawning behaviour in fishes (Vivekanandan and Rajagopalan, 2009), inter-annual variability in fish abundance (Sathianandan *et al.*, 2011), productivity changes in coastal waters (Grinson George, 2014), community structure changes in marine biodiversity (Krishnan *et al.*, 2013) and habitat shift of marine species (Jayasankar *et al.*, 2013). Climate changes have altered the production and distribution of some commercially important pelagic fishes in coastal waters. Historically, the distribution of sardines and mackerels were restricted to the Malabar upwelling system along the southwest coast of India (Lat. 8-16^{o} N). However, a clear cut distribution shifts in these two species were observed since 1989. Oil sardine emerged as a major species along southeast coast, while mackerel fishery along the northwest coast. Both these fishes have shown population crashes and sudden recoveries, and very strong inverse relationship (Manjusha *et al.*, 2010). Small pelagic fishes having short life span such as sardines, anchovies and mackerels are the best indicators of climate change as their pelagic coastal water habitat is more directly influenced by ocean-atmosphere variability related to climate change.

The revelation that coastal ecosystems such as mangroves, seagrass meadows and marshy coastal wetlands trap and store vast quantities of carbon has created new interest for exploring the role of these habitats in climate change adaptation and mitigation schemes (Ghosh *et al.*, 2014). These ecosystems form important coastal carbon sinks, also termed ‘blue carbon’. In spite of availability of vast expanse of mangroves, seagrass meadows and marshy coastal wetlands in India, the opportunity for using blue carbon has not been adequately realized.

In Indian context, marine fishers live along the coastline and are quite vulnerable to the disasters, as has been observed during the December 2004 *Tsunami*, where in due to lack of any mangrove cover, the coastal villages became highly susceptible to strong wind/wave. Cyclones also render coastal resources vulnerable. The reefs in Andaman and Nicobar Islands suffered severe damage following a tropical cyclone in the Bay of Bengal off Myanmar coast during March 2011 (Krishnan *et al*., 2012). The investigation exposed the vulnerability of the reefs to oceanographic features which generally remain unnoticed. The wind tracks of cyclone were generated using weather research and forecasting (WRF) models (Grinson George, 2014) which clearly indicated the passage of cyclone where reefs suffered damage. In aquaculture sector extreme events such as floods, drought, cyclones, variability in rainfall patterns as well as intensity, and demographic issues are cited as major challenges affecting production. Vulnerability of inland fisheries and aquaculture sector can be assessed by gauging the sensitivity of these systems and the time period of exposure of these climate factors in inland systems.

Aquaculture

As a traditional practice, fish culture in India was mainly confined to the eastern states of Bengal, Odisha and Bihar. During early part of twentieth century, with the organization of Fisheries Departments in certain states, attempts were made to extend fish culture practices to other parts (Bhimachar and Tripathi, 1967). The Madras Fisheries Department made pioneering efforts with introduction of exotic gourami (*Osphronemus gorami*) at Sunkesula in 1916 (Nicholson, 1918; Hornell, 1920) and common carp (*Cyprinus carpio*) in Ootacamund in 1939 showed encouraging results. The nesting and breeding habits of *Mystus aor* and *M. seenghala* (Hornell, 1922) and *Osphronemus gorami* (Jones, 1939; Kulkarni, 1943 and Bhimachar *et al*., 1944) were studied, along with culture of brackishwater fishes to utilize the coastal saline swamps and low-lying areas in the deltaic regions.

Improvements in carp culture methods were suggested by Sen (1941) and Hora (1943a,b,c, 1945a). Studies on the bionomics and spawning of carps were also made in the Punjab and Bengal Fisheries Department (Das, 1917; Muzumdar, 1939; Khan, 1942, 1943, 1945; Ahmad, 1944; Das and Das Gupta, 1945; Hora, 1945b; Husain, 1945) and in the University of Calcutta (Mookerjee, 1945). The modern research in aquaculture took momentum after independence with work concentrated around Indian major carps, some of the exotic carps and cultivable catfishes in freshwater at Pond Culture Division of CIFRI. The research on coastal aquaculture received attention only in 1970s, with culture of bivalve molluscs and marine shrimps like *Penaeus monodon* and *Fenneropenaeus indicus* by CMFRI.

Water and Soil Quality in Fish Culture Pond

The physico-chemical factors and nutrient status of the culture environments play an important role in governing productivity of the culture system. The study of Sewell (1927) in a Museum tank in Kolkata was probably the first attempt to analyse water quality, while studying the fish mortality in a fish pond. Banerjea (1967) studied the water quality and soil parameters of 90 freshwater fishponds in different states of India in relation to fish production. Considering the fact that the soil and water characteristics are interdependent in a fish pond, due importance was given to study both soil and water parameters by different workers while undertaking culture experiments (Saha *et al*., 1971; Ghosh *et al*., 1974; Jana and De, 1988; Jena *et al*., 2002b; Sahu *et al*., 2007b). While dissolved oxygen, pH, temperature, carbon dioxide, total alkalinity and inorganic nutrients like nitrogen and phosphorus were the important water quality parameters studied, the study of soil parameters largely included organic carbon, nitrogen and phosphorus contents (Banerjea and Mandal, 1965; Saha, 1969a; Banerjea and Ghosh, 1970; Chattopadhyay and Ghosh, 1976). According to Banerjea (1967) phosphorus (P_2O_5) levels of <30 ppm, 30-60 ppm and > 60 ppm can be considered as the poor, average and highly productive soil. Further, nitrogen levels ranging 50-75 ppm and organic carbon contents of 1.5-2.5% were suggested to be more favourable for fish production. Studies have shown that addition of these soil nutrients in the form of fertilizers or manures result in increased production of natural food and thereby the fish production in freshwater and brackishwater culture ponds (Saha, 1969b; Ghosh, 1975; Saha and Chatterjee, 1975; Saha *et al*., 1975; Banerjee *et al*., 1979; Garg and Bhatnagar, 1996, 1999). Application of phosphate fertilizer in fish ponds found to be the most critical single factor in the maintenance of pond fertility (Jana and Das; 1992; Jana and Sahu, 1994). Further, application of some trace elements have also shown to enhance production (Das, 1967; Banerjea and Banerjee, 1967).

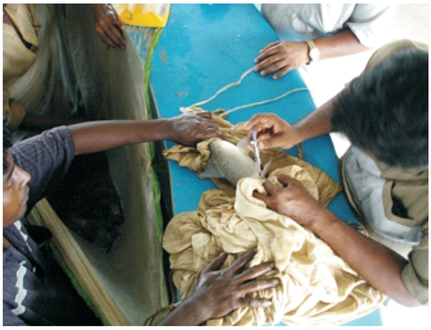
Studies were carried out to evaluate different toxicants for eradication of predatory and weed fishes, as pre-stocking pond management measures. Mahua oilcake was found to be most effective toxicant of plant origin when applied at 200-250 ppm, which also serves as an effective nitrogenous fertilizer (Bhatia, 1970). Several other plant materials, anhydrous ammonia, commercial bleaching powder, etc. were found to be effective in eradicating unwanted fishes (Bhuyan, 1967; Das, 1969; Ramaprabhu, 1986; Janakiram *et al*., 1988; Mohanty *et al.*, 1993). Considering the fact that dissolved oxygen being the most important critical parameter in high-density farming, the usefulness of aeration for improvement of water quality, mineralization of organic matter and enhancement of production was also demonstrated by several workers (Vijayan and Verghese, 1986; Mohanty, 1993; Jena *et al*., 2005; Das *et al*., 2012).

Breed Improvement and Seed Production

Fish breeding and seed production in India dates back to over a century, with successful controlled breeding of carps achieved in *bundhs* through simulation of riverine conditions in early 19th century in West Bengal. However, following the success of induced breeding techniques by hypophysation in late 1950s and subsequently with the development of technologies of controlled breeding and larval rearing of most of the commercially-important fish and shellfish species, the seed requirement for aquaculture at present is largely met from hatchery-produced seed.

Freshwater Fish and Shellfish Species

Carps: Success in induced breeding of carps is considered the most significant achievement in aquaculture development in the country. Khan (1938) first succeeded in inducing ovulation in mrigal using mammalian pituitary hormones and it was Chaudhuri (1955) who successfully induced *Esomus danricus* to breed by intra-peritoneal injection of catla pituitary gland extract. However, success in induced breeding of *Cirrhinus reba*, a minor carp, by the scientists of Pond Culture Division of CIFRI led by Chaudhuri and Alikunhi at Angul (Odisha) through administration of aqueous carp pituitary extract in 1957 is considered a major technological breakthrough. Further, all the three Indian major carps, viz., rohu, catla and mrigal were bred and the protocol was standardized for mass-scale breeding (Chaudhuri and Alikunhi, 1957; Chaudhuri, 1960, 1963). Chinese carps, viz. grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypophthalmichthys molitrix*) were successfully bred in 1962 by employing similar techniques (Alikunhi *et al.*, 1963) and subsequently mass-scale breeding of these species was also demonstrated (Chaudhuri *et al.*, 1966). Use of crude HCG combined with fish PG extract, and subsequently HCG alone were demonstrated as effective inducing agents for breeding of Indian major carps and also silver carp (Chondar, 1985). Synthetic hormone ‘Ovaprim’ developed by Syndel Laboratory, Canada, which was standardized for effective use in carps and later other freshwater fishes in the country and the subsequent availability of other inducing agents under the trade name ‘Ovatide’ and ‘Wova-FH’ made induced breeding a simple and user-friendly technology.



Induced breeding

Carp hatchery

While Indian major carps normally breed once a year, Bhowmick *et al.* (1977) reported breeding twice with an interval of about two months with production of almost equal quantities of eggs in each spawning. Gupta *et al.* (1995) reported the quadruple breeding of catla in the same season. Use of broods that have bred once or more in the preceding breeding season(s), termed as professional brood fish, were found to mature early and breed easily. The total spawn production in such quadruple breeding was found to be 3-4 folds higher than the conventional breeding operation. Rath *et al*. (2001) further found effectiveness of hormones to shorten the latency period and effective spawning periods in such induced breeding operations.

Spectacular achievements in hatchery technology for carp in the last five decades (Bhowmick, 1978; Dwivedi and Zaidi, 1983; Gupta *et al.*, 2000; Rath and Gupta, 1997), from double-walled *hapa* to eco-hatchery, provided a scope to produce and handle mass quantities of eggs. Development of FRP portable hatchery by CIFA has added one more dimension for decentralized production of seed (Sarkar *et al*., 1995).

Emphasis on species diversification in the recent past has led to development of technology of breeding and hatchery management of several regionally-important cultivable carp and barbs, *viz. Labeo fimbriatus, L. dussumieri, L. gonius, L. calbasu, L. bata, Puntius sarana* and *P. gonionotus*. Extensive work on inter-specific and inter-generic hybridization among and between Indian major carps and Chinese carps was taken up by different workers with a view to develop positive or useful traits (Chaudhuri, 1973, Bhowmick *et al*., 1981, Reddy and Varghese, 1983). Although some of the crosses, viz. rohu × catla, mrigal × catla, rohu × mrigal and fringe-lipped carp (*Labeo fimbriatus*) × catla were found to possess useful traits in terms of growth (Reddy, 1999), most of them did not demonstrate appreciable hybrid vigour for commercial farming.

Artificial gynogenesis, both meiotic and mitotic, has been successfully induced in carps, viz. *C. catla, L. rohita, C. mrigala* and *L. calbasu.* Induced polyploidy using colchicine in rohu, Reddy *et al*. (1987) could achieve tetraploids and mosaics. However, using thermal shock, Reddy *et al*. (1990) successfully induced triploidy in rohu, and tetraploidy in rohu and catla.

With an objective to achieve higher growth in rohu, a selective breeding programme was undertaken with five riverine stocks, based on combined selection method (Reddy *et al*., 1999, 2001). Development of genetically improved strain of *Labeo rohita*, CIFA IR 1 (*Jayanti* rohu) through selective breeding, demonstrating over 17% higher growth efficiency per generation after seventh generation was a significant achievement for increasing productivity and production in carp-based farming systems in the country (Pers. Comm.).

Species-specific sperm cryopreservation protocols were developed for 28 finfish species (Padhi and Mandal, 1995, 1998; Ponniah *et al*., 1998 a, b, 1999; Gopalakrishnan, *et al*., 1999; Koteeswaran and Pandian, 2002; Lal *et al*., 2009). Routray *et al*. (2006) cryopreserved sperms collected from *L. rohita,* 8 hr after fish death. Besides tackling the issues of asynchronous maturation in certain species of commercial importance, milt cryopreservation could be used as an important tool in stock upgradation and also conservation programmes.

Concerted efforts on seed rearing of major and minor carps for the past five decades have led to development and standardization of practices for raising fry and fingerlings with higher growth (80-100 mm in 2-3 months) and survival levels (60-80%) (Mitra and Das, 1965; Das, 1967; Chakraborty *et al*., 1973; Jena *et al*., 1996, 1998a,b,c, 1999; Sharma and Chakrabarti, 1999, 2003; Sahu *et al*., 2007a; Pawar *et al*., 2009; Das *et al*., 2012). Higher fry survival levels of 40-60% through intensive rearing of carps during nursery stage were demonstrated at stocking densities of 5-10 million/ha in earthen ponds (Jena *et al*., 1998a) and up to 30 million in ferro-cement tanks. Harvesting 3-4 crops of fry even in a season of 3-4 months, i.e., during June-September is possible now. Further, the technology of fingerlings rearing has demonstrated 60-80% survival (Jena *et al*., 1998b, 2005), with mean fingerlings size of 80-100 mm within a culture period of 2-3 months in earthen ponds, at stocking densities of 0.2-0.3 million/ha (Jena and Das, 2011a).

Availability of seed at all parts of the country, with an annual production of 32 billion carp fry today largely meeting the quantum of seed requirement, is the testimony of effectiveness of the developed technologies of induced breeding and seed rearing. With quality seed production being the priority, the problem of inbreeding depression needs to be addressed on a scientific and systematic manner. Establishment of ‘broodbanks’ ensuring maintenance of pure line foundation broodstocks and production of certified broods to the hatcheries can ensure supply of quality seed supply in each of the region. Further, the envisaged policy intervention with regard to seed certification and hatchery accreditation can also help in ensuring quality seed production, boosting the aquaculture productivity and production.

Catfish and Other Commercially-important Fish Species: The spawning success in magur (*Clarias batrachus*) by Ramaswamy and Sundararaj (1956, 1957) with two doses of pituitary extract is considered a milestone in breeding of catfishes, which was subsequently improved by Rao and Ram (1991). In spite of availability of standardized technology for induced breeding and larval rearing of the species (Rao *et al*., 1994) and further demonstration of its multiple spawning (Sahu and Sahoo, 2000), issues with regard to low fecundity, need for sacrificing the male, cannibalism in larval phase and necessity of indoor rearing are the major constraints in establishing commercial hatcheries and thereby large-scale seed availability. Good environment, suitable larval feed and optimum density are some of the criteria during larval rearing. Success was also achieved in induced breeding and larval rearing of large catfishes like *Pangasius pangasius* (Gupta *et al*., 1992; Sahoo *et al*., 2002a,b), murrels (Parameswaran and Murugesan, 1976; Haldar *et al*., 1991; Haniffa *et al*., 2000; Haniffa and Sridhar, 2002; Dayal *et al*., 2013), climbing perch, *Anabas testudineus* (Sarkar *et al*., 2005; Kumar *et al*., 2012) and featherbacks, *Chitala chitala* (Sarkar *et al*., 2006). Malhotra *et al*. (1969) produced hatchlings from hilsa brought in commercial catches. With the growing interests on culture of exotic pangus catfish, *Pangasianodon hypophthalmus* all over the country, there has been a growing demand for the seed of the species. In spite of the fact that the increasing thrust on species diversification over the years has led to development of protocol of breeding and hatchery management of several of these commercially important species, these technologies, however, need further up-scaling for their mass-scale seed production.

Freshwater Prawns: Although initial success in maturation, breeding and larval rearing in certain non-commercial freshwater palaemonid prawn was achieved in early sixties (Rajyalakshmi, 1961a, b), breeding and hatchery technology of the giant freshwater prawn, *M. rosenbergii* was developed and standardised only during late ‘80s and early ‘90s (Rao and Tripathi, 1993; Pillai

Seed production of freshwater prawns

and Rao, 1997). Kevalramani *et al*. (1971) demonstrated the controlled breeding and rearing of the Indian river prawn, *M. malcolmsonii* in Maharashtra and Rao (1991), Kanaujia and Mohanty (1992) and Kanaujia *et al*. (1999) achieved the breeding and large-scale larval rearing. Successful seed production of *M. malcolmsoni* was further demonstrated in synthetic seawater by Kanaujia *et al*. (1996). Establishment of commercial hatcheries in the coastal states adequately addressed the seed requirement of *M. rosenbergii*. However, it is necessary that the initial success achieved in seed production in inland saline belts using artificial seawater and ground saline water is scaled up to meet the required seed demand of the land-locked states.

Coldwater Species

The exotic rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta fario*), the indigenous mahseer and snow trout are among the important coldwater fishes which have received attention for their controlled breeding and seed production. The first attempt at induced breeding of mahseer was by Ahmad (1948) on pond reared *Neolissocheilus hexagonolepis*. However, the artificial fecundation of eggs of a true mahseer (*T. khudree*) was carried out by Kulkarni and Ogale (1986) at the Tata Electric Companies fish farm at Lonavla, Maharashtra. Development of a flow-through hatchery system yielded 3-folds increase in hatching and survival compared to conventional methods (Sarma *et al*., 2009; 2010; Mahanta and Sarma, 2010). Over the years, considerable knowledge has been gained on methods of artificial propagation, hatchery management, rearing of fry and fingerlings, and broodstock management of mahseers; *T. khudree, T. putitora, T. tor* and *T. musullah* (Kulkarni and Ogale, 1986; Ogale, 2002) and snow trouts; *Scizothoraichthys niger, S. esocinus, S. micropogon, S. curvifrons* and *S. richardsonii* (Raina *et al*., 1985 a, b). With the availability of technology of controlled seed production of most of the important species today, it is necessary that small hatchery units are established in different regions as decentralized resource centres.

Brackishwater Finfish and Shellfish Species

Success in breeding and seed production of Indian white shrimp (*Fenneropenaeus indicus*) under controlled conditions was achieved at Narakkal (Kerala) (Muthu and Laxminarayana, 1977; Halder, 1978; Silas *et al*., 1985). Small-scale hatchery technology was developed for *F. indicus* and for black tiger prawn, *Penaeus monodon* by Laxminarayana *et al*. (1995) and Rao *et al*. (1995). By 1978, studies on the life history of almost all the penaeid shrimps under captivity were completed and morphological features of all the larval stages documented. Though male penaeids were found to mature and mate in estuarine phase of their life cycle, females of most of the species do not mature in estuaries or in captivity. Therefore, initially the shrimp hatcheries were dependent on the fully-matured wild spawners for the production of larvae. Adiyodi and Adiyodi (1970) showed that removal of GIH through eyestalk ablation leads to maturity in most of the decapod crustaceans. The technique was successfully employed by Alikunhi *et al.* (1975) in inducing maturation in *Penaeus merguiensis* and *P. monodon*.

Establishment of two large-scale shrimp hatcheries in Andhra Pradesh and Odisha for *P. monodon*, was a significant step, that led to the establishment of over 350 private shrimp hatcheries with production capacity of about 14 billion PL-20/years in the country (Ravichandran and Pillai, 2011) and thereby to meet the seed requirements. Production of pathogen-free seed is increasingly being emphasized to overcome losses due to WSSV. Specific pathogen free (SPF) broodstock are produced by rearing the shrimps in a high biosecure facility which excludes most of the OIE listed pathogens over a period of 2-3 generations. With the culture of exotic Pacific white shrimp, *Litopenaeus vannamei* taking the centrestage in recent years, the commercial hatcheries were permitted to import specific pathogen free (SPF) domesticated strains.

The mud crab, *Scylla serrata*, considered one of the tastiest of all crab species, is an important candidate for brackishwater aquaculture. The success in developing seed production technology of the species has opened up avenues for commercialization of mud crab culture technology (Srinivasagam *et al*., 2000).

Among the brackishwater finfishes, technology for the breeding and seed production was developed for seabass, *Lates calcarifer* and pearl spot, *Etroplus suratensis* (Arasu *et al*., 2009; Padmakumar *et al*., 2009a). Attempts to breed the grey mullet, *M. cephalus* in captivity in the country since 1960s has shown some degree of success in spawning and larval rearing (Mohanti, 1971; Chaudhari *et al*., 1977; Rajyalakshmi *et al*., 1991; Krishnan *et al*., 1996), however, the technology of mass-scale seed production is yet to be perfected.

Marine Species

Mariculture in the country until recently, was confined largely to bivalve molluscs. The technology for seed production of commercially important mussels, oysters, pearl oysters and clams was developed during 1980s (James and Narasimham, 1991). Controlled breeding, spawning and production of pearl oyster *Pinctada fucata* was achieved in 1981 (Alagarswami *et al*., 1983) and *P. margaritifera* in 1984 (Alagarswami *et al*., 1989). The seed production of *P. fucata* and edible oyster (*Crassostrea madrasensis*) was developed by thermal stimulation or chemical stimulation (Victor *et al*., 1995). Methods for cultch-less spat production in the hatchery were also developed (Nayar *et al*., 1984; Rao *et al*., 1992).

In recent years, the seed production and farming of cobia (*Rachycentron canadum*) has gained momentum due to its high growth potential of 8-10 kg in two years. Broodstocks were developed in sea cages and the species was successfully induced bred and seed production achieved in 2010. Broodstock development and spawning of the greasy grouper, *Epinephelus tauvina* under controlled conditions was accomplished by Mathew *et al*. (2002). Seed production of sea cucumber, *Holothuria scabra* (James *et al*., 1988) and *H. spinifera* (Asha and Muthiah, 2002) and the sand lobster, *Thenus unimaculatus* (Gopakumar *et al.*, 2007) have provided for diversification.

Ornamental Fish Species

Captive breeding and larval rearing of several indigenous freshwater and marine ornamentals were standardized in the recent years, with 12 species from Western Ghats by Anna Mercy *et al*. (2007), freshwater ornamentals by Mitra *et al*. (2006) and Swain *et al*. (2011), clown and damsel fish species by Ajith Kumar and Balasubramanian (2009), Gopakumar *et al*. (2011), Swain *et al*. (2011), Dhaneesh *et al*. (2012) and Madhu *et al*. (2012).

Production Technologies

Large-scale adoption of technology-mediated aquaculture, especially carp polyculture in freshwater during last three decades has met the growing domestic needs. With the development of technologies of breeding, seed rearing and grow-out production of a number of finfishes and freshwater prawn species, the culture practices in freshwater sector over the years have also undergone species and systems diversification (Ayyappan and Jena, 2001, 2003). On the contrary, the coastal aquaculture sector has largely remained confined to shrimps, bulk of which is being exported.

Freshwater Culture: The grow-out technology of carp polyculture, often referred to as composite carp culture, that was developed involving three Indian major carps, viz. catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) and exotic silver carp (*Hypophthalmichthys militrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) during 1960s and 1970s through a series of experimental trials (Sukumaran *et al*., 1968; Alikunhi *et al.*, 1971; Lakshmanan *et al.*, 1971; Singh *et al*., 1972; Chaudhuri *et al*., 1974,1975; Chakraborty *et al*., 1975, 1980; Das *et al*., 1975, 1977) was a significant achievement, that subsequently resulted in a kind of 'blue revolution' in the country. Much of the research and development on this aspect further were taken up through an All India Coordinated Research Project (AICRP) on 'Composite Culture of Indian and Exotic Fishes' initiated by the CIFRI during 1971, renamed as 'Composite Fish Culture and Fish Seed Production', operated at 12 centres till 1984 (Sinha *et al.*, 1973; Sinha and Gupta, 1975).

With a view to reduce the cost of production and enhance contribution of natural food in the production systems, studies emphasized effective use of several potential fertilizers (Saha *et al*., 1975, 1978), manurial inputs, viz. biogas slurry (Tripathi *et al.*, 1992), *Azolla* as a biofertizer (Ayyappan *et al*., 1991) and development of weed-based culture, involving grass carp as a major component species (40-50%) (Tripathi and Mishra, 1986; Aravindakshan *et al*., 1999). Studies on intensive carp culture carried out during 1989-1994 demonstrated production levels of 10-15 tonnes/ha/year in all the experiments with highest national production of 17.3 tonnes/ha/year (Tripathi *et al.*, 2000).

In order to provide greater flexibility to the farmers on use of varied inputs, based on their resource availability, environmental characteristics and investment capacity, several packages of practices were also advocated from time to time (Ayyappan *et al*., 1990; Jena *et al.*,2001, 2002a; Das *et al*., 2004, 2012). Multiple cropping and polyculture were found more remunerative as compared to other harvesting systems (Jena *et al.*, 2002b; Ayyappan and Jena, 2005). While production levels of 4-5 tonnes is a common occurrence in most part of the country with the adoption of technology of carp polyculture, several farmers in Punjab and Andhra Pradesh are able to produce 8-12 tonnes/ha/year (Ayyappan and Jena, 2005).

Efforts on species diversification in recent years have led to development of protocol for grow-out farming of some of the regionally important medium-sized carps as components of conventional carp polyculture systems, viz. kalbasu, *Labeo calbasu*; fringe-lipped carp, *L. fimbriatus;* kuria labeo, *L. gonius;* olive barb, *Puntius sarana*; and exotic silver barb, *P. gonionotus* (Jena *et al*., 2007a, b; 2008; Sahu *et al*., 2007; Jena and Das, 2011a, b).

Development of packages of practices of non-conventional culture practices, viz., sewage-fed fish culture (Chatterjee *et al.*, 1967; Ghosh *et al*., 1974), integrated fish farming with cattle, pig, duck and poultry (Jhingran and Sharma, 1980; Sharma and Olah, 1986; Sharma and Das, 1988) and paddy-cum-fish culture (Muddanna *et al.*, 1970; Sinhababu and Venkateswarlu, 1995; Sinhababu, 2011) have shown great potential due to their strong economical viability and possibility of resource recycling (Gopakumar *et al*., 2000; Ayyappan and Jena, 2003).

The importance of catfish farming in the country was realized with the initiation AICRP on Air-breathing Fish Culture', which generated some preliminary culture techniques for *C. batrachus*, *H. fossilis*, *Channa* spp. and *Anabas testudineus*. Production levels of 3-4 tonnes magur/ha under monoculture in small, shallow ponds in 5-6 months culture were demonstrated (Jhingran, 1991). While the importance of diversified farming of several other non-air-breathing catfishes, viz. *Pangasius pangasius, Sperata seenghala, Ompok pabda, O. bimaculatus, Horabagrus brachysoma* was realized quite early (Gopakumar *et al*., 1999), systematic research trials on their grow-out production is taken up only in recent years. Further, research efforts on seed production and farming of climbing perch (*Anabas testudineus*), murrels (*Channa striatus* and *C. marulius*) and feather-back (*Chitala chitala*) in recent years have shown the potential for monoculture of these species.

Integrated aquaculture model

African catfish (*Clarias gareipinus*) and pangus catfish, *Pangasianodon hypophthalmus* (*Pangasius sutchi*) are the two exotic catfishes, which have received great interest amongst the farmers in certain states. While the culture of the former over years has reduced due to its adverse impact, *P. hypophthalmus* has shown large-scale adoption in over 15,000 ha in Andhra Pradesh, resulting in a production of about 0.2 million tonnes. The farming of the species is further gaining increasing attention in northern India owing to its local preference.

Diversification of freshwater aquaculture systems with introduction of high valued freshwater prawns (*M. rosenbergii* and *M. malcolmsonii*) has led to moderate success (Raje and Joshi, 1992; Pillai and Rao, 1997; Kanaujia *et al*., 1997). The giant freshwater prawn, *M. rosenbergii*, being the largest and fastest growing prawn species obviously received greater attention for its farming under monoculture and polyculture with major carps. Better yields were reported under mixed culture of carps and prawns (Riji John *et al*., 1995). Under mixed farming, production levels of 300-500 kg prawn/ha and 2,000-3,000 kg of carps/ha were demonstrated.

Increased emphasis on farming of high-value species has led to initiation of research programmes on pearl culture with freshwater mussels, viz. *Lammellidens marginalis, L. corrianus* and *Parreysia corrugata*, with the former being the most important species (Janaki Ram, 1989). The packages of practices of pearl culture including pre-operative conditioning, implantation of grafts and nuclei, post-operative care and pond culture of implanted mussels were developed (Janaki Ram and Tripathi, 1992). Various surgical procedures, viz. mantle cavity insertion, mantle tissue implantation and gonadal implantation were developed for obtaining shell-attached half round or design pearls; unattached and irregular to oval graft pearls;and unattached and round pearls, respectively.

Mariculture: The earliest mariculture attempt made was in 1958-59 with the farming of milkfish, *Chanos chanos* (Gopakumar *et al*., 2007) and further, culture techniques of green mussel (*Perna viridis*) and brown mussel (*P. indica*) were standardized (Qasim *et al*., 1977; Kuriakose and Appukutan, 1996). Rack method, long line and raft culture methods were used (Kuriakose, 1980) and cultured mussel production of the country has increased from almost none in 1996 to about 18,500 tonnes in 2010.

One of the first reports on oyster farming in India is that of Hornell (1910) who had attempted collection of oyster spat by placing lime-coated tiles in Pulicat lake. Edible oyster farming got an impetus in the 1970s with the natural collection of spat and experimental trials were carried out in different estuaries and backwaters, growing them to adult stage (Rao *et al*., 1983; Mohan Joseph and Santha Joseph, 1983; Purushan *et al*., 1983) and the production rose from 5 tonnes in 1996 to 3,000 tonnes in 2010. Production of triploid *C. madrasensis* with higher growth rate and meat content (126% higher dry weight; 30% more glycogen and lipids) compared to normal diploid individuals (Mallia *et al*., 2006) is noteworthy.

The golden pearl oyster, *Pinctada fucata* producing golden pearls, and the black lip pearl oyster, *P. margaritifera* producing black pearls, are the species producing gem quality pearls. The technology of pearl culture involving introduction of nuclear beads along with a secretory mantle tissue into a recipient oyster was developed in 1973 (Alagarswami, 1974). Success was also achieved in the production of *Mabe* pearls in *P. fucata* using pallial insertion method at Kollam Bay and Vizhinjam, Kerala; *P. margaritifera;* the winged pearl oyster,


Pearl culture


Raft for green mussel culture


Open sea cage culture

Pteria penguin in the Andaman and Nicobar Islands (Kripa, 2011) and on onshore production of good quality pearls larger than 6 mm diameter from *P. fucata* (Pillai and Katiha, 2004).

The seaweed resources of the country are mainly confined to the coasts of Tamil Nadu and Gujarat and some of them, viz. agarophytes (*Gracilaria edulis* and *Gelidiella acerosa*) as raw material for agar industry; carragenophytes and edible seaweeds (*Sargassum*, *Caulerpa*, *Hypnea* and *Turbinaria* spp.) are commercially important. Seaweed culture experiments were initiated in Gujarat in 1964 (Thivy, 1964) for the first time in the country and further refined (Bhanderi, 1974; Chennubhotla *et al*., 1978). Farming of seaweeds is carried out either by vegetative propagation using fragments from mother plants or by reproductive method using different kinds of spores such as zoospores, tetraspores, carpospores, etc. Culture of seaweeds in the country mostly deals with cultivation of *G. edulis*, due to its high regenerative capacity of 1 kg seed material yielding over 3 kg/m^2 of net in 60 days (Gopakumar *et al*., 2007). During the last decade, cultivation of *Kappaphycus alvarezii*, a carragenophyte, has attracted the attention of entrepreneurs along the south-east coast and is spreading to other areas.

Sea cage farming in the country was initiated during 2007 with seabass (*Lates calcarifer*). The potential of the farming practice was demonstrated on both the west and east coasts at Vizhinjam, Kerala; Karwar, Karnataka; Vishakhapatnam, Andhra Pradesh; Veraval, Gujarat and Balasore, Odisha. Achieving success with seabass, farming was recently extended to cobia (*Rachycentron canadum*), groupers (*Epinephelus tauvina*), pompano (*Trachynotus blochii*) and lobster (*Panulirus homarus*). Recently, success was achieved in open sea cage culture of seabass and cobia with production figures of 25 kg/m^3/eight months and 35 kg/m^3/eight months, respectively. Selective intensification and scaling up of these culture systems and developing a package of practices along with formulation of appropriate scientific policy framework can lead to substantial increase in the production of marine fish through open water cage culture (Ayyappan *et al*., 2011).

Inland Saline Water Fish Culture: Land-based aquaculture using saline ground water assumes importance owing to the availability of over 8.57 m ha with twin problems of salinity and sodicity in the states of Haryana, Punjab, Rajasthan and Uttar Pradesh. Experiments on culture of milkfish (*Chanos chanos*) and grey mullet (*Mugil cephalus*) were conducted at salinity levels of 24-28‰ (Dwivedi and Lingraju, 1986). A breakthrough was made in seed production of scampi using inland saline water in 2005 (Raizada *et al*., 2003) and successful grow-out trials were also carried out subsequently (Raizada *et al*., 2005; Allan *et al*., 2009; ACIAR, 2012).

Coastal Aquaculture: Brackishwater aquaculture in India, confined to the *bheries* of West Bengal and *pokkali* fields of Kerala, is a traditional system (Unnithan, 1985). With no additional inputs, except that of trapping the naturally bred fish and shrimp seed, these systems have been sustaining production levels of 500-750 kg/ha/year, with almost 25% contribution by shrimp (George *et al*., 1968). The scientific shrimp farming in the country was initiated during early 1970s (Rajyalakshmi, 1988) and large scale development of shrimp farming using scientific principles in the country in early 1990s. Subsequently with the adoption of scientific methods of shrimp farming, that included stocking of healthy seed, feeding with nutritionally balanced feed, monitoring and maintenance of water quality and health management (Ravichandran and Ponniah, 2011), the shrimp farming in the country took the shape of an integrated practice.

The commercial farming, however, remained confined to black tiger prawn, *Penaeus monodon* owing to its high export potential. The total area under shrimp culture in the country at present is 12.7% of the potential water area of 1.2 million ha (Ravichandran and Ponniah, 2011). With five-fold increase in production over the last one and half decades, shrimp farming has witnessed a shift from *P. monodon* to the exotic Pacific white shrimp, *Litopenaeus vannamei*, due to the its fast growth at higher stocking density, low incidence of native diseases, availability of Specific Pathogen Free (SPF) domesticated strains, culture feasibility in wide salinity range of 0.5-45‰ and better international market (Ayyappan and Jena, 2011).

Brackishwater prawn culture

While there have been attempts at culture of other shrimp species, viz. *Fenneropenaeus* (*Penaeus*) *indicus*, *P. merguiensis*, *Marsupenaeus japonicus* and *P. semisulcatus*, finfishes, viz. seabass (*Lates calcarifer*), pearl-spot (*Etroplus suratensis*) and milkfish (*Chanos chanos*); as also the mud crab (*Scylla serrata*), development viable technologies is needed for commercial farming (Sebastian and Nair, 1975; Padmakumar *et al*., 2009a). An example is the fattening of crab, *S. serrate*, that has opened up avenues for its commercial farming (Kathirvel *et al*., 2004). Grow-out culture of carnivorous seabass (*L. calcarifer*) is another aspect in diversification in the brackishwater aquaculture (Arasu *et al*., 2009). High density farming of *E. suratensis* in floating net cages in open waters of Vembanad Lake in Kerala and adopted by the self-help groups and local *panchayats* (Padmakumar *et al*., 2009b) is highly rewarding.

Coldwater Fish Culture: Aquaculture in hilly cold water areas of the country is still at its infancy, with potentials of cultivable species, viz., trout, mahseers and snow trouts. However, trout farming is being practised in several fish farms of northern India, Tamil Nadu and Kerala (Sarma *et al*., 2010; Mahanta and Sarma, 2010). Although capital-intensive, availability of breeding and hatchery technology of important cultivable species offers potential for adoption of scientific cold water aquaculture.

Ornamental Fish Culture: The ornamental fish trade in the country largely involves freshwater varieties; the breeding of live-bearers till market size is taken up at on a cottage-scale all over the country. Among the egg-layers, the goldfish is the most common species, with others being Angel fish, tetras, Siamese fighting fish and gouramies. With ready market and access to export business, areas around Kolkata, Chennai and Mumbai have become major breeding centres, and units coming up in states such as Kerala, Andhra Pradesh, Odisha and Bihar (Silas *et al*., 2011).

Ornamental fish culture

Fish Nutrition and Feeds

With a transition from natural food to supplementary feeds for intensifying culture systems, fish nutrition research focuses on understanding dietary requirements of cultured species, leading to formulation of several cost-effective diets.

Nutritional Requirements and Feed Formulation

Research programmes on feed formulations with synthetic protein supplements and plant and animal protein source for carps (Mohanty *et al*., 1990; Seenappa and Devaraj, 1995; Jena *et al*., 1996, 1999; Giri *et al*., 2003; Biswas *et al*., 2006 a,b) and catfishes (Venkatesh *et al*., 1986; Giri *et al*., 2003) were undertaken in the last three decades. Under controlled laboratory conditions, optimum dietary crude protein levels for different carp species were in the range of 30-45% (Sen *et al*., 1978; Renukardhya and Varghese, 1986; Das *et al*., 1991; Ali, 1992; Mohanta *et al*., 2008a). Rangacharyulu *et al.* (1996) reported requirement of fishmeal as a major protein supplement for *C. batrachus*. Silkworm pupae, meat meal and chicken viscera were found to be suitable substitutes for fish meal for both carp and catfish feeds (Paul *et al*., 1997; Jayaram and Shetty, 1980; Jena *et al*., 1998c;

Rangacharyulu *et al.,* 2003; Giri *et al*., 2000, 2009). The amino acid requirements of three Indian major carps and other cultivable cyprinids were also evaluated by several workers (Ravi and Devaraj, 1991; Ahmed and Khan, 2004; Abidi and Khan, 2004a, b).

Carbohydrate utilization by carps and barbs received attention due to their herbivorous feeding habit and adequate availability of ingredients like rice bran and wheat bran as cheap sources of digestible energy (Saha and Ray, 2001; Erfanullah and Jafri, 1998; Mohanta *et al*., 2009). Dietary lipid requirement of 7-9% was observed in grow-out stages of carp (Mohanta *et al*., 2008b). Evaluating use of different lipid sources in diets of Indian major carp (*C. catla*) and magur (*C. batrachus*), Mukhopadhyay and Rout (1996) and Mukhopadhyay and Mishra (1998) suggested essential nature of both n-3 and n-6 fatty acids for maintenance of healthy stock and promotion of rapid growth in these species. Paul *et al*. (1998) reported phospholipid (PL) to have influence on higher survival and growth of carp spawn. Studies on dietary nutrient requirement and feed formulation of shrimp species were largely restricted to *P. monodon* and *F. indicus* (Bhaskar and Ali, 1984; Gopal and Raj, 1990; Ali, 1990, 1993, 1994; Syama Dayal *et al*., 2003; Vijayagopal *et al*., 2008, 2009). With an emphasis on species diversification in recent years, attention has been given to nutrient requirements and feed formulation of some brackishwater and marine finfish species (Kandasami *et al*., 1987; De *et al*., 2011, 2012; Ghosh *et al*., 2011). Commercial diets, viz. 'CIFACA' and 'CIFAMA' for the carp grow-out and larvae of magur, respectively, have been commercialized, along with 'Mahima', a shrimp feed and also a trout feed.

Food Additives: A number of feed additives like phytase, citric acid, á-amylase and microbial and fungal cellulases enhance the bioavailability of minerals, reduce the nitrogen and phosphorus load of the culture system, significantly change the fatty acid profile of the tissue and improve the amount of muscle protein (Baruah *et al*., 2005, 2007; Debnath *et al*., 2005; Kumar *et al*., 2006; Biswas *et al*. 2007).

Antinutritional Factors: The presence of protease inhibitors in plant protein sources adversely affect the digestive proteases in fish. Hence, there is a need to eliminate/reduce the amount of such inhibitors through proper processing before incorporation into aquafeeds (Garg *et al*., 2002; Mukhopadhyay and Ray, 2005; Maitra *et al*., 2007).

Digestive Enzymes: While there is an understanding developed on digestive enzymes in fish species with regard to their ontogenic development (Chakrabarti *et al*., 1995, 2006a, b; Kumar and Chakrabarti, 1998; Kumar *et al*., 2000, 2007; Chakrabarti and Sharma, 2005; Rathore *et al*., 2005a, b; Debnath *et al*., 2007), commercial fish feeds incorporating this aspect are yet to be developed (Seenappa and Devaraj, 1995).

Probiotics/Gut Microflora: *In vitro* studies on enzyme production show that bacterial flora in the gastrointestinal tract of rohu are potent producers of proteolytic enzymes and can also moderately produce cellulase (Ghosh *et al*., 2001). Yeast extract powder addition in the diet affected the gut microflora by supplying additional digestive enzymes leading to better nutrient utilization (Ghosh *et al*., 2001, 2005).

Live Food and its Importance: Live food, especially zooplankton, was recognized an important source of natural food for larvae and adults of many cultivable species. A majority of them initially require a micro-zooplankton diet, then progressively feed on larger and different items and make a gradual transition to adult feeding habits (Jhingran and Pullin, 1985). While outdoor larval rearing largely depends on fertilization-mediated *in situ* plankton production, exogenous introduction of live plankton was also demonstrated as a viable management strategy for carp larviculture (Jana and Chakrabarti, 1990a, b; Chakrabarti and Jana, 1991a, b, 1992, 1998; Chakrabarti and Sharma, 1998). Phatarpekar *et al*. (2000), Giri *et al*. (2002) and Mitra *et al*. (2007) evaluated the nutritional value of live plankton diets. Higher survival and growth are reported in post-larvae of *M. rosenbergii* fed with *Artemia* nauplii enriched with probiotic bacterium *Lactobacillus sporogenes* (Seenivasan *et al*., 2012).

Fish Health Management

Initial research efforts on fish health management concentrated on identification and listing of pathogens, bacterial and parasitic diseases in various water bodies with limited chemical control measures (Tripathi, 1955; Gopalakrishnan and Gupta, 1960; Pal and Ghosh, 1975; Pal and Tripathi, 1978). Studies received a thrust in the wake of outbreak of two diseases, viz., epizootic ulcerative syndrome (EUS) in fish and white spot syndrome virus (WSSV) in shrimp in the early 1990s that caused heavy economic loss to the sector. Concurrently, shift in culture conditions from extensive to semi-intensive and intensive conditions favoured the emergence of a large number of emerging, re-emerging and transboundary diseases of viral, bacterial, fungal and parasitic origin either in acute outbreak forms or as latent infections.

Disease Prevalence: The important pathogens reported in Indian freshwater culture systems are: parasitic (*Argulus* sp., *Dactylogyrus* sp., *Gyrodactylus* sp. *Lernaea* sp., Acanthocephalans, Myxosporideans, Digenic trematodes, *Ichthyphthyrius* sp., *Trichodina* sp., fouling protozoans in freshwater prawns including *Zoothamnium*, *Vorticella*), bacterial (motile aeromonads including *Aeromonas hydrophila*, *Edwardsiella tarda*, *Pseudomonas* sp., *Flexibacter columnaris*, *Streptococcus* sp., *Vibrio alginolyticus* and *Vibrio parahaemolyticus*), viral (*Macrobrachium rosenbergii* nodavirus with associated extra small virus) and fungal (*Aphanomyces invadans*, *Saprolegnia* sp.).

The major pathogens that cripple brackishwater sector are mostly viral [WSSV, monodon baculo virus (MBV), hepatopancreatic parvo virus (HPV), infectious hypodermal haematopoietic necrosis virus (IHHNV), Laem-Singh virus (LSNV) of shrimps (Otta *et al*., 2003; Umesha *et al*., 2006; Prakasha *et al*., 2007; Rai *et al*., 2009; Sathish Kumar *et al*., 2011); viral nervous necrosis (VNN) in seabass and grouper irridovirus] followed by bacterial (*Vibrio harveyi* in shrimp hatcheries) along with incidental parasitic (myxosporidia, ciliates, flagellates, sporozoans, cestodes, trematodes, nematodes, crustaceans, acanthocephalans, branchiurans, copepods and leeches) problems. Development of molecular techniques and identification of new sequences provided evidence for the source of this virus entry into India (Pradeep *et al*. 2008a, b). Molecular typing based on these sequences has been found helpful in identifying strains that are generally dormant and strains causing epidemics (Shekar *et al*., 2007). Whole genome sequence of two important viruses of shrimp in Asia, *Penaeus monodon* densovirus (HPV) (Safeena *et al*., 2010) and *Penaeus stylirostris* densovirus (IHHNV) (Rai *et al*., 2011) has been carried out.

Epizootic ulcerative syndrome (EUS) in fresh and brackishwater fishes, first reported in May, 1988 in the North Eastern states of India, spread across the country (Lilley *et al*., 1998) and over 30 species were reported to be affected (Das, 1997). Of the infective agents associated with EUS, the bacterial coenoses, *Aeromonas hydrophila* complex was perceived as a possible primary pathogen (Karunasagar *et al*., 1995). However, from the initial outbreaks, Mohan and Shankar (1995) provided evidence of association of a highly invasive fungus, *Aphanomyces invadans* with EUS in Indian fishes. Experimental infection studies demonstrated that yearlings of Indian major carps are able to resist the infection with *A. invadans* and higher numbers of inflammatory cells and more efficient epithelioid cell layer formation play an important role in the resistance mechanism (Pradhan *et al*., 2007). A protozoan parasite *Perkinsus beihaiensis* in edible oyster *Crassostrea madrasensis* population was reported by Sanil *et al*. (2012), with no disease outbreaks in mariculture systems.

Immunology: Studies on immune responses to various pathogens are important to understand molecular pathogenesis for developing immunoprophylaxis against those diseases. Several studies pertaining to host immune responses to important bacteria (*A. hydrophila*, *E. tarda*) and parasites (*Argulus* sp.) in carps, virus in *M. rosenbergii* (*Mr*NV), bacteria (*Vibrios*) and viruses (WSSV) in shrimp were studied. The ontogeny of immunocompetent organs through histology and immune-related genes of rohu (Nayak *et al*., 2011) was studied to determine the age for vaccination in carps. Also the maternal transfer of immunity in carps was proved (Swain *et al*., 2006). Some of the immune-related genes, viz. toll-like receptors of carps (Samanta *et al*., 2012), lysozymes, ceruloplasmin, transferrin and interleukins (Sahoo *et al*., 2011, 2013) were characterized from important cultured fish species. Expressed sequence tags (ESTs) for immune related genes for few commercially important species, viz. *Labeo rohita* (Robinson *et al*., 2012), *Clarias batrachus* (Singh *et al*., 2012), *P. monodon* and *M. rosenbergii* were generated. The immune molecules in Indian major carps and Asian catfish are still under explored and need detailed characterization through functional genomics approach to draw better understanding on disease development process.

Disease Diagnosis: Several diagnostics, both immunological and molecular, for a wide range of pathogens were developed, enabling understanding of disease development process and developing effective management strategies. ELISA-based diagnostics for *A. hydrophila*, *E. tarda*, *Pseudomonas* sp., Vibrios, WSSV (Swain *et al*., 2003; Makesh *et al*., 2006; Patil *et al*., 2007) (using either polyclonal or monoclonal antibodies), Mab-based immunodot for *A. invadans* (Gayathri *et al*., 2004), immunoperoxidase tests for *Mr*NV and XSV (Shekhar *et al*., 2011; Neethi *et al*., 2012), PCR/RT-PCR based diagnostics for WSSV, *Mr*NV-XSV, bacterial pathogens and parasites (*Argulus* sp., *Perkinsus beihaiensis*) are some of the important developments. Further, dig-labeled OMP based DNA probe for

Aeromonas species (Khushiramani *et al*., 2009) is available. Quantitative real-time PCR assay for Laem Singh virus (LSNV) of shrimp that causes monodon slow growth syndrome (MSGS) (Sathish Kumar *et al*., 2011) and other shrimp viruses (MBV, HPV, IHHNV, WSSV) is being formulated. Diagnostic primers and probes for WSSV, MBV and HPV (Otta *et al*., 2002; Umesha *et al*., 2003) for various purposes is being carried out. Monoclonal antibodies were produced against serum immunoglobulins of *Labeo rohita* (Rathore *et al*., 2008), *Channa striata* (Sood *et al*., 2011) and T lymphocytes of *Catla catla* (Chaudhary *et al*., 2012a) for their use in disease diagnosis and pathogenicity study. While diagnostics are available for a few pathogens, it is imperative to develop rapid, sensitive and farmers'-friendly diagnostics for others and real time PCR-based diagnostics for transboundary pathogens.

Cell Lines: Cell lines are important for viral isolation and other virological studies. Several cell lines have been developed and characterized from different tissues of freshwater and marine fish species, *viz.* eye, fin, heart and swim bladder tissue of *Labeo rohita* (Ahmed *et al*., 2010; Lakra *et al*., 2010b); fin epithelial cell line and heart fibroblastic cell line from common carp (Lakra *et al*., 2010a); macrophage cell line from *Catla catla* (Chaudhary *et al*., 2012b); fibroblast-like cells from eye of *Puntius* (*Tor*) *chelynoides* (Goswami *et al*., 2012), PSCF, a caudal fin cell line from *Puntius sophore* (Lakra and Goswami, 2011); two cell lines, PDF and PDH from the caudal fin and heart of *P. denisonii* (Lakra *et al*., 2011; Swaminathan *et al*., 2012); TTCF, a fibroblastic cell line from *Tor tor* (Yadav *et al*., 2012); fin tissue cell line from *Clarias batrachus* (Babu *et al*., 2011); cell lines from fin, eye, gill, kidney and brain of *Etroplus suratensis* (Swaminathan *et al*., 2010; Sarath Babu *et al*., 2012); a pluripotent embryonic stem cell-like cell line designated as SBES from blastula stage embryos of Asian sea bass, *Lates calcarifer* (Parameswaran *et al*., 2007a); two cell lines, SIMH-fibroblastic and SIGE-epithelial from the heart of milkfish, *Chanos chanos* and the eye of grouper, *Epinephelus coioides* (Parameswaran *et al*., 2007b). These cell lines will have tremendous impact on understanding of viral pathogenesis as well as in vaccine development, besides their role in *in vitro* toxicity studies.

Control Measures

Initial studies focused on use of antibiotics and chemicals/pesticides for control of fish diseases, however, there is a shift towards preventive measures and development of ecofriendly substances.

CIFAX for EUS: CIFA, Bhubaneshwar made a breakthrough in developing CIFAX, a chemical formulation that helped in prevention and control of EUS.

Vaccines: Studies were carried out on laboratory scale with whole cell inactivated vaccines, various forms of subunit vaccines and biofilm based vaccines against *A. hydrophila* and *Edwardsiella tarda*, with partial success. Reports on development of recombinant outer membrane protein-based vaccines for *E. tarda* (using ompA) (Maiti *et al*., 2011) and *A. hydrophila* (using ompts, Aha1, ompW, omp48) (Khushiramani *et al*., 2007, 2012) in Indian major carps were encouraging. The vaccine potential of rough attenuated variants derived from two smooth virulent types of *A. hydrophila* proved their effectiveness to be used as candidates for fish immunization (Swain *et al*., 2010). Nanoparticles such as poly d, l-lactide-co-glycolic acid (PLGA) microparticles (Behera *et al*., 2010), surface modified poly-[-caprolactone microspheres (Behera and Swain, 2012), calcium phosphate nanoparticles (Behera and Swain, 2011) and chitosan coated egg yolk lecithin based liposomes (Behera *et al*., 2011) proved to be suitable antigen carriers in carps, enhancing both innate and specific immunity, and could be used in fish vaccination programmes.

Efforts are underway to produce DNA vaccine designed to express double stranded RNA that inhibits the expression of the crucial viral gene vp28 of WSSV and rendered protection up to 75% upon challenge (Krishnan *et al*., 2009). By the use of dsRNA, it was possible to control WSSV in tiger shrimp by targeting both the structural and non-structural genes of the virus (Sanjuktha *et al*., 2012).

Immunostimulants: Considerable efforts have gone into screening and development of immunostimulants for different stages of fish and shrimp to protect from divergent pathogens (Sahoo, 2007) that led to development of products, viz. immunoboost C for carp broods, CIBASTIM and Aquastim MBL for shrimps. Besides, a few herbal products, viz. seed extracts from medicinal plant *Achyranthes aspera* (Chakrabarti *et al*., 2012), garlic and ginger extracts, neem plant materials, etc. were also used in stimulating the immune system of fish and rendering defence against bacterial diseases. The ameliorative effects of aflatoxin induced immunosuppression by beta, 1,3 glucans, levamisole and vitamins C and E were found useful (Sahoo and Mukherjee, 2002).

Probiotics: Several brands of live feed supplements, probiotics, are widely used in aquaculture, particularly the probiotic strains of lactic acid bacteria and *Vibrios* from cultured species (Ninawe and Selvin, 2009).

Bacteriophages: Studies were carried out to examine the antibiotic resistance in the shrimp larval pathogen, luminous *Vibrio harveyi* and persistence of this organism in shrimp hatcheries by formation of biofilms. Bacteriophages belonging to Siphoviridae family were found potential candidates to reduce *V. harveyi* load in prawn hatcheries (Karunasagar *et al*., 2007). Based on these findings, a consortium of phages for therapy has been commercialized in India.

Disease Resistant Fish: A significant breakthrough was made in production of selectively bred aeromoniasis-resistant rohu with selection response of 56.7% in first generation of disease resistant line (Sahoo *et al*., 2011). Further, serum ceruloplasmin was found to serve as an indirect immune marker for selection of carp for resistance to aeromoniasis (Sahoo *et al*., 2013).

Fish Physiology

The research activities on fish physiology in India are quite widespread, with several universities actively involved in undertaking studies pertaining to reproduction and endocrine regulation, digestion, respiration, osmoregulation, excretion and other stressors since pre-independence period. Development of the technology of hypophysation through administration of exogenous pituitary extract resulting in successful spawning of fish is probably the biggest contribution of research on reproductive physiology. The nervous and endocrine systems of vertebrates act in concert to coordinate reproductive events. Major links in the chain of events leading from the perception of environmental stimuli to the release of gametes occur through brain-hypothalamo-hypophysis-gonadial axis. The reception of the environmental stimuli is mediated by the nervous systems and involves the passage of information from sensory receptors to the brain. It is well known that hormones produced from brain, pituitary and gonad regulate the reproduction in fishes. While GnRH stimulates the release of pituitary GtH into the blood circulation, GtH in turn regulates the function of the gonad. The cellular and molecular mechanism of gonadal development including the role of gonadotropin (GtHs) and final maturation of oocytes and spawning in fish species like carps and catfishes were studied by several workers (Guraya *et al.*, 1977; Singh and Singh 1983; Narayan *et al.*, 1985; Singh *et al.*, 1987; Chatterjee and Chakrabarti, 2014). The understanding of structure of GnRH has led to development of synthetic analogue of salmon GnRH by Syndel Laboratory Canada, which is used extensively for breeding of different fishes in the country. GnRH was isolated and purified from the hypothamus of two Indian teleosts (Bhattachharya *et al*., 1990 and Haldar *et al*., 1991). Studies were also undertaken to understand role of vitellogenin in formation of yolk (Nath and Maitra, 2001). (Sundararaj and Vasal (1976) demonstrated longer exposure of photoperiod in conjunction with higher temperature to induce faster gonadal development in *Heteropneustes fossilis*. Such information could be of practical relevance in off season breading of three Indian major carps (2010).

X-organ-sinus gland system is neuroendocrine organ in optic ganglia of crustaceans' eyestalk synthesize and excrete several kinds of neuropeptides (Adiyodi and Adiyodi, 1970). These hormones could regulate several metabolic processes in crustaceans. Demonstration of vitellogenesis and precocious maturation of ovary of penaeid shrimps, viz. *Penaeus monodon* and *Fenneropeneous indicus* and crab *Paratelphusa hydrodromous* achieved with eyestalk ablation (Muthu and Laxminarayana, 1977; Mohamed and Diwan, 1991) could be effectively used for controlled spawning of these species. In addition to reproduction, other physiological and metabolic processes are affected by the removal of the X-organ sinus gland complex located in the eyestalk. The effect of unilateral and bilateral eyestalk ablation on the concentration of several haemolymph metabolites, phenol oxidase system, moulting and growth in female and male crustaceans from Indian waters were investigated by Subhashini and Ravindranath (1981), Radhakrishnan and Vijayakumaran (1984) and Diwan and Usha (1987). This could suggest an endocrine control of this mechanism. As a consequence of reducing or suppressing moult-inhibiting hormone (MIH) production, the duration of the molting cycle was significantly shorter in eyestalk-ablated crustaceans (Adiyodi and Adiyodi, 1970; Dayanithi and Ravindranath, 1981).

There has been considerable research interest in bioenergetic studies on aquatic organisms over the last few decades in Indian Universities. Relationships between feeding rates, metabolism, oxygen consumption or growth rates of fish subjected to different environmental conditions. Bioenergetics experiments were carried out to quantify consumption, growth, and activity rates of different fishes and crustaceans (Ameer Hamsa and Kutty, 1972; Arunachalam *et al*., 1976; Mohamad Kasim, 1986; Pandian and Vivekanandan, 1976; Ponniah and Pandian, 1986; Vivekanandan and Pandian, 1977; Nagarajan and Shasikumar, 2002). Bioenergetics modeling has the potential to provide insight into the mechanisms in relation to habitat utilization and fish production.

Biotechnology Application in Fisheries

Chromosome set manipulation for inducing ploidy, production of androgens, gynogens and monosex population were attempted by John *et al*. (1984, 1988), Reddy *et al*. (1987, 1990) and Pandian and Koteeswaran (1998). The first Indian transgenic zebra fish was generated in 1991, followed by the first triploid transgenic *Brachydanio rerio* in 1995 (Sheela *et al.*, 1998; Pandian *et al.*, 1991; Pandian and Marian, 1994). Transgenic rohu and singhi grew faster than the respective controls and converted food at a significantly higher efficiency, exhibiting four times higher growth rate in culture conditions (Pandian, 2003). The growth hormone (GH) gene along with its regulatory sequences of six *Labeo* species (*L. rohita, L. calbasu, L. fimbriatus, L. gonius, L. bata*, and *L. kontius*) was isolated and characterized (Rajesh and Majumdar, 2007) and autotransgenic gene constructs of *L. rohita* were prepared having either histone 3 or â-actin promoter (Rajesh and Majumdar, 2008).

DNA barcoding has applications in accurately identifying fishes, fish eggs and larvae; fish product/meat sample of a species and in resolving taxonomic ambiguity including discovery of new species. Reference DNA barcodes of more than 500 finfish species and shellfishes reported from Indian waters were prepared by NBFGR, Lucknow and other agencies (Lakra *et al*., 2009, 2010c; Divya *et al*., 2010; Sachithanandam *et al*., 2012). DNA barcoding was also successfully employed in a legal case in Kerala for forensic examination of whale shark meat (*Rhincodon typus*) (Sajeela *et al*., 2010) and in identification of cooked pomfret (*Pampus chinensis*) served in a restaurant in Mumbai. Reliable reference DNA barcodes are yet to be developed for many other commercially important aquatic groups and this calls for concerted, joint efforts of molecular biologists and traditional taxonomists to generate accurate baseline information.

The ability to characterize individuals at a variety of gene loci has led to far greater information on the genetic stock structure of wild populations, that has found particular applications. Efforts in recent years have led to development of polymorphic microsatellite loci (Mohindra *et al*., 2001, 2004, 2005, 2007; Gopalakrishnan *et al*., 2004, 2009; Punia *et al*., 2006; Singh *et al*., 2008; Singh *et al*., 2012) and description of population structure for 24 prioritized Indian finfish and five shellfish species (Lal *et al*., 2004; Chauhan *et al*., 2007; Gopalakrishnan *et al*., 2009; Goswami *et al*., 2009; Abdul Muneer *et al*., 2012; Singh *et al*., 2010, 2011, 2012; Mandal *et al*., 2011, 2012; Chathurvedi *et al*., 2011, Luhariya *et al*., 2011; Das *et al*., 2012). Distinct population structure was observed in many of these species indicating that propagation-assisted restoration programmes must be stock-specific to replenish declining populations.

Barman *et al.* (2012) and Rajesh *et al.* (2012) reported differential expression of genes associated with salinity tolerance in *M. rosenbergii* and *P. monodon*, respectively. Barman *et al*. (2010) identified three novel transcripts in the spermatogonial cells of rohu, with potential for utilization as biomarkers. Mohindra *et al*. (2012) generated 1,937 ESTs from spleen of *Clarias batrachus* of which, 221 contained microsatellite repeats (EST-SSR); and 31 SNP loci, useful in linkage mapping, comparative genomics studies and for genetic improvement programmes of magur.

Application of microbe-mediated processes of biofertilization, processing of organic matter, biofiltration and waste recycling has been demonstrated in aquauclture (Ayyappan, 1994). Tissue culture technology for marine pearl production in *P. fucata* and abalone *Haliotis varia* (Dharmaraj and Suja, 2003; Gopakumar *et al.*, 2007) and freshwater mussel, *Lamellidens marginalis* (Barik *et al.*, 2004) has enabled enterprises in the area.

Post-harvest Technology

In India, advancements in post-harvest sector had taken place after 1950 with the focus on export of fish products. Major technological advancements over the century have been in fish preservation, processing, packaging and improvements in processing machinery.

Fish Processing

Among preservation techniques, sun drying is a traditional preservation technique widely practised along the coastal states. Drying on raised platform/ rack, solar driers and irradiation preservation are the improvements made in recent years. Salting and smoking are the other two preservations methods widely used. Modern smoke kilns and use of liquid smoke were found effective in imparting desired colour and flavour to smoked products and reducing the risk of benzopyrene. Hygienic drying was demonstrated for small-scale enterprises, especially for fisherwomen and smoke kilns were successfully installed in various north eastern states where smoked fish is a delicacy.

Polymer based materials are widely used in packaging of fishery products. As these films have disadvantages such as poor barrier properties and inadequate mechanical strength, many types of co-extruded and laminated materials with low permeability and good heat seal strength are being used for packing dried, chilled, frozen and other fish products, also for transportation (Gopal and Ravishankar, 2001). Cost effective reusable, collapsible, corrugated polypropylene boxes were developed for transportation for short distance. Insulated and refrigerated trucks have become an integral part of the cold chain for long distance transportation.

Introduction of icing helped to enhance the shelf-life of fish and reduce the post harvest losses. Refrigerated seawater and chilled seawater systems were introduced for onboard preservation of the catch. Later on, technologies were developed for the production of rapid ice and also non-conducting synthetic materials like expanded polystyrene and other synthetic packaging systems for carrying ice to the landing places and factories. Vacuum and modified atmosphere packaging enhance the chilled storage life of fish and shellfish (Gopal *et al*., 1986). Recent techniques like active and intelligent packaging techniques, *viz.* O_2 scavenger, CO_2 emitter (Mohan *et al*., 2008, 2009, 2010), moisture regulator, antimicrobial and antioxidant packaging have enabled enhanced shelf-life of fish products.

Freezing of fish started as an export oriented activity and initially only whole fishes were frozen and later on, value added products like fillets, steaks, cooked shrimps, squid, cuttlefish, octopus and battered and breaded products have been developed (Joseph, 2003). Freeze drying technique was developed for the production of low moisture products, that have good demand due to their better appearance, flavour, colour, quality and rehydration properties. Extrusion techniques were widely used for developing snack foods from fish and shellfish in combination with cereal flours. Metallised films are ideal material for packing extruded fish products (Gopal *et al*., 2008). Equipment for extrusion and packing under inert atmosphere were also developed indigenously (Gopal *et al*., 2007).

Canned fish products from India had high demand during 1950s and later on the high cost of tin cans resulted in the closure of the canning industry. However, introduction of tin free steel (TFS) cans with easy open ends and flexible retortable pouches helped revive the thermal processing industry. Many ready-to-serve fish and shell fish products were standardized in retortable pouches and TFS cans with a shelf-life of more than a year at ambient temperature (Gopal *et al*., 2001; Ravishankar *et al*., 2002; Mallick *et al*., 2006).

Apart from the edible portion, other fish parts like fish offal, fish scale, head, fish skin, shrimp shell waste, cephalopod skin and gut waste, etc. pose environmental threats. Several technologies are now available for converting waste into high value byproducts, including use of fish meal and fish oil for fish and poultry feed. Shrimp waste accounts for nearly 50–55% of the total weight, mainly comprising head and body shell. Chitin and chitosan prepared from shrimp waste has various industrial, nutraceutical and pharmaceutical applications. Industries have actively taken up production of by-products like chitosan and gelatin for further nutracuetical and food applications.

Biochemistry and Fish as Health Food: Chemical and analytical methods were developed and standardized to determine the fish spoilage using carbonyls and nucleotides as biomarkers. The enzyme systems responsible for the deteriorative changes of biomacromolecules in fish were isolated and characterized. Studies on knowledge of proteolytic enzymes provided valuable inputs for evolving of suitable method of preservation of fish. Investigations on the activities of polyphenolases contributed significantly in the improvement of quality and shelf-life of the fishery products. Thus, the melanosis blackening in crustaceans could be effectively prevented by applying chemical treatment and controlled environment (Antony and Nair, 1975; Mukundan and Nair, 1977). Nutrient composition, amino acid, fatty acid and mineral profile of majority of fish and shellfish available in Indian waters were documented (Gopakumar and Nair, 1972).

Fish plays a vital role in human nutrition as it provides all the essential nutrients, particularly protein of high biological value. Marine lipids are characterized by a high degree of unsaturation and PUFA extracted from fish lipids were found to

Fish processing and product development

exhibit many pharmacological and bioactive properties. They are good source of vital ω-3 fatty acids mainly eicosapentanoic acid (EPA) and docosahexanoic acid (DHA), which are known to support proper cognitive and mental development in children. Enzymatic and chemical methods were developed for the extraction of ω-3 PUFA concentrate rich in EPA and DHA in fish oils (Gopakumar and Nair, 1967; Kamdar *et al.*, 1967; Anandan *et al.*, 2007). Nutritional benefits of dietary chitin/chitosan supplementation were also examined in detail (Anandan *et al.*, 2004). The pharmaceutical properties of glucosamine in alleviating ulcer and arthritis were also studied. The marine potent isoprenoid antioxidant, squalene richly present in shark liver oil was found to prevent arsenic poisoning and aging in rats (Farvin *et al.*, 2004; Rajesh and Lakshmanan, 2008). Squalene is reported to possess antilipidemic, antioxidant and membrane stabilizing properties.

During the last two decades, emphasis has been given to the extraction of many valuable bioactive molecules from marine resources for incorporation in nutraceutical products. The rheological properties of the proteins and lipids of fish were optimized to modulate the process parameters required for stable fishery products. The influence of food additives such as phosphates, citrates and sugars in modulating the functional properties of proteins during different storage conditions were investigated (Devadasan and Nair, 1971). Nutritional benefits of dietary chitin/chitosan supplementation, pharmaceutical properties of glucosamine in alleviating ulcer and arthritis, antilipidemic, antioxidant and membrane stabilizing properties of squalene were also studied (Anandan *et al.*, 2004). The oyster peptide extract recently developed is found to have strong immune stimulatory, anti-inflammatory, antioxidant and antibacterial properties (Asha *et al.*, 2012).

Collection, isolation and classification of marine organisms, such as micro-algae and macro-algae, microorganisms including cyanobacteria, sea anemones, tunicates and fish from the Indian Ocean and extraction, isolation and characterization of useful bioactive compounds, as well as algae-based biofuels are future research areas.

Quality and Safety of Fish and its Products

The export of fish and fishery products from India has increased from ₹ 3.92 crore in 1961-62 to ₹ 30,200 crore in 2013-14. In association with the Bureau of Indian standards, National voluntary standards for production of various forms of frozen, cured, smoked and canned fishery products were recommended. When European Union regulation was implemented during 1995, the concept of Hazard

Analysis Critical Control Point (HACCP) was made mandatory for all export oriented units.

Conventional culture methods are the most reliable and accurate techniques for food-borne pathogen detection (Lalitha and Gopakumar, 2000; Kumar *et al*., 2008; Das *et al*., 2009). Recently, real-time PCR based methods have emerged as a leading technology for rapid identification and quantification due to their speed and high degree of sensitivity (Kumar *et al*., 2010). Using DNA markers, it is possible to trace the source of contamination within a food manufacturing process (Kumar *et al.,* 2008). Quality problems and the specific spoilage flora of fishery products like dried fish, canned fish, vacuum and modified atmosphere packed fish were identified for extension of shelf life and quality and safety (Lalitha *et al*., 2005; Lalitha and Surendran, 2006; Manju *et al*., 2007).

Several rapid methods were developed to detect seafood-borne pathogens/ shrimp viral pathogens/toxins and multiple infections in fishery products and cultured fish/shrimp. Major thrust in the coming decades should be on novel diagnostic methods for detection of fish/shrimp pathogens and fish-borne pathogens and evolving control strategies. Fool-proof, novel and high resolution source tracking of pathogens using molecular typing and refinement in the detection methods for antibiotic residues and bacterial inhibitors in farmed and processed fish need to be undertaken. Development of Farm-to-Fork Food Safety Management System (FSMS) protocols for traceable and safe fish and fishery products and controlling food safety hazard with validated control measures is an emerging food safety and trade requirement. Improvements in the domestic marketing sector need to be stressed with monitoring of emerging pathogenic microorganisms in fish landing centres, production centres and fish markets.

Path Ahead

Looking at way ahead, the annual fish production of the country is projected to be 12.70 million tonnes by 2020. Taking a long-term perspective it is expected that the requirement of fish would be much higher than the production from the available resources. In order to meet the demand, it is necessary that the growth rates in the production from different sectors, especially in aquaculture sector, are enhanced. This would require greater emphasis on environmental sustainability, effective natural resource management, quality of the produce, post-harvest preservation and value-addition is necessary. We need to tackle the problems of biodiversity loss, depletion of fish stocks, overfishing in coastal waters, oceanic and deep sea fisheries, impact of climate change on fisheries, trans-boundary fisheries including migration of fish stocks. We need to carry out further research on ecosystem health including incidence of diseases, inland and coastal pollution, and large-scale sedimentation of rivers, estuaries and lakes/wetlands. For improving aquaculture, diversification of practices, effective water management, quality seed production and control, introduction of exotics with due quarantine procedures, monitoring emergence of new diseases, farm mechanization should receive attention. The fish marketing issues like cold chain and hygienic fish handling, compliance of code of conduct of responsible fisheries, quality assurance in value-addition, overseas and domestic market fluctuations, disaster management and insurance to be addressed on priority.

The marine fisheries sector must focus on enhancing the gear efficiency and reduction of discards; selective, need/area-based motorization of traditional craft and fuel efficiency; resource-specific offshore fishing; exploitation of deep-sea shrimps and deep-sea lobsters between 120-500 m depth zones. Further, considering the recent success in mariculture, especially the sea-cage culture and potential of the sector, it is envisaged that technologies are developed for controlled breeding and mass-scale seed production of diversified cultivable finfishes; grow-out farming in cages; development of different types of re-circulatory and raceway systems for land-based mariculture. Seed production of sea cucumbers, sand lobsters, crabs, etc. may also require certain degree of attention for diversification of mariculture in the country.

In coastal aquaculture, sound research back up would be necessary on species diversification, *i.e.* from the present dependence on two shrimp species, *viz. Penaeus monodon* and exotic *Litopenaeus vannamei* to a wide spectrum of candidate species. Development of technologies of captive broodstock and domestication of identified finfish and shellfish species; protocol for supply of pathogen-free seed; development of environment-friendly and cost-effective culture technologies of both shrimp and finfish; protocols for water quality management in culture ponds including effluent treatment measures; and comprehensive health management approach in shrimp hatcheries and farms, including development of diagnostics, therapeutants, probiotics and vaccines need greater focus in coming years.

Improving and spread of culture-based fisheries in large number of suitable water bodies provide ample opportunity for fisheries enhancement and will bring in more equity among landless fishers. Further researches need to focus on yield enhancement in small and medium reservoirs and wetlands with due importance on environmental upkeep; large-scale cage and pen culture in reservoirs; formulation of appropriate management norms; development of ecosystem-based models; scientific estimation of environmental flows for the riverine systems for sustenance of fisheries is essential. Further, the research thrust on upland coldwater fisheries in the country envisaged to focus on promotion of trout and mahseer farming through scientific management for enhancing production, including mass-scale seed production; fish stock enhancement in upland reservoirs; need-based modification of carp farming in mid-altitude waters to other hilly regions.

Considering the availability of technologies and proposed plan to enhance the mean pond productivity to 4 tonnes/ha/yr in the next decade, it is necessary that the research should focus on diversification of species and systems; selective breeding in important fish/shellfish species for useful traits; programmes on transgenics for disease resistance; stem cell development, genomics, proteomics and nanotechnology; quality seed production of potential finfish and shellfish species including ornamental fishes; farm-made feeds and commercial feeds to suit different levels of farming. Stock characterization of commercially important species; milt cryopreservation as a tool for stock up-gradation and *ex-situ* conservation; impact of exotics; and development of molecular markers and their use in molecular taxonomy would need greater attention towards effective biodiversity management and stock up-gradation. As capture fisheries is still an important component of Indian fisheries, due importance needs to be given to habitat restoration and fish conservation in different ecosystems. Further, considering the recent development of several new sciences, it is necessary that the researches in fisheries are also emphasized in the areas of stem cell development, genomics, trancriptomics, proteomics and nano-technology.

With the road maps being brought out for enhancing productivity and production in different segments, it is expected that the fisheries sector would increasingly contribute to the nutritional security. However, it is necessary that the research-development linkages are strengthened further to utilize the relevant outputs of the all of our research programmes undertaken by the key fisheries institutions of ICAR and other relevant organizations under different ministries and Universities.

Summary

India with sizeable marine and inland fishery resources encompassing huge variability of ecosystems and fish diversity offers a great potential to harness it for food, nutrition security of our people including livelihoods to millions of fishers operating along these resources. To translate this vision of harnessing potential for societal benefit required a strong science-led approach.

This approach was initially strategized through knowing, characterizing and documenting our fish stocks, to carry out this task at National level, Zoological Survey of India was set up in 1916. This important work on fish taxonomy and descriptive natural history carried out by ZSI was the basic information on the identification and distribution of fish stocks so critically needed for any stock management initiative. The fish stocks were exploited from varied ecosystems for livelihoods and markets, without any knowledge-based regulation, resulting decline in stocks both in-terms of quantity and quality, eventually impacting economic returns on fishing itself. To address this problem we needed the scientific information on ecosystem properties, functions, interaction with environment and understanding of fish biology including ecology. Accordingly trained manpower was needed with adequate institutional structure. This led to the establishment of specialised fisheries research institutions, viz. Central Marine Fisheries Research Station (renamed as Central Marine Fisheries Research Institute-CMFRI) and Inland Fisheries Research Station (elevated and renamed as Central Inland Fisheries Research Institute-CIFRI) in 1947 for generating these critical information on marine and inland sectors, respectively. Establishment of these institutes not only helped in creating trained manpower but provided a strong base to the fisheries research of the country on the aspects of locating productive fishing grounds, fish stock assessment, fish biology, generation of ecological databases on fish habitats, designing and refinement of fishing crafts and gears for fishing effectively. All this understanding of science behind fish and fisheries helped the scientists to provide necessary guidance to fishers and development departments to implement the required policy measures to conserve and harness the stocks in a sustainable manner.

The fisheries research focusing on fish catch estimations and structure including population studies in our marine and coastal waters was spearheaded mainly by CMFRI and supplemented by other institutions established from time to time in the coastal states. In comparison, the inland institute (CIFRI) while looking basically at capture fisheries problems was slowly and seriously addressing important fish farming issues especially in respect of Indian Major Carps through a group of scientists working at its Pond Culture Centre. This pioneering group was responsible to develop basic protocols for aquaculture, which in years ahead revolutionised the carp farming in the country. The scientists at the centre also estabilished a strong linkage between pondfertility and fish production-this has become an important management tool. This eventually led to establishment of independent institute CIFA in 1987. The scientists at this institute over time not only up-scaled the existing aquaculture technologies responsible for fresh-water blue revolution in the country but developed new frontline technologies that resulted in developing improved strain of rohu giving 17% higher growth, effective disease diagnostics and control, diversification of species, aquaculture engineering and mechanization, feed and nutrition, including integrating aquaculture with other farming systems. All these improved technologies resulted in achieving average fish production of over 3 tonnes of production per hectare of water area.

During the same period through an All India Coordinated Project on Brackish-water Fisheries based at CIFRI, the science of farming key brackish-water shell and fin species was being developed. The technologies generated helped in improving the productivity of prawns, establishment of exclusive institute CIBA for brackish-water fishery research and developing trained manpower in this specialised field. Similarly through another CIFRI based All India Coordinated project on Reservoir Fisheries helped us to generate scientific information on our reservoirs in the country useful for testing different enhancement protocols to improve their fish productivity.

While significant science-led development was taking place in freshwater and brackish-water aquaculture in the country, the issues of biodiversity, environment and sustainability were getting focused. To address these issues , the initial efforts of Zoological Survey of India had to supplemented with new knowledge of genetics, biotechnology , documenting biodiversity with habitat variables led to establishment of NBFGR . This institute through the efforts of scientists by making use of new tools of biotechnology and genetics generated valuable information on stock characterization including suitable genetic traits for fish improvement programme also developed repository of fish genetic material for future use.

This major initiative of science-led fishery growth in the country needed trained manpower to man these research institutes. To address this critical issue of manpower requirement for the sector, a pioneering role was played by CIFE, which later was elevated to Deemed University in 1989. Their efforts were supplemented by various Fishery Colleges established in selected SAU,s but the contribution of Fishery Colleges at Managlore and Pantnagar have been very significant in Fishery HRD.

Our marine and coastal sector from the very beginning was involved in export of fish and products thereby earning significant foreign exchange for the country.

To address the exporters demand with regard to quality of processing, value addition, packaging, effective harvesting, a specialised institute CIFT was established. This institute has developed engineering protocols for making varied value added fish products including drugs and utilised fish waste into economical products apart from provided scientific backstopping to exporters.

This scientific knowledge generated over the years in fisheries has helped us to achieve significant growth in freshwater aquaculture, make major improvements in brackish water aquaculture, enhance our productivity from reservoirs and wetlands, produce improved strain of fish, promote ornamental fish trade, address the issues of fish disease including control through development of products, better fish nutrition and feeds, more controlled seed production and hatcheries, increase our export share through better processing and value addition, and produced high quality trained manpower for fishery sector. All this contributed to higher GDP for the sector in national economy. These significant development places us globally in a second position in fishery after China.

However, a lot more remains to be achieved in order to meet the protein requirements of the expanding population. A critical appraisal of the situation hints us to focus more on the transfer of existing technologies than to develop more technologies. This is a big challenge; a balance is required to be effected between the knowledge generation and knowledge dissemination. Apart from this technology dissemination issue the biggest challenge fishery sector will face in future is diminishing water resources especially freshwater both in terms of quantity and quality, coupled with climate change scenario, we need to develop suitable mitigation plans and cultivable species that can withstand climate induced stress. We should aim at climate smart fishery and aquaculture.

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