Tropical Marine Fisheries-Role of Central Marine Fisheries Research Institute in Research and Development: Achievements, Ongoing Activities and the Way Forward

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1. Introduction

The Central Marine Fisheries Research Institute (CMFRI) was established by the Government of India, on 3rd February, 1947 under the Ministry of Agriculture and joined the ICAR family in 1967. Over the past 65 years, the Institute has emerged as a leader in global marine fisheries. The present review examines the various aspects on tropical marine fisheries research and development in India, critically examines the existing system of conservation research and proposes a viable alternative of production research for a carbon smart world.

2. Marine Capture Fisheries- Achievements, Initiatives and the Way Forward

One of the major achievements of CMFRI is the development, in 1950, of a unique National Marine Fishery database. Data collection and compilation was refined in 1970, using a "Stratified Multistage Random Sampling" method unique to India. The Institute now has data on 200 species covering the entire coast of about 8000 km. The database provides information on species-wise marine fish landings at all major centres in India, as well as on craft and gear used in the fishery.

It is important to have robust estimates of fishery potential as an aid to manage fisheries resources in the EEZ. However, so far, we have been unable to arrive at figures that are widely acceptable to experts in the field. Prime focus on future fisheries resource research will be oriented towards building a spatio-temporal database on the GIS platform as a decision support tool. Numerical and time-series model data and databases from RS-GIS sources have taken a priority over real time observations and have revolutionised our research. But the evident gaps in *in situ* observation and assessment of fishery resources have to be nullified through regular surveys, sampling and analysis. Automation of landing data estimation, geo-referencing of fish catches, local spawning and fishing ground delineation, resolving physical process supporting the fishery resources, the resource vulnerability to climate change, resource economic evaluation and international trade policies impacting our resources are some of the research areas to be given due attention in the next few years. With climate change impacts making Indian fisheries sector vulnerable to forces other than over-exploitation, the ChloRIFFS (Chlorophyll based remote-sensing assisted Indian Fisheries Forecasting System) programme calls upon a thorough revalidation involving interdisciplinary efforts in marine fisheries research to point out the lacunae and set-right the contradictions between predicted and harvested resources.

Knowledge of stock movement and advisories to the fishermen regarding the availability, season, and abundance of fish such as high valued Yellowfin tuna is very essential. Only very few countries in the world have been able to achieve this. However, highly motivated CMFRI scientists, without any formal training, have succeeded in pop-up tagging efforts, joining an elite group in the world.

Trawl bans are a long term management measure. Very few countries in the world are able to close their fishing operations on a large scale. Over the years, CMFRI, in association with other research organizations and associations/NGOs, has recommended a close on mechanized fishing for

47 days on both the coasts and the Department of Animal Husbandry, Dairying and Fisheries of the Ministry of Agriculture, has been able to successfully implement the ban. This measure has a long term positive effect. Design and development of energy saving selective fishing gear systems through material substitution will lead to substantial fuel savings. Energy saving trawling technologies such as high speed demersal trawls, trawls for deep sea operations and large mesh semi-pelagic trawls are some other innovations in this direction.

Sustaining/rebuilding the marine ecosystems; tidal mudflats, wetlands, mangroves, marshes, estuaries, beaches, lagoons and coral reefs; have also become a prime responsibility in marine fisheries management. CMFRI for the last 6 decades has contributed immensely to biodiversity conservation and continues to do so. Along with the fishing pressure there is also a concern about habitat degradation. A major activity by CMFRI in this direction is with respect to artificial reefs. Artificial reefs enhance sustainability of artisanal fisheries and increase productivity naturally. CMFRI has designed and established artificial reefs along the Tamil Nadu Coast at 50 places, with catch rates increasing at all locations, with up to 10 times the previous catch reported in some. The establishment of artificial reefs may also be considered as an alternative rehabilitation option to mitigate the effects of development activities such as power plants.

3. Climate Change- Visualizing Better Productivity and Production of Marine Fish to Counter the Vulnerability of Coastal Areas

Climate change is one of the biggest global challenges facing mankind and governments worldwide are looking for practical and time-bound strategies and plans for mitigation and adaptation. With the major share of marine fish catch coming from coastal and near-coastal waters, any environmental change in this zone would have a debilitating impact on the sector and on the country's food basket in general. Such aberrations in the marine environment are bound to affect the fish culture initiatives inland as well. Climate change is projected to influence the abundance and availability of the coastal fish stock and is bound to act as a major factor in triggering collapse of stocks in the near future. Warming of waters and sea level rise are two such pervasive factors, which may severely impact the fishery. The patterns exhibited by this environmental upheaval warrant concerted efforts by various domains to study, understand and counter them. Hence, a multipronged research initiative has been set in motion, focussed on all the natural resources including fishery resources.

Climate changes have altered the production and distribution of some commercially important pelagic fishes from Indian waters. Historically, the distribution of sardines and mackerels was restricted to the Malabar upwelling system along the southwest coast (8-16° N latitude) of India. However, clear-cut distribution shifts in these two species have been observed since 1989. Oil sardine emerged as a major species along southeast coast of India, while mackerel fishery has emerged along the northwest coast. Like many other tropical pelagic fishes, Indian mackerel and Indian oil sardine have shown population crashes and sudden recoveries, and very strong inverse relationships. Studies from Pacific and Atlantic Oceans suggest that small pelagic fishes having short life span like 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 in-house project on "Impact and yield study of climate change on the small pelagic fishes", initiated in 2007, investigates the role of ocean-atmosphere variables responsible for the habitat shifting/switching of small pelagic fishes such as oil sardine and mackerel, the phenology related to abundance/spawning from different region along the coast, the influences of El Nino/La Nina events, and the ocean-atmosphere forcing mechanisms on the

fluctuations in the fishery of small pelagics, the inverse relationship between oil sardine and mackerel fishery, and the genetic characteristics and food and feeding habits of newly emerged oil sardine and mackerel fishery in comparison to that of the traditional fishery from the Malabar upwelling system.

Understanding the impacts of climate change and natural hazards is critical for developing adequate risk management strategies. Coastal vulnerability describes the susceptibility of the natural system and of coastal societies (persons, groups or communities) towards coastal hazards. It is a condition resulting from a system's social, economic and ecological properties and is a function of its natural and social coping and adaptive capacity to adverse impacts, namely its resilience. Assessing coastal vulnerability is an important prerequisite to determine areas of high risk, why they are at risk and what to do to reduce the risk. The climate change effects have multidimensional impacts on environment, fishery, social, economic and development drivers. The perception of the primary stakeholders- fishing communities, plays a major role in proactive participation in disaster management, adaptation and mitigation plans. The development of the conceptual framework progressed with identification of the coastal districts and villages based on the different environmental, fishery and socio-economic parameters.

CMFRI implemented the PARS methodology - Parameter, Attribute, Resilient Indicator and Score, a conceptual framework developed for assessing the climate change vulnerability of coastal livelihoods to prioritise and rank the different impacts as perceived by the fishers. The fishers' perception on climate change effects revealed that fishery was the most impacted parameter followed by economic and environmental impacts. Social impact is the least impacted parameters as perceived by the fishers. The study indicates that the long term effects of climate change are not realized/perceived among the fisher households. Fishers perceive that the fishery and economic parameters are of importance in the climate change adaptation and mitigation plan. The level of awareness is minimal which indicates that the fishers could not correlate environmental changes consequent to climate change to their livelihood. The fishers were prone to loss in fishing days due to erratic monsoon. The work done by CMFRI suggests the immediate need to improve on the awareness of the primary stakeholders' knowledge with respect to climate change by involving them in the disaster preparedness, management and mitigation planning and implementation process. Researchers at CMFRI are working on chlorophyll dynamics and fish productivity in a climate change regime, simulation models for forecasting climate change effects, species vulnerability due to climate change, database development and ocean acidification/climate change issues on marine resources.

4. Open Sea Cage Culture: Boon to the Landless

CMFRI has undertaken the large scale demonstration of open sea as well as backwater cage culture in most of the maritime states of India. The technology is purely indigenous and highly economical and sustainable. It is very easy to adopt. Capital investment for a 6 m diameter circular cage in the sea is about Rs. 3 lakhs initially, including the cost of cage frame, nets, mooring, seed and feed. By adopting culture of high value species the production of 3-5 tonnes/ cage can be attained with an economic return of Rs. 6 to 10 lakhs per harvest, spread over a period of 6-8 months depending on the species. The life of a cage frame is above 5 years. The MoA/NFDB have recognized this as a government scheme eligible for 40% subsidy and the technology is gaining lot of popularity among coastal fisherfolks. Seed inputs are abundantly available along the coast and fisherfolks are skilled in collecting them. The feasibility of several species emerging as candidate species for cage culture is due to the on-going breeding programmes and the possible collection

from the sea may be discontinued in the long run. Similarly, there are about 5 large feed mills in Andhra Pradesh with high production potential for manufacturing suitable feed for marine fish.

Demonstration of open sea cage culture, indigenously designed and developed by CMFRI for the first time in India, was successfully accomplished in most of maritime states with high value local species. This has led to raised awareness and increased interest among fishers and state officials. However, to further propagate this on a large commercial scale, open water leasing policies have to be formulated by different maritime states. Several training programmes involving all states including UT of Lakshadweep were conducted and a few farmers have already started commercial operations, with the help of Government sponsored subsidy schemes. Considering mariculture is the best option to enhance the production of high value fish in India, particularly in the context of promoting fish as health food, seed of the high valued fish which are rare in nature are being developed. Breeding of high value marine fish all over the world is highly challenging and though we are late entrants to the field, CMFRI successfully developed the broodstock, induced breeding, seed development and suitable farming technology for four species viz., Cobia (*Rachycentron canadum*), Silver Pompano (*Trachinotus blochii*), Orange spotted Grouper (*Epinephelus coioides*) and Red Snapper (*Lutjanus argentimaculatus*). In addition, the institute has developed several bivalve hatchery and culture technologies and mussel culture has become very popular in Kerala, with production of about 20000t/year. The institute has also developed breeding and seed production technologies for 15 species of high value marine ornamental fish.

CMFRI's grow out experimental feed for Pompano based on feed formulation produced commendable results. Results of this study indicated the highest observed omega-3 fatty acid composition (16.98%) in the fish meat fed by this feed. Hence, the feed is not only available on demand but also is efficient in the fish meat quality it produces. Similarly, there are millions of hectares of low lying saline areas which are not utilized and can be brought under mariculture with suitable incentives from the government/NFDB. CMFRI has established the first Recirculation Aquaculture System (RAS) laboratory in India and marine fish brood bank in these RAS acts as a model for establishing some more RAS in public sector to maintain the quality and quantity for sustainable seed production. The goal is production of fertilized eggs/first day larvae and their supply to the hatcheries at a nominal cost, so that private hatcheries can raise them further and deliver them to the needy farmers at a price. Marine fish broodstock maintenance is complicated and risky. Hence, private entrepreneurs may not be enthusiastic in marine fish seed production. Further, a regulation of fish seed production under public sector also ensures quality seed production. There are initiatives in basic research in marine biotechnology for improved fish feeds for food and ornamental fishes, bio-prospecting, diseases surveillance and stock identification also.

5. Biotechnology and Bio-Prospecting- Recent Activities and the Way Forward

There are active groups working on fish nutrition, bio-prospecting from marine organisms, molecular diagnosis and mitigation of diseases related to marine organisms, genetic stock characterization for effective fishery management of marine resources and molecular taxonomy of commercially important marine species. The major activities which are currently progressing at the institute are as follows;

5.1 Green mussel extract and green algal extract

Millions of people in India suffer from rheumatic arthritic pains. CMFRI, with concerted and focused research, was able to develop and commercialize two nutraceuticals from cultivable marine species- Green Mussel extract (GMe) from green mussel (*Perna viridis*), containing lysolecithin and amidated polysaccharides and Green Algal extract (GAe) from seaweeds, containing sulphated

polysaccharides and phenolic compounds. These compounds which are natural, cheap show selective activity against proinflamatory enzymes, cyclooxygenase2 and lipoxidase5 and proved to safely and effectively relieve the pains, which is a great service to the society. LD_{50} values of both these nutraceuticals were found to be more than 5000mg/kg body weight of experimental animals.

5.2 Mitigation of disease outbreaks

Disease outbreaks are the main setback in the development of aquaculture. Diseases caused by viral and bacterial pathogens result in heavy economic losses to aquaculture. Development and practice of proper management is a must in any farming venture. Stocking of healthy, disease free animals and adoption of prophylactic methods is a must for sustainable aquaculture. The Marine Bio-Technology Division at CMFRI is working on development of various molecular diagnostic techniques for detecting various bacterial and viral pathogens of maricultured species. A highly specific and sensitive RT-LAMP (Reverse Transcriptase-Loop Mediated Isothermal Amplification) technique has been developed for detecting NNV (Nervous Necrosis Virus) infection, which is economical and easy to use as it does not require expensive thermal cyclers to carry out the reaction and the result can be easily interpreted. Nested-PCR as well quantitative PCR techniques have also been developed for the same. Development of vaccines against vibriosis is also progressing in the division. Various vibrio antigens have been cloned, recombinantly expressed and purified for development of subunit vaccines against vibriosis in fish. Under NAIP funded project "Bioprospecting of genes and allele mining for abiotic stress tolerance", genes for tolerance against fluctuations in temperature, salinity and acidity have been isolated from various stress tolerant microalgae using suppression subtractive hybridization technique. The isolated genes have been functionally validated by recombinant expression in *Escherichia coli*. Among the mined genes are some potential candidates for developing transgenic stress tolerant plants.

5.3 Barcoding of Indian Ocean tunas using mitochondrial cytochrome c oxidase gene

Barcoding and phylogenetic analysis of Indian ocean tunas belonging to the family Scombridae (*Tribe Thunnini*) was carried out using partial sequences of mitochondrial cytochrome c oxidase gene. The sequences of *Auxis rochei*, *A. thazard*, *Katsuwonus pelamis*, *Euthynnus affinis*, *Thunnus albacares*, *T. tonggol*, *T. obesus*, *Sarda orientalis* and *Gymnosarda unicolor* were deposited in the Barcode of Life Database (BOLD) and GenBank database of National Centre for Biological Information (NCBI).

5.4 Species-specific molecular markers for green mussel *Perna virdis* and edible oyster *Crassostrea madrasensis*

Species-specific molecular markers were developed and standardized for the identification of the larval stages of these species using species-specific PCR primer based on the CO1 gene. Application of the species specific nested PCR for *P. viridis* and *C. madrasensis* in natural plankton samples was tested and evaluated.

5.5 Studies on genes involved in bio-mineralization process of pearl formation in *Pinctada fucata*

Expression analysis of four genes involved in bio-mineralization process of pearl formation viz. nacrein, prismalin-14, calreticulin and N19 following mabe implantation was studied using semi-quantitative PCR. Housekeeping gene encoding glyceraldehyde-3-phosphate dehydrogenase (GAPDH) was selected as reference for the calculation of relative expression levels of target genes. Expression levels of nacrein, prismalin-14 and N19 showed a predominant up-regulation with slight variations among the different time periods.

5.6 Characterisation of functional gene, superoxide dismutase, from edible oyster *Crassostrea madrasensis*

Characterization of the anti-oxidant enzyme gene, superoxide dismutase (SOD) from *C. madrasensis* revealed the characteristic domains classifying the gene as Cu/Zn SOD. PCR reactions using both genomic DNA as well as cDNA as template resulted in the amplicon of same size viz., 464 bp. This clearly indicates the absence of introns in this gene. This is in contrast with SOD gene of other species where introns are present. It has been suggested that the lack of introns may help to circumvent the block of RNA splicing, allowing the rapid synthesis of proteins. This characteristic enables ready expression of these proteins during periods of stress.

5.7 Selective breeding to develop small artemia using native *Artemia franciscana* strain

Mass selection was practiced to develop small nauplii strain (SNS) following the established method with suitable modifications. Selective breeding was carried out for fifteen generations (F1 to F15). Substantial reduction in naupliar size could be achieved. Naupliar length (first day length - FDL) could be reduced from 517 microns to 439 through selective breeding. Correlated response in other life history biometric traits such as third day length (TDL), sixth day length (SDL), length of male at sexual maturity (LMSM) and length of female at sexual maturity (LFSM) are also calculated.

5.8 Characterisation of HSP 70 gene in *Crassostrea madrasensis*

The Open Reading Frame (ORF) of *HSP 70* gene in *C. madrasensis* was deciphered. Amino acid sequence encoded by the complete coding sequences (CDS) of HSP70 gene was elucidated and their canonical domains detected. BLAST search of the coding sequences have shown 93% identity with *C. gigas,* 92% with *C. ariakensis* and 92% with *Ostrea edulis*. Expression analysis of the stress management genes was carried out. The up-regulation of the stress management genes was found to result in enhanced thermo tolerance in the edible oyster, indicating higher stress tolerance ability.

5.9 Development of pellet feed for marine fish

Developed and launched a sequel of indigenous dry formulated ornamental fish feed *viz.* Cadalmin^{TM}Varna as a substitute for fresh feeds and distributed to aquarium hobbyists, ornamental fish breeders and farmers. 'Varna' is a scientifically evaluated slow sinking marine ornamental fish feed containing, 38% protein, 9% fat, 39% carbohydrates, 7% ash (minerals) and less than 2% fiber. The slow sinking crumbles are available in three particle sizes 0.25 mm, 0.75 mm, and 1 mm produced through twin screw extrusion technology which is the state of art in aquatic feed production.

6. Socio-economics of the Fisherfolk

Fish and fish products recorded the highest increase in price among all food commodities-transforming from a poor man's food to a luxury. The gross value of marine fish at the landing centre and retail level is estimated at Rs. 27,577.1 crores and Rs. 44,054 crores, respectively. The private capital investment in fishing equipments has increased from Rs. 10,352 crores in 2003-04 to Rs. 15,496 crores in 2009-10. The per capita investment per active fisherman is estimated at Rs. 3,11,799 in the mechanized and Rs. 17,205 in the non-mechanized sector. The percentage share of fishermen in consumer rupee (PSFCR) ranged from 40% for oil sardines to 80% for seer fish in private marketing channel. Fishing villages having Self-Help Groups (SHGs) or cooperative fish marketing resulted in PSFCR which is consistently above 70% for all varieties of fish. Domestic marketing system requires more attention on modernization, including quality control. There exists inadequate coastal infrastructure for domestic fish marketing, other than the commercial landing centers. This has led to polarization of harbour based infrastructure development and isolation of

small centers, high level of occupational risks and also inter and intra sectoral marginalization. There is a lack of positive attitude towards non-fisheries livelihood options.

Based on the stakeholder interactions with the institute scientists, the following aspects of fishery socio-economics have to be considered for marching ahead:

- Formulation of a cogent Marine Water Leasing Policy
- Identification of suitable mariculture sites and central sector schemes for community oriented mariculture enterprises (as Open Sea Fishery Estates)
- Biomass augmentation through Artificial reefs and Marine parks
- Promotion of export oriented marine ornamental fish culture as a cottage industry and development of Special Fishery Enterprise Development Zones (SFEDZ)
- Empowerment of fisherwomen through capacity building interventions and training programmes
- Incentives for value addition enterprises
- Investment for coastal infrastructure development (through Public Private Partnership mode)
- Modernization of domestic fish markets
- Special banking schemes for small scale fishery- related enterprises
- Compulsory registration of craft and optimization of fleet size
- Mandatory sea safety measures made
- Introduction of insurance schemes focusing on the fishery sector
- Development of bio-shields, installation of early warning systems, and strengthening PFZ delivery
- Integrated Coastal Zone Development including Responsible Coastal Tourism

7. Conclusion

Marine fishery resources have supplemented the protein requirement in nutrition globally and earned the status of 'cheap protein' during the past five decades. With the increased awareness about quality protein available in fish and other marine resources, there has been a steep rise in demand for marine fish during the past two decades. This period witnessed a spurt in fishing efforts, resulting in dwindling marine fish catches as higher exploitation rates affected sustainability. Globally, there were several instances in temperate waters where certain species and their fishery collapsed. Better diversity, higher fecundity and varied spawning peaks helped the Indian marine fishery to overcome the challenges driven by mechanized crafts in pursuit of high quantity 'cheap protein'. Even though there were peaks and troughs in the inter-annual abundance of fishes landed along the coastal waters of India and other global fishing nations; the trends differed in their decadal growth averages.

Sustainable fisheries management options, if implemented properly, indicate possible enhancement of harvestable potential in Indian EEZ to the extent of 6 million tonnes per annum or more. Opportunities in open sea cage culture and related developments in the field of mariculture during the last 5 years show a way forward in open sea mariculture practices and propose a production ideal to the tune of 4 million tonnes per annum in the coming years from mariculture sector alone. High mariculture production in countries like China is due to production of sea weeds and molluscs, but the Indian sea food market comprises mainly of finfishes of edible standards. If properly implemented, there are possibilities that the marine fish production may be enhanced to the tune of 10 million tonnes per annum (6 million tonnes from capture and 4 million tonnes from mariculture) by 2050.