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COURSE MANUAL

Workshop-cum-Training Programme on Fisheries and Aquaculture

African-Asian Rural Development Organization
2, State Guest Houses Complex Chanakyapuri
New Delhi- 110 021, INDIA

ICAR- Central Marine Fisheries Research Institute
(Indian Council of Agricultural Research)
Post Box No. 1603, Ernakulam North P.O.
Kochi- 682 018, Kerala, INDIA

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International Workshop-cum-Training Programme on "Fisheries and Aquaculture"

14-28 March, 2018

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(*Indian Council of Agricultural Research)*
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International Workshop-cum-Training Programme on Fisheries and Aquaculture

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March, 2018

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FOREWORD

Marine fisheries contribute to food, nutrition, employment and income generation in India. The sector supports about four million people for their livelihood and nearly one million fishermen by way of employment and contributes significantly to the export earnings of the country and balance of trade. The sector contributes to an economic wealth valued at nearly US$10 billion annually. The marine fisheries of the country consist of small-scale and artisanal fishers belonging mechanized, motorized and non-mechanized sectors and a range of other stakeholders, including governmental and non-governmental agencies. Though India is not a leading producer in true mariculture we are second in aquaculture production after China. Coastal aquaculture of shrimp has a major role in aquaculture production and export in India. Even though there is vast scope, recently only India has taken up mariculture technologies to the stake holder level. Due to the success achieved mariculture, it has been identified as a potential source of production enhancement for high valued species like lobster, seabass, cobia and pompano for which the capture fishery is negligible.

I am proud to state that ICAR-Central Marine Fisheries Research Institute (CMFRI) has significantly contributed towards the development of marine fisheries and mariculture in the region, by different means including human resource development and capacity building.

It was with great pleasure that my colleagues and I had this opportunity to host such an important International Workshop cum Training in CMFRI, Kochi, India. **The Manual** released on this occasion covers important aspects of marine fisheries and mariculture prepared by experts in their respective fields. I congratulate the **Course Director and Head in Charge Mariculture Division, Dr. Imelda Joseph and Dr. Somy Kuriakose, Principal Scientist, Fishery Resource Assessment Division** and all other staff members of CMFRI for their efforts in bringing out the Manual in time and to arrange the programme in a befitting manner.

A. Gopalakrishnan

March, 2018

PREFACE

ICAR- Central Marine Fisheries Research Institute (CMFRI) is the premier marine fisheries research institute in India and has the infrastructure and man power for capacity building at any level of stake holders. We have organized a series of international programmes including those with funding from Commonwealth U.K., SAARC (Coastal Zone Management Centre, Male, Maldives), BOBLME, Asian Fisheries Society etc and has played lead role in capacity building in Marine Fisheries and Mariculture in the region. This is our first collaboration with African-Asian Rural Development Agency (AARDO) and I hope it will be the beginning of a long lasting collaboration. It is a great opportunity for the 16 participants from 13 AARDO member countries to visit India and get trained in Fisheries and Aquaculture at the premier national institute. The countries represented are Bangladesh, Republic of China (Taiwan), Iraq, Jordan, Lebanon, Libya, Malaysia, Malawi, Mauritius, Oman, Palestine, Sudan and Tunisia.

H.E. Eng. Wassfi Hassan El-Shrein, the Secretary General and **Dr. Khusnood Ali**, Head & Programme Coordinator, AARDO, New Delhi are gratefully acknowledged for identifying CMFRI in organizing the programme. I thank **Dr. A. Gopalakrishnan**, Director CMFRI for the facilitation in successful conduct of the Training cum Workshop. **Dr. Somy Kuriakose**, Principal Scientist & Course coordinator was also instrumental in running the programme smoothly and I specially thank her for her selfless service and support. I thank Dr. M. K. Anil and Dr. Santhosh for making excellent arrangements at Vizhinajm for the exposure visit of the participants. The resource persons from CMFRI headquarters and centres were very supportive in smooth conduct of the programme. The support from Mariculture Division at Kochi, which includes Technical staff, research scholars and supporting staff also supported us in organising the programme. The support from farmers cannot be ignored. All Heads of Divisions at CMFRI also supported us in this endeavour. I thank the entire Administration and Accounts staff of CMFRI for being such wonderful support.

The Course Manual released on this occasion contains the lecture notes by the resource persons identified for the programme. I am confident that the Course Manual released on this occasion would be of use for the participants to enhance their knowledge and competence in the area of marine fisheries and mariculture and will be of use in their future research in their countries.

Imelda Joseph
Course Director

March, 2018

CONTENTS

ICAR- Central Marine Fisheries Research Institute (CMFRI) at a Glance

A. Gopalakrishnan
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The ICAR- Central Marine Fisheries Research Institute (CMFRI), one of the major fisheries research organisations in the world, has celebrated its platinum jubilee in 2017 to mark the eventful 70 years of research activities by the institute in the area of marine fisheries. Established as a marine fisheries research station on February 3rd1947 in Madras, the institute joined Indian Council Agricultural Research (ICAR) family in 1967 and started functioning as a premier research establishment to undertake marine fisheries research in the country. The headquarters was shifted from Mandapam in Tamil Nadu in 1972.

CMFRI is the lead marine fisheries research institute in India which has played a key role in laying foundation for the tropical marine fisheries research in the region providing services and advises to policy planners and developmental agencies not only within the country but also to the Indian Ocean Rim Nations. The mandate of the institute is:

- Monitor and assess the marine fisheries resources of the Exclusive Economic Zone (EEZ) including the impact of climate and anthropogenic activity and develop sustainable fishery management plans.
- Basic and strategic research in mariculture to enhance production.
- Act as a repository of geo-spatial information on marine fishery resources and habitats.
- Consultancy services; and human resource development through training, education and extension.

From estimation of marine fish landings to its valuation and taxonomic studies, the research activities of CMFRI are diversified to a variety of niche areas such as sea farming and coastal mariculture, development of hatchery technologies for commercially viable marine fish species, cage farming, biotechnological applications of marine resources, biodiversity studies, development of sustainable ecosystem management interventions, policy studies and so on. Apart from the Headquarters at Kochi, Kerala, India, the ICAR-CMFRI, country's premier R&D body in marine fisheries, has 11 Regional Research Centres located at Mandapam Camp, Visakhapatnam, Veraval, Mumbai, Chennai, Calicut, Karwar, Tuticorin, Vizhinjam, Mangalore and Digha, in addition to fifteen field centres throughout the coastal belts of the country and 1 KVK at Narakkal, Ernakulum.There are 154 scientists, 81 PhD scholars and over 600 other staff working at CMFRI in as many as 10 research divisions and we have always targeted the fishermen community in the country for a coordinated research which is demand driven.

Achievements of CMFRI include fish landing statistics, fishing fleet estimation and recommendations, marine fisheries census, resource tracking and harvest policies. National marine fisheries policies and mariculture technologies are few of CMFRI's significant contribution to the sector. Technologies developed by the institute have contributed to expanding opportunities for sustainable marine fish harvest, environmental conservation, income generation, poverty reduction and export earnings. CMFRI has also been successful in generating technologies, advancing academic wisdom, generating trained man power in mariculture and steering outreach activities for the benefit of the fisher folk and for sustaining the fish food security of the nation.

With the capture fisheries lowering at potential level not much increase in the production is anticipated from fishing. But the thrust is to utilize the coastal water bodies for the finfish and shellfish mariculture related activities for enhancing production. Hatchery seed production of 5 finfishes, 21 ornamental, 4 bivalves and 2 holothurians have been developed by CMFRI. CMFRI is coming up with National Mariculture Policy guidelines for submission to the Government of India which is going to have a major impact in the country's fish food security.

Shrinking arable land reiterates the need for producing more from the sea to support our growing population which further augments the expectation from our research output. CMFRIs contributions are recognized nationally and globally with many of our documents vetted or recommended by the FAO and regional fisheries management organization such as BOBP, BOBLME, IOTC, SAARC, MSC, Common wealth, African & Caribbean nations. Imparting trainings at national and international level is an integral part of CMFRIs activities. During the last 5 years we have organized a total of 36 training programmes in CMFRI headquarters and the centres of CMFRI including 6 international programmes for:

1. SAARC nations
2. BOBLME on genetics stock identification
3. Maldivian Officials
4. Srilankan scientists
5. Bangladesh fishery officials
6. BoBP country members and
7. AARDO (Present Programme)

Over the past seven decades the institute has grown significantly in size and stature emerging as a leading tropical marine fisheries research institute in the world displaying an unparalleled research acumen and unbridled commitment which helped in boosting the marine fish production and management of the fisheries sector and for the livelihood of 4 million fisher folk of the country.

Indian Marine Fishery Resources - Present Status

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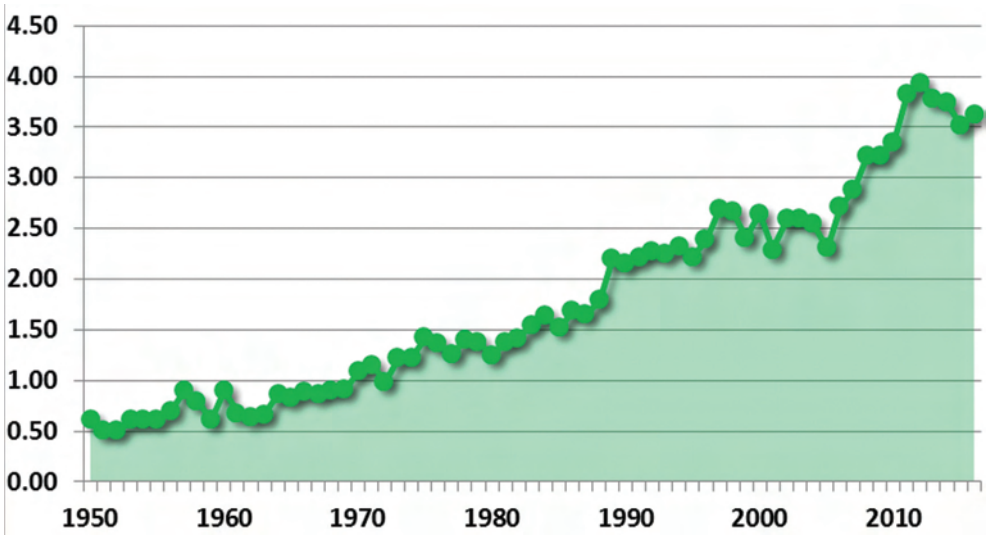
India being a tropical country is blessed with highly diverse nature of marine fishery resources in its 2.02 million square kilometer Exclusive Economic Zone with an estimated annual harvestable potential of 4.414 million metric tonnes. The marine fisheries sector provide livelihood to nearly 4.0 million people of India and meets the food and nutritional requirements of a significant proportion of the population. Also, it contributes to export earnings of the country. Sustainable harvest of the marine fishery resources are necessary as over-exploitation of the resources is likely to harm the diversity and cause reduction in the availability of some of the resources. Monitoring of the harvest of the diverse marine fishery resources of the country is being carried out regularly by CMFRI since its inception through a scientific data collection and estimation system from all along the Indian coast leading to fish stock assessment for deriving management measures to keep the harvest of the resources at sustainable levels.

Marine fisheries is an important source of food, nutrition, employment and income generation. In India, four million people depend for their livelihood on marine fisheries sector which provides employment to nearly one million fishermen and contributes significantly to the export earnings of the country and balance of trade. The sector contributes to an economic wealth valued at nearly Rs. 65,000 crores annually. The marine fisheries of the country consist of small-scale and artisanal fishers belonging mechanized, motorized and non-mechanized sectors and a range of other stakeholders, including governmental and non-governmental agencies. The marine fisheries resources are not in-exhaustive and over-exploitation would lead to loss of biodiversity and reduced availability of resources for our future generations. Uncontrolled harvest will result in depletion of the resources. Management and regulations are necessary for sustainable harvest of marine fishery resources.

India is one among the top marine fish producing countries of the world and at present the country is at 7th position in global marine capture fish production after China, Indonesia, USA, Russia, Japan and Peru. The global marine fish catch remains almost stagnant after 1990 whereas the marine fish production in India showed a steady increase from 2.3 million tonnes in 1990 to 3.94 million tonnes in 2012.

Many of the world's fisheries have experienced series of environmental shifts in recent decades involving collapse or fluctuations in the dominant fish assemblages and as a result, many fisheries-dependent human communities have lost majority of their population, while the respective countries in general were growing (Hamilton and Otterstand, 1998). In a tropical country like India, wherein the marine fisheries is supported by multispecies assemblages, severe collapses in fishery are unlikely and

the marine fish production of the country has been increasing from a meager of 0.05 million tonnes to 3.94 million tonnes over the last 62 years. This is imperative, as the marine fisheries sector in India is characterised by the dominance of small scale subsistence based fishery. In many of the societies, small-scale fishermen suffer the greatest deprivations as they have low social status, low incomes, poor living conditions and little political influence (Pomeroy and Williams, 1994). Implementation of regulations in the fishery for the sustained production from the sector has to take into account its impact on the livelihood of the considerably poor fisher population. The information necessary for such inferences are generated through census.



Time series plot of marine fish landings in India from 1950 to 2016 (in million tonnes)

The estimate of landings of marine fish resources along the coast in the main land of India for the year 2016 is 3.63 million metric tonnes. The contribution by the maritime states West Begal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat, union territories of Puducherry and Daman & Diu towards the total landings (in lakh tonnes) are 2.72 (7.5%), 1.17 (3.2%), 1.92 (5.3%), 7.07(19.5%), 5.23 (14.4%), 5.30 (14.6%), 0.61 (1.7%), 2.92 (8.1%), 7.74 (21.3%), 0.45 (1.2%), 1.17 (3.2%) respectively. The increase in landings in 2016 is mainly due to increase in marine fish landings along the coasts of West Bengal by 1.53 lakh tonnes, Karnataka by 86,000 tonnes, Gujarat by 53,000 tonnes, Kerala by 40,000 tonnes, Daman & Diu by 35,000 tonnes and Maharashtra by 27,000 tonnes. There is reduction in landings in Andhra Pradesh by 1.03 lakh tonnes, Puducherry by 34,000 tonnes, Odisha by 24,000 tonnes, Goa by 7,000 tonnes and Tamil Nadu by 2,000 tonnes.

When examined at the resource level contribution, Indian mackerel had the maximum with 2.49 lakh tonnes (6.8% of total landings) followed by oil sardine 2.45 lakh tonnes (6.7%), ribbonfishes 2.20 lakh tonnes (6.0%), penaeid prawns 2.01 lakh tonnes (5.5%) and lesser sardines 1.95 lakh tonnes (5.4%). The resources showed increased landings in 2016 are Perches by about 77,000 tonnes (81%), Hilsa shad

73,000 tonnes (354%), Ribbon fishes 43,000 tonnes (24%), Bombayduck 35,000 tonnes (31%), Squids 22,000 tonnes (24%) and Non-penaeid prawns 21,000 tonnes (14%). The resources with significant reduction in landings are Lesser sardines 61,000 tonnes (24%) and oil sardine 21,000 tonnes (8%).

Among the three sectors there was 81% contribution from mechanized sector towards the total landings, motorized sector contributed 17% and the contribution from the traditional non-mechanized sector was only 2%. Mechanized trawlnets accounted for 58% of the total marine fish landings whereas mechanized gillnets and outboard ringseines contributed 8% each. The total number of species found in the landings along the Indian coast during 2016 is 817 where as it was 730 in 2015. Number of species landed in different maritime states in 2016 and 2015 are shown in the following diagram. Though Gujarat had maximum landings among all the maritime states species diversity is less compared to Kerala and Tamil Nadu.

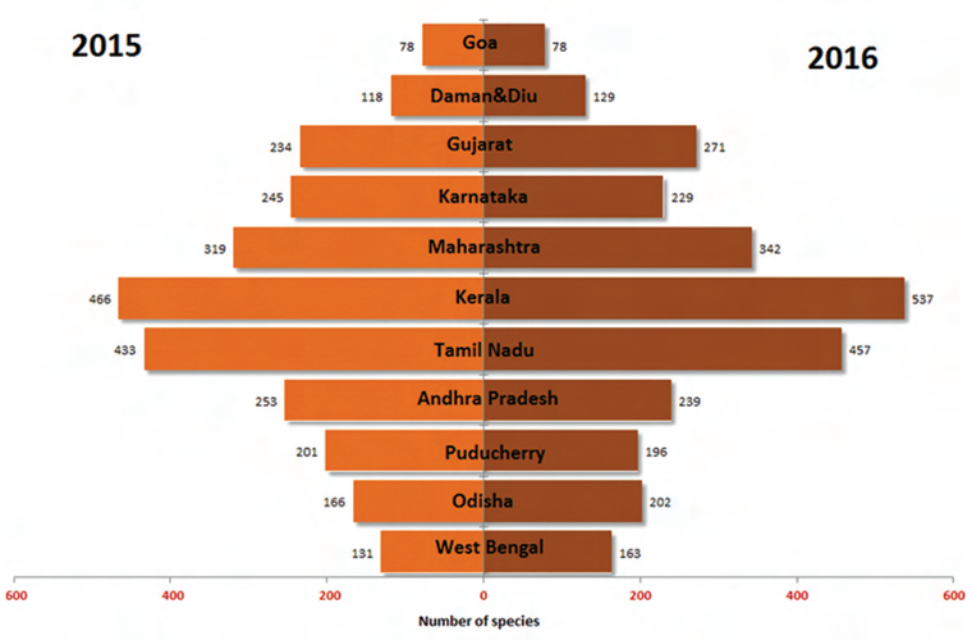


Fig.1. Numbers of species landed in different maritime states in 2016 and 2015

India is one among few countries where a system based on sampling theory is used to collect marine fish catch statistics. The sampling design was developed by CMFRI in association with the Indian Agricultural Statistics Research Institute by conducting preliminary surveys. The sampling design adopted is stratified multistage random sampling, stratification being done over space and time.

Fish landings takes place at numerous locations all along the coastline in all seasons during day and night. Sampling and estimation are performed for geographical area referred as fishing zone. There are 75 fishing zones covering 9 maritime states and two coastal union territories. All the 1,511 landing centres are covered under the sample design and data collection is by qualified and trained field staff

stationed at 25 locations across all maritime states. The overall operation is coordinated by the Fishery Resources Assessment Division of CMFRI.

Fish is a natural resource with capacity to rebuild. If not monitored and managed over- exploitation will lead to stock depletion and some may become extinct. Harvest of this resource needs to be maintained at sustainable level through monitoring and control. The primary objective of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources. Fish stock assessment can be described as the search for the exploitation level that in the long run gives maximum yield from the fishery. The aim of fish stock assessment is for a fishing strategy that gives the highest steady yield year after year.

The basic goal of fishery management is to estimate the amount of fish that can be removed safely while keeping the fish population healthy. These estimates may be modified by political, economic, and social considerations to arrive at an optimum yield. Overly conservative management can result in wasted fisheries production due to under-harvesting, while too liberal or no management may result in over-harvesting and severely reduced populations. Fisheries Management draws on fisheries science in order to find ways to protect fishery resources so that sustainable exploitation is possible. Fisheries Management is the integrated process of information gathering, data analysis, planning, consultation, decision making, allocation of the resources and implementation of regulations or rules to govern fishing activities with enforcement as and when necessary to ensure steady and sustainable harvest of the resources. Fisheries Management is not about managing fish but about managing people and related businesses. Fish populations are managed by regulating the actions of people. These management regulations should also consider its implications on the stakeholders.

New Threats to Coastal Habitats and the Way Forward for Developing a Sustainable Ecosystem

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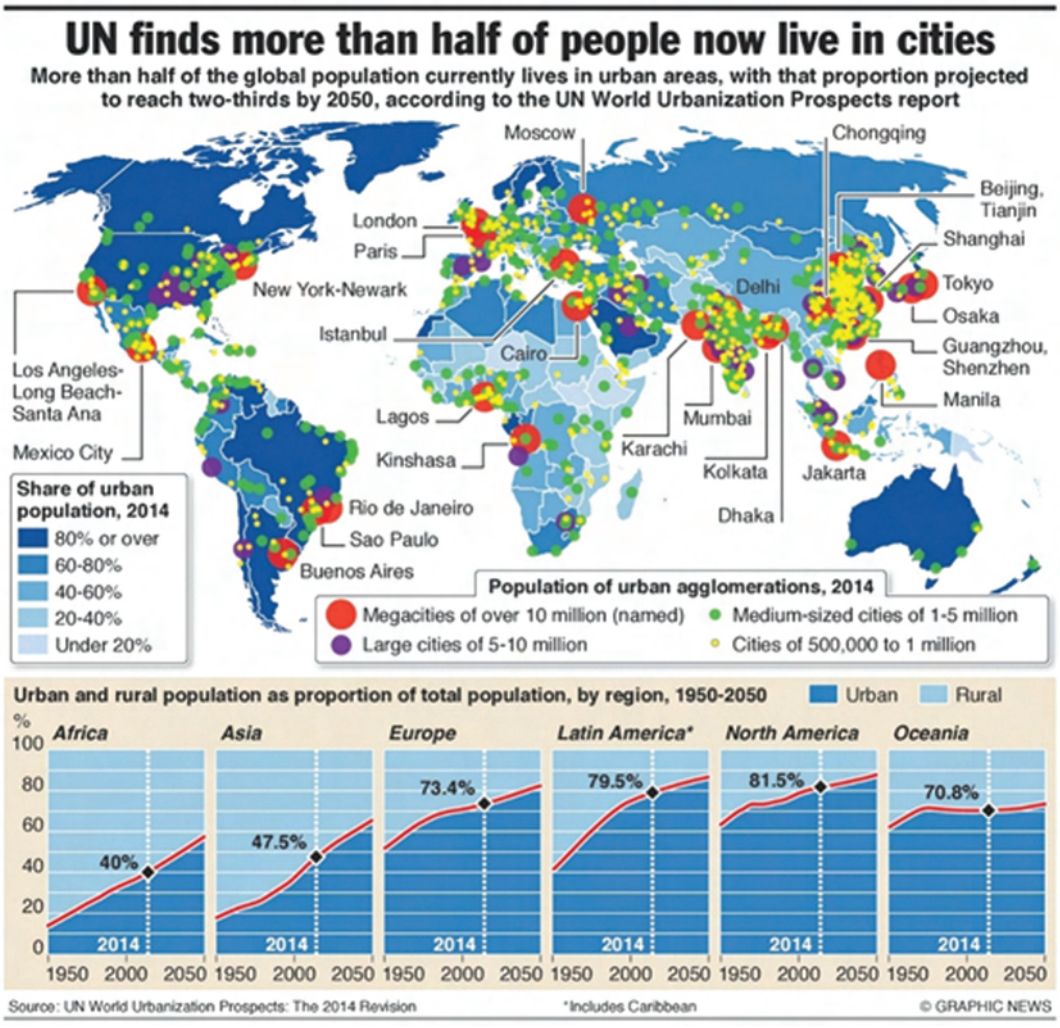
Introduction

The coastal and marine ecosystems all over the world have supported fisheries and aquaculture activities since time immemorial. With modernisation and new technological developments, opportunities



for employment have diversified resulting in increased the production from these two sectors. Nevertheless, problems related to the environment started making a deep impact on these two industries. During 1900, out of every 10 only two were living in urban areas and now by 2010 it has increased to 5 and by 2050, it is expected that 7 out of every 10 will be a resident of urban areas. Moreover, the increasing coastal population and unplanned developmental activities in these regions have led to degradation and loss of critical habitats. The African and Asian Regions are in the growing phase and it is essential that we evaluate the negative impacts of antropogenic activities and work towards a fast track rectification action plan. In this write up only the new threats are listed. The earlier well recognised pressures still stand unaddressed to a large extent. While several rules and regulations have been drafted to resolve these issues, the implementation part is still week.

Climate change and fisheries

The impacts of climate change are pronounced on small pelagic fish, the Indian oil sardine. Fluctuation in fishery of the group of fishes –herrings, anchovies and sardines (HAS) has been attributed to ocean atmospheric processes like the El Nino.The biological cycles of the Indian oil sardine, *Sardinella longiceps* has also been found to be closely related to upwelling and monsoon. The climate impacts in the form of extreme events like excess or deficit rain during south west monsoon and north east monsoon have affected recruitment. Along with this, the unusual high temperature and low food creating situations similar to drought have been identified in the coastal waters. These are reflections of the *El nino* of 2015 which led to poor recruitment.

The Indian oil sardine is not only a food fish, but also a forage fish supporting the higher predators in the tropical ecosystems. They form the food of dolphins and sea birds. Hence decline in biomass of sardine will have cascading effect on the trophic system. It can be inferred that climate change has a critical role to play in fishery fluctuations. Only limited fisheries management programs and governance are in place in many Afro-Asian countries. There is no preparedness to face fishery collapses.

Very effective FMP (especially good governance) should in place in all maritime states. Similarly effective predictions should be developed on climatic factors and eggs and larval studies. There should be International research collaborations for capacity building on these themes. Similarly there should be schemes to financially support small scale fishers during fish biomass decline due to natural calamities Asian agriculture.

Litter in aquatic systems

Marine litter has become one of the biggest threats in the world. According to United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), 60 to 80%, of the global litter found in the coastal and marine ecosystems has originated from land and only the rest from sea based activities. Understanding this, the UNEP has recently initiated a special program *'Global Initiative on Marine Litter'*. Three main industries which are affected by marine debris are fisheries, shipping and tourism and the estimated damage to these sectors in APEC region is US$1.265 million annually. It is also estimated that about 4.8 and 12.7 million metric tonnes enter the oceans.

Plastic products ranging from small ice cream spoons to large sheets and crates are dumped as litter on the beaches and obtained along with fish catch in gears like bag nets and trawls. In the estuaries, these occur in gill nets and drift nets. Studies suggest that 70% of marine litter sinks to the seabed, 15% continues to drift within the water column and 15% ends up on beaches. Micro-plastics have been found to enter the food chain. In the recent years nylon threads have been obtained from the gut of Indian oil sardine, anchovies birds and mackerel, while large pieces of plastics have been obtained from the gut of ribbon fishes, tuna, and whales. This clearly indicates that micro and macro plastics have started entering the marine food chain. What impact does it have on the marine fauna? Not much information is available on this. The benthic ecosystem is one of the most productive areas which support the demersal fishes, shrimps and several invertebrates like the octopuses, sea cucumbers, gastropods and bivalves. They depend on benthic substrate for all their major life cycle activities like foraging and breeding and hence are more vulnerable to impacts of marine litter.Picture shows the huge quantity of plastic covers dumped in inshore areas which are nursery grounds of shrimps and fishes. Another threat is the leaching of chemical from plastics. The toxicity of additive chemicals (default in manufacture) eg: phthalates (endocrine disrupting and carcinogenic), bisphenol A (endocrine disruption and cytotoxicity), brominated flame retardants (immunotoxicity, cytotoxicity, neurotoxicity, endocrine disruption), triclosan, bisphenone and organotins which can leach from the polymer into the surroundings as they bond weakly with the polymer is scientifically proved now.The fragmentation of plastics increases leaching of these chemicals and enable more surface area for adsorption of toxic chemicals from environment. To overcome this problem, a well charted out action plan as given below is suggested.

1. Awareness campaigns——student blue/green brigades
2. Collection mechanism from individual house-holds and other places
3. Segregation based on nature/type at source itself
4. Efficient transportation from collection centre to storage or processing centres
5. Treatment facilities (recycling / upscaling)
6. For fishermen -Incentives – for litter reduction
7. Formulation of rules: punishments for violating stipulated rules
8. Implementation of Rules and regulations.

Harmful Algal Blooms (HAB)

The intensity and frequency of blooms in coastal waters has increased though incidences of shellfish poisoning is not seen in Indian waters.Complete disruption of normal food chain is common during such periods. The way forward is to develop prediction and early warning systems which would help to rescue the aquaculture farms. More important is to reduce eutrophication and coastal pollution which promote such HABs

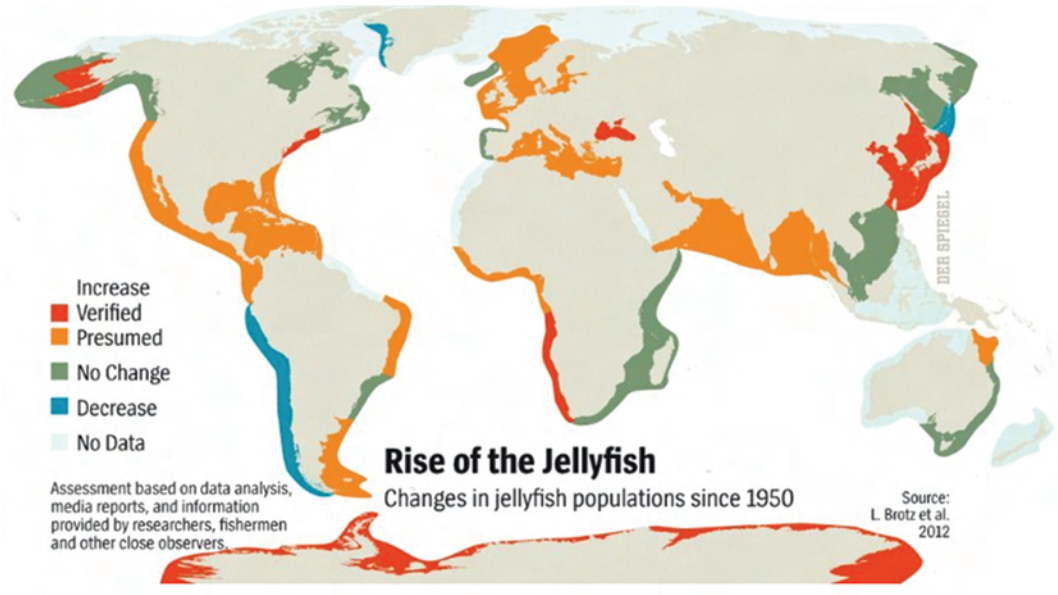
Habitat alterations

Ecologically destructive developments which involve reclamation and flow disrupting hindrances in the estuaries and coastal waters change the physical nature of the critical habitats. Subsequently the

reduced water flow changes the water quality and increases sedimentation resulting in shallow regions. These alter the ecosystem characteristics affecting the faunal diversity and biomass. Picture shows a weed infested portion in the Cochin backwaters, Kerala during post monsoon period. Proliferation of bio-invasive weeds have also led to habitat alterations.These hinder fishing activities and also breeding of local species. Aquaculture also becomes impossible. The way forward is to remove these manually and start developmental activities. Clear enforceable habitat protection provisions will help to safeguard fish and fisheries

Jellyfish in coastal habitats

Extreme events like droughts reduce the flow of water to the sea and this has been found to increase the occurrence of Jelly fishes in backwaters. Similarly the increase in jellyfish blooms is a major threat to the resources. Ecological imbalance due to removal of top predators, eutrophication of coastal waters due to urbanization, low oxygen and occurrence of new structures in coastal waters where the polyps can attach are some of the reasons for increase in jellyfish occurrences.



There is only limited data available on this issue. Hence it is suggested to include jellyfish research as a focal theme and develop early warning systems for bloom forming species. It will be appropriate to utilize jelly fish. These are used in collagen preparations; treat rheumatoid arthritis and are known to have rich biomedical properties. As food- dried and chopped into noodle-like strips to be added to soups, entrepreneurial Japanese are even making vanilla-and-jellyfish ice cream. Above all it is important to reduce eutrophication through proper control measures

Destruction of critical habitats by oil pollution

Oil spillages have led to considerable damage to the coastal ecosystems. The increased oil tanker traffic has called for urgent action by each nation to provide a critical habitat map to the shipping

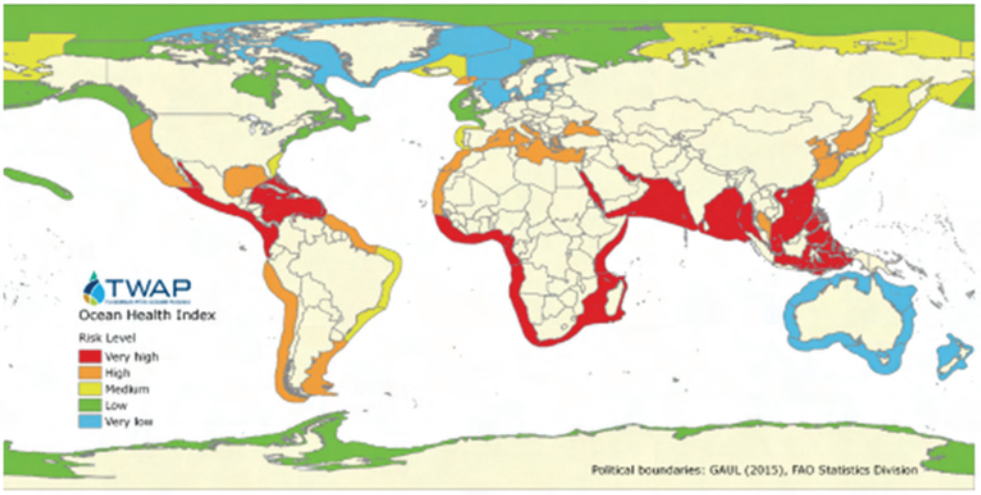
industry. Along with this, preparedness to handle oil spillages using sophisticated methods has to be developed.

Chemical pollution

Changes in habitat ecology due to effluents from factories and industrial units have been a major concern since more than half a century. In almost all nations, coastal zone regulation acts and integrated coastal zone management has come into force. However, in several areas, the effluents are discharged directly to the coastal waters leading to high BOD and COD. Most often this results in sudden fish kills. The poor water quality has been found to affect the fin fish farms in coastal areas. In spite of repeated warnings and public protests, the chemical pollution still continues as a major threat in some areas. Unless strict action is taken to stop this, the deterioration of coastal habitats will continue.

Ocean Health Index

The Ocean Health Index is a valuable tool for the ongoing assessment of ocean health. By providing a means to advance comprehensive ocean policy and compare future progress, the Index can inform decisions about how to use or protect marine ecosystems(http://www.oceanhealthindex.org/)



Factors like Food provision, Artisanal fishing opportunity, Natural products, Carbon storage, Coastal protection, Coastal livelihoods and economy, Tourism and recreation, Sense of place, Clean waters and Biodiversity are considered for calculating the OHI. India's rank is 66nd and there is scope to increase this by improving the environmental health. All nations should look at their OHI and work towards improving the score.

Fish Biodiversity of Indian Exclusive Economic Zone

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Introduction

Indian fisheries have a long history, starting with Kautilya's *Arthasastra* describing fish as a source for consumption and provide evidence that fishery was a well-established industry in India and fish was relished as an article of diet as early as 300 B.C, the ancient Hindus possessed a considerable knowledge on the habit of fishes and the epic on the second pillar of Emperor Ashoka describing the prohibition of consumption of fish during a certain lunar period which can be interpreted as a conservation point of view. Modern scientific studies on Indian fishes could be traced to the initial works done by Linnaeus, Bloch and Schneider, Lacepède, Russell and Hamilton. The mid 1800s contributed much in the history of Indian fish taxonomy since the time of the expeditions was going through. Cuvier and Valenciennes (1828-1849) described 70 nominal species off Puducherry, Skyes (1839), Günther (1860, 1872, 1880) and *The Fishes of India* by Francis Day (1865-1877) and another book *Fauna of British India* series in two volumes (1889) describing 1,418 species are the two most indispensable works on Indian fish taxonomy to date. Alcock (1889, 1890) described 162 species new to science from Indian waters.

In the 20th century, the basis of intensive studies on the different families and groups of freshwater fishes was done by Chaudhuri along with Hora and his co-workers. Misra published *An Aid to Identification of the Commercial Fishes of India and Pakistan* and *The Fauna of India and Adjacent Countries (Pisces)* in 1976. Jones and Kumaran described about 600 species of fishes in the work *Fishes of Laccadive Archipelago*. Talwar and Kacker gave a detailed description of 548 species under 89 families in his work, *Commercial Sea Fishes of India. The FAO Species Identification Sheets for Fishery Purposes - Western Indian Ocean* (Fischer and Bianchi) is still a valuable guide for researchers.

The long coastline of 8129 km^2 with an E2 of 2.02 million sq. km including the continental shelf of 0.5 million sq. km harbors extensively rich multitude of species. Vast regions of mangroves are found along the coast of West Bengal, Odisha, Andhra Pradesh, Tamilnadu, Maharashtra, Gujarat and Andaman Islands which extends up to about 6,82,000 ha area. Coral reefs are found in the Gulf of Kutch, along the Maharashtra coast, Kerala coast, in the Gulf of Mannar, Palk Bay and the Wadge Bank along the Tamilnadu coast and around Andaman and Lakshadweep Islands. The variety of coastal ecosystems includes brackish water lakes, lagoons, estuaries, back waters, salt marshes, rocky bottom, sandy bottom and muddy areas provides a home and shelter for the mega biodiversity of India. These regions support very rich fauna and flora and constitute rich biological diversity of marine ecosystems. Diversity in the species complex, typical of tropical waters and co-existence of different fish and shellfish species in the same ground are important features of Indian Marine Biodiversity.

Species Diversity

Fin fishes

Of the 33,059 total fish species of the world, India contributes of about 2,492 marine fishes owing to 7.4% of the total marine fish resources. Of the total fish diversity known from India, the marine fishes constitute 75.6 percent, comprising of 2,492 species belonging to 941 genera, under 240 families of 40 orders. Among the fish diversity-rich areas in the marine waters of India, the Andaman and Nicobar Archipelago, shows the highest number of species 1,431, followed by the east coast of India with 1,121 species and the west coast with 1071. Detailed taxonomy of 18 families of fishes occurring in Indian EEZ was done as shown in the Table 1. As many as 91 species of endemic marine fishes are known to occur in the coastal waters of India. As of today, about 50 marine fishes known from India fall into the Threatened category as per the IUCN Red List, and about 45 species are Near-Threatened and already on the path to vulnerability. However, only some species (10 elasmobranchs, 10 seahorses and one grouper) are listed in Schedule I of the Wildlife (Protection) Act, 1972 of the Government of India. The ecosystem goods and services provided by the fauna and flora and the interrelationship between the biodiversity and ecological processes are the fundamental issues in the sustainability and equilibrium of the ecosystem.

Table 1. List of Fish families and corresponding authors

No	Name of the Family /group	Authors
1	Flatfishes	Norman, 1934, Menon, 1977
2	Scombridae	Jones and Silas, 1962
3	Mugilidae	Sarojini, 1962
4	Clupeidae	Whitehead, 1985
5	Trichiuridae	James, 1967
6	Leiognathidae	James, 1975
7	Chirocentridae	Luther, 1968
8	Mullidae	Thomas, 1969
9	Sphyraenidae	De Sylva, 1975
10	Syngnathidae	Dawson, 1976
11	Scorpaenidae	Eschmeyer, 1969
12	Platycephalidae	Murty, 1982
13	Callionymidae	Ronald, 1983
14	Sciaenidae	Lal Mohan, 1972, 1982, Trewavas, 1977
15	Nemipteridae	Russell, 1986
16	Priacanthidae	Phillip, 1994
17	Carangidae	Sreenivasan, 1976, Joshi, 2011
18	Balistidae	Sathish Sahayak, 2015

Recent analysis indicates that 18 resource groups fall under abundant category, five fall under less abundant category and one each fall under declining, depleted and collapsed category. The resource groups under the abundant category indicates good condition of the stock. The less abundant category includes elasmobranchs, threadfins, ribbon fishes, mullets and flat fishes. Big-jawed jumper under the declining category, flying fishes under depleted and unicorn cod is in the collapsed category. While certain stocks such as those of Mackerel, Lesser Sardines, White bait, Seer fish, Coastal and oceanic tunas, Croakers, Pig face breams, Groupers, Snappers, Cat fish, Lizard fish, Silver bellies and Goat fishes are exploited all along the Indian coast. Bombay duck is caught mainly along the Gujarat and Maharashtra coast and to a lesser extent along certain pockets of Andhra, Odisha and West Bengal coasts. *Hilsa* is harvested mainly along the West Bengal coast and Gujarat coast.

Elasmobranchs

The elasmobranchs consists of sharks, sawfishes, rays, skates and guitar fishes. They are fished using different types of gears and in recent years have assumed great significance in the export market. They are exploited by a variety of fishing gears like gillnets, long lines and trawls along the Indian coast by both traditional and mechanized sectors. Though there is no directed fishing for elasmobranchs in certain places of Tamilnadu, large meshed bottom set gillnets called as 'thirukkuvalai' are operated for fishing the rays. They are all predatory feeding on a wide range from zooplankton to benthic invertebrates, bony fishes, other sharks, turtles, seabirds and marine mammals. Akhilesh *et al*. (2014) provided a checklist of 227 chondrichthyan species belonging to 11 orders and 41 families from Indian seas and it was mentioned that 27 species (12%) have questionable status with regard to their occurrence because their distributional range does not fall within Indian seas.

The Whale shark is huge, sluggish, pelagic filter-feeder, often seen swimming on the surface. Viviparous and gravid female have 300 young ones of several stages of development. The protected elasmobranchs as per the Wildlife (Protection) Act, 1972, Schedule I are *Rhincodon typus* (Whale shark), *Anoxyprisits cuspidata* (Pointed saw fish), *Prisits microdon* (Large tooth sawfish), *Prisitis zijsron* (Longcomb sawfish), *Carcharhinus hemiodon* (Pondicherry shark), *Glyphis gangeticus* (Ganges shark), *Glyphis glyphis* (Speer tooth shark), *Himantura fluviatilis* (Gangetic sting ray), *Rhynchobatus djiddensis* (Giant guitarfish) and *Urogymnus asperimus* (Thorny ray).

Ornamental fish

The Gulf of Mannar, Palk bay, Gulf of Kutch, South West coast and the Lakshadweep and Andaman group of Islands are known to be rich in Ornamental fishery. The Wrasses, Damsel fish, Surgeon, Butterfly fish, Moorish idol, Squirrel fish, Trigger fish, Rabbit fish, Parrot fish, Angels, Goat fish and Puffer fish are the major aquarium fishes represented by about 180 species. As the majority of these fishes is associated with coral reefs and those in great demand are not very abundant, their exploitation may disturb the habitats and result in depletion of stock, if a suitable mechanism for sustainable exploitation for example sample traps, monitoring the exploitation and export are not developed. The seahorses and pipefishes are known to live in seagrass beds, mangroves and reefs in most shallower coastal waters of the

temperate and tropical regions. About 300 species of ornamental fishes from 30 genera are known. CITES have listed all the seahorses in the Appendix I to stop the trade of these organisms. Indian wild Life Act 2002 also protects the seahorse by putting them in Schedule list I. Dried seahorse has got a high demand in Singapore and China for making soup and for medicinal purposes.

Ecosystem Diversity

Gujarat coast

Gujarat has the longest coastline of more than 1,600 km and the most extensive continental shelf of nearly 1,64,000 km^2, which represents nearly 20% and 32 % of India's coastline and continental shelf. The EEZ of Gujarat covers 2,14,000 km. The coast has broadly been divided into four sections: the Gulf of Kutch, the Saurashtra coast, the Gulf of Khambhat and the South Gujarat coast. The ecological importance is that India's first Marine National Park was notified in the Gulf of Kutch. In the ecological sense, the habitats exhibit considerable diversity and they include mangroves, salt marshes, coral reefs, beaches, dunes, estuaries, intertidal mudflats, gulfs, bays and wetlands. Gujarat has India's second largest extent of area under the mangroves. Gulf of Khambhat (Gulf of Cambay) is 190 km wide at its mouth between Diu and Daman, rapidly narrows to 24 km. The gulf receives many rivers, including the Sabarmati, Mahi, Narmada, and Tapti. The Gulf of Kutch is rather shallow with a depth of nearly 60 m at the mouth to less than 20 m near the head. The total gulf area is about 7,350 km^2. In the Gulf of Kutch, there are 42 islands & some islets, covering a total area of about 410.6 km^2.

About 306 fish species are listed from the sea and coastal waters of Gujarat. Some of the important group of fishes that are occurring in the Arabian sea and also ventured into Gujarat waters include sharks, rays, sea horses, catfishes, groupers, ribbon fishes, jewfishes, mullets, puffer fish, coral fish, lady fish *etc*. Out of total 306 reported species, 23 fish species were found in the IUCN's Red Data list. Importantly, 9 of these species belong to shark families, including the whale shark, are also listed in Schedule I of Wildlife Protection Act, 1972. The fishery at present is dominated by fishes like ribbon fishes (*Trchiurus lepturus*), Bombay duck (*Harpodon nehereus*), croakers, carangids, threadfin breams, lizard fishes, tuna (*Euthynnus affinis, Thunnus tonggol, Katsuwonus pelamis, Thunnus albacores* and *Sarda orientalis*), seerfish, pomfrets, catfish, flatfishes and non penaeid prawns. The Bombay duck (*Harpodon nehereus*) fishery was dominant at Nawabunder, Rajpara and Jaffrabad along the Saurashtra coast.

Mumbai coast

The Maharashtra coast that stretches between Bordi/Dahanu in the North and Redi/Terekhol in the South is about 720 km long and 30-50 km wide. The shoreline is indented by numerous west flowing river mouths, creeks, bays, headlands, promontories and cliffs. There are about 18 prominent creeks/estuaries along the coast many of which harbor mangrove habitats. Bombay duck fisheries form the mainstay of the commercially important fisheries of the coast from Ratnagiri to Broach. The coastline between Bombay and Kathiawar is found to be productive for Sciaenids, *Leptomelanosoma indicus (=Polynemus indicus), Polynemus* spp., perches and eels. The Gulf of Cambay and North Bombay coast are also rich

in Bombay duck fisheries. About 285 species have been reported from the coast. Major finfishes along this coast was Bombay duck, ribbonfish, sharks, pomfrets, lizardfish, catfishes, oil sardine, anchovy, barracudas, fullbeaks, sailfish, Cobia, wolf herring, groupers, whitefish and mackerel.

Konkan coast

The Konkan coast stretches like a beautiful chain of 720 km formed from the coastal districts of the states of Maharashtra, Goa and Karnataka. Many river mouths, creeks, small bays, cliffs and beaches, interspersed with historic forts, lend an alluring charm to this landscape. Konkan is also rich in coastal and marine biodiversity. Mangrove forests, coral reefs, charismatic marine species like dolphins, porpoises, whales, sea turtles, many species of coastal birds and other fauna make the Konkan coast a veritable treasure trove biological diversity. The Malvan Marine Sanctuary has spread over 29 km^2; the sanctuary is rich in coral and marine life. The Karwar group of islands with its unique rocky with sandy shore supports a wide range of fauna. There are more than 170 different species of food fishes landing in the coast and is famous for its large shoals of mackerel, *Rastrelliger kanagurta* dominating the coasts of Karnataka. Oil sardine along with *Sardinella fimbriata,* anchovies, clupeids, ribbonfishes, seerfishes, *Lactarius lactarius*, carangids, pomfrets, croakers, catfish, whitefish, flatfishes, silver bellies also contribute much to the fisheries of both the coasts.

Malabar Coast

Characteristic features of the Malabar Coast are the upwelling, southwest monsoon, northeast monsoon, mud-bank along the southwest coast and high coastal production. Upwelling occurs in the region between Kanyakumari and Karwar during the onset of southwest monsoon. It starts in the southern region first and then extends northwards with the progress of southwest monsoon. Southwest monsoon season is the period when mud-banks are formed in some places along the southwest coast of India especially the Kerala coast. Mud banks of the Alleppey region is formed by the subterranean mud and the Vembanad lake system provides the mud for this. The mud-banks between Parapanangadi and Tanur are the aggregation of coastal mud. The mud-banks at Chellanam, Narakkal, Valappad, Elathur, Quilandy, Muzhuppilangadi, Kottikalam, Anjur, Adakathubali, Kumbala, Uppala and Ullal are formed by the sediments and organic debris discharged from river and estuaries. Mud-banks at Vypeen are formed from dredging operation. Along the southwest coast in India the maximum production of phytoplankton takes place during the southwest monsoon months.

The peak of plankton biomass is observed during peak southwest monsoon and pre-monsoon periods that is during and after upwelling, while the abundance of fish eggs and larvae shows peak during the pre-monsoon. Thus, it is well known that the intensity of southwest monsoon plays an important role in the fluctuation of the fishery resources especially the pelagic fishes. The fish diversity occurs at the mud banks are characteristic of the fishing grounds off the south-west coast of India. About 50 species of fish were recorded from these regions. Fishes of the families Carcharhinidae, Clupeidae, Dussumieriidae, Engraulidae, Chirocentridae, Bagridae, Hemiramphidae, Sphyraenidae, Mugilidae, Polynemidae, Ambassidae, Terapontidae. Sillaginidae, Lactaridae, Siganidae, Carangidae, Gerridae, Leiognathidae, Pomadasydae, Sciaenidae,

Trichiuridae. Scomberesocidae, Stromateidae, Cynoglossidae, Chirocentridae and Drepaneidae were come across in the landings.

Lakshadweep

The Union territory of Lakshadweep consists of 36 islands covering an area of 32 km^2 of which 10 islands are inhabited, 20,000 km^2 of lagoons and 4,000 km^2 oceanic zones. Among the fishes of Lakshadweep, those of ornamental value are abundant. Of the 603 species of marine fishes belonging to 126 families that are reported from the islands, at least 300 species belong to the ornamental fish category. Oceanic species of tuna such as Skipjack and Yellowfin tuna constitute the major tuna resources from Lakshadweep Islands. The main economy of the islanders is dependent on the tuna catch and fishing is done for nearly six months of the year from October to April. The most common species of sharks that occur in Lakshadweep are the Spade-nose shark/Yellow dog shark, and the Milk shark. The Blacktip Shark and Hammerhead shark are also commonly found in the waters around Lakshadweep.

Gulf of Mannar

The Gulf of Mannar located in the Southern part of the Bay of Bengal with a string of 21 islands which has been declared as a marine National Park under the Wild Life (Protection) Act 1972 by the Government of India. The reserve covers 10,500 km^2, which comprises of a variety of sensitive marine habitats like coral reefs, mangroves and sea grasses, and could be considered as one of the most productive ecosystems. The core area of the reserve is comprised of a 560 km^2 of coral islands and shallow marine habitat. The Gulf of Mannar alone produces about 20% of the marine fish catch in Tamil Nadu. A total of 1,182 species belonging to 476 genera in 144 families and 39 orders was reported from GOM ecosystem. The finfish resources, mainly comprises of small pelagics, barracudas, silverbellies, rays, skates, eels, carangids, flying fish, full beaks and half beaks. The demersal finfish resources, mainly associated coral reefs are threadfin breams, grouper, snappers, emperor and reef associated fishes. Further, large pelagic species like skipjack tuna, yellowfin tuna, bigeye tuna, kawakawa, frigate tuna and seer fish, bill fishes, eagle rays are most abundant in offshore and oceanic areas, but also occur in coastal waters are found in certain areas of the Gulf of Mannar.

Palk Bay

Palk Bay is situated on the southeast coast of India encompassing the sea between Point Calimere near Vedaranyam in the north and the northern shores of Mandapam to Dhanushkodi in the south. The Palk Bay itself is about 110 km long and is surrounded on the northern and western sides by the coastline of the State of Tamil Nadu in the mainland of India. The coastline of Palk Bay has coral reefs, mangroves, lagoons, and sea grass ecosystems. Elasmobranchs are the largest group of fishes and are well represented in the fishery wealth of the Rameswaram Island on the Palk Bay side. This is one of the best fishing grounds for smaller sardines, silver bellies, common white fish and half beaks, mullets and sciaenids. The common fishes found in this area also include Sharks, Rays, Skates, Tiger-sharks and Hammer-headed sharks.

Coromandel Coast

Seer fishes are most abundant in the Coromandel Coast of Tamil Nadu along with miscellaneous fisheries formed of trichurids and percoids. The flying-fish fishery is an important seasonal fishery on the east coast of India extending from Madras to Point Calimere along the Coromandel Coast. Three species of flying-fish, *viz.*, *Hirundichthys coromandelensis, Cheliopogon spilopterus* and *C. bahiensis*, are generally found in these waters, but more than 90% of the catch consists of *C. coromandelensis*.

Deep-sea fish diversity

A first authentic record of the deep-sea fishes from India was by Alcock in the book *A Descriptive Catalogue of the Indian deep-sea fishes in the Indian museum* based on the fishes collected during the explorations in the Indian Ocean by *RIMS Investigator* (1889-1900). Then comes the results of R.V. *VARUNA* cruises (1962-1968) showed the presence of *Anodontostoma chacunda*, *Atropus atropos*, *Benthodesmus tenuis*, *Brachirus orientalis*, *Chlorophthalmus agassizi, C. corniger, Carangoides malabaricus, Caranx kalla, Centropristis investigatoris, Chascanopsetta lugubris, Chlorophthalmus corniger*, *Cubiceps natalensis, Cynoglossus bilineatus*, *C. semifasciatus, Decapterus russelli*, *Drepane punctata*, *Epinnula orientalis, Goniolosa manmina*, *Grammoplites scaber*, *Himantura urnak*, *Holocentrum rubrum*, *J. diacanthus, Johnius dussumieri*, *Kowala coval*, *L. argentimaculatus*, *L. bindus*, *L. johni, L. kasmira, L. malabaricus*, *Lactarius lactarius*, *Leiognathus splendens*, *Lepidopus caudatus*, *Lepturacanthus savala*, *Megalaspis cordyla*, *Myripristis murdjan, Nemipterus japonicus*, *Netuma thalassinus*, *Opisthopterus tardoore, Otolithes argentatus, P. sexifilis, Parastromateus niger*, *Paseneopsis cyanea*, *Pastinachus sephen*, *Pellona ditchela*, *Polymixia nobilis, Polynemus plebius*, *Pomadasys hasta*, *Psenes indicus, Pseudorhombus arsius, Rexea prometheoides, Rhynchobatis djiddensis, Saurida tumbil*, *Scoliodon palasorrah, Scyllium hispidum, Sillago sihama*, *Solea elongata, Sphyraena acutipinnis*, *Synagrops japonicus*, *Synodus indicus*, *Thrissocles mystax*, *T. malabarica, Trichiurus lepturus and Tylosurus crocodilus* from the depth zone of 1 to 450m.

A checklist of fishes of Indian EEZ was published based on the surveys of FORV *Sagar Sampada* in the EEZ of India during 1985-'87. This list is arranged alphabetically by families and genera. The list contains 242 species belonging to 87 families with both conventional and nonconventional fish fauna of the Indian EEZ with the scientific and common names of fishes, details of the depth of occurrence, depth of fishing, position and the gear were also included. The study by Hashim (2012) reported and the occurrence of 188 species of deep-sea fishes from Indian EEZ during the exploratory surveys. Deep sea fish species like *Psenopsis cyanea, Bembrops caudimacula, Chlorophthalmus bicornis*, *C. agassizi*, *Uranoscopus archionema, Gavialiceps taeniola*, *Priacanthus hamrur* and *Neoepinnula orientalis* were found to be the most abundant during the study. Hashim (2012) observed a highest diversity in Arabian Sea (4.95) followed by Andaman Waters (4.12) and Bay of Bengal (3.55).

Biodiversity conservation

The exploited marine fisheries resources from the Indian EEZ area have been reached maximum from the present fishing grounds up to 200 m depth. The coastal fisheries faces several threats such as

indiscriminate fishing, habitat degradation, pollution, social conflicts, the introduction of highly sophisticated fishing gadgets with a need for management measures and conservation of marine biodiversity to maintain sustainable use of marine biodiversity. A total of 65 species of fishes is under the threatened category of IUCN from the Indian seas (Table 2).

Table 2. Threatened fishes from the Indian seas (1,2)

	Species	Family	Threat Category
1	*Aetobatus flagellum*	Myliobatidae	Endangered (EN)
2	*Aetomylaeus maculatus*	Myliobatidae	Endangered (EN)
3	*Aetomylaeus nichofii*	Myliobatidae	Vulnerable (VU)
4	*Alopias pelagicus*	Alopiidae	Vulnerable (VU)
5	*Alopias superciliosus*	Alopiidae	Vulnerable (VU)
6	*Alopias vulpinus*	Alopiidae	Vulnerable (VU)
7	*Anoxypristis cuspidata*	Pristidae	Endangered (EN)
8	*Balistes vetula*	Balistidae	Vulnerable (VU)
9	*Carcharhinus albimarginatus*	Carcharhinidae	Vulnerable (VU)
10	*Carcharhinus hemiodon*	Carcharhinidae	Critically Endangered (CR)
11	*Carcharhinus longimanus*	Carcharhinidae	Vulnerable (VU)
12	*Carcharhinus obsucurus*	Carcharhinidae	Vulnerable (VU)
13	*Carcharhinus plumbeus*	Carcharhinidae	Vulnerable (VU)
14	*Carcharias taurus*	Odontaspididae	Vulnerable (VU)
15	*Carinotetraodon travancoricus*	Tetraodontidae	Vulnerable (VU)
16	*Centrophorus squamosus*	Centrophoridae	Vulnerable (VU)
17	*Chaenogaleus macrostoma*	Hemigaleidae	Vulnerable (VU)
18	*Cheilinus undulatus*	Labridae	Endangered (EN)
19	*Cromileptes altivelis*	Serranidae	Vulnerable (VU)
20	*Epinephelus lanceolatus*	Serranidae	Vulnerable (VU)
21	*Epinephelus marginatus*	Serranidae	Endangered (EN)
22	*Etroplus canarensis*	Cichlidae	Endangered (EN)
23	*Glaucostegus granulatus*	Rhinobatidae	Vulnerable (VU)
24	*Glaucostegus typus*	Rhinobatidae	Vulnerable (VU)
25	*Glyphis gangeticus*	Carcharhinidae	Critically Endangered (CR)
26	*Gymnura zonura*	Gymnuridae	Vulnerable (VU)
27	*Hemigaleus microstoma*	Hemigaleidae	Vulnerable (VU)
28	*Hemipristis elongata*	Hemigaleidae	Vulnerable (VU)
29	*Himantura gerrardi*	Dasyatidae	Vulnerable (VU)
30	*Himantura leoparda*	Dasyatidae	Vulnerable (VU)
31	*Himantura polylepis*	Dasyatidae	Endangered (EN)
32	*Himantura uarnak*	Dasyatidae	Vulnerable (VU)
33	*Himantura undulata*	Dasyatidae	Vulnerable (VU)
34	*Hippocampus histrix*	Syngnathidae	Vulnerable (VU)
35	*Hippocampus kelloggi*	Syngnathidae	Vulnerable (VU)
36	*Hippocampus kuda*	Syngnathidae	Vulnerable (VU)

37	*Hippocampus trimaculatus*	Syngnathidae	Vulnerable (VU)
38	*Hyporhamphus xanthopterus*	Hemiramphidae	Vulnerable (VU)
39	*Isurus oxyrinchus*	Lamnidae	Vulnerable (VU)
40	*Lamiopsis temminckii*	Carcharhinidae	Endangered (EN)
41	*Makaira nigricans*	Istiophoridae	Vulnerable (VU)
42	*Manta birostris*	Myliobatidae	Vulnerable (VU)
43	*Mobula mobular*	Myliobatidae	Endangered (EN)
44	*Monopterus fossorius*	Synbranchidae	Endangered (EN)
45	*Monopterus indicus*	Synbranchidae	Vulnerable (VU)
46	*Nebrius ferrugineus*	Ginglymostomatidae	Vulnerable (VU)
47	*Negaprion acutidens*	Carcharhinidae	Vulnerable (VU)
48	*Oostethus insularis*	Syngnathidae	Vulnerable (VU)
49	*Plectropomus areolatus*	Serranidae	Vulnerable (VU)
50	*Pristis pectinata*	Pristidae	Critically Endangered (CR)
51	*Pristis pristis*	Pristidae	Critically Endangered (CR)
52	*Pristis zijsron*	Pristidae	Critically Endangered (CR)
53	*Rhina ancylostoma*	Rhinobatidae	Vulnerable (VU)
54	*Rhincodon typus*	Rhincodontidae	Vulnerable (VU)
55	*Rhinobatos obtusus*	Rhinobatidae	Vulnerable (VU)
56	*Rhinoptera javanica*	Myliobatidae	Vulnerable (VU)
57	*Rhynchobatus djiddensis*	Rhinobatidae	Vulnerable (VU)
58	*Sphyrna lewini*	Sphyrnidae	Endangered (EN)
59	*Sphyrna mokarran*	Sphyrnidae	Endangered (EN)
60	*Sphyrna tudes*	Sphyrnidae	Vulnerable (VU)
61	*Sphyrna zygaena*	Sphyrnidae	Vulnerable (VU)
62	*Stegostoma fasciatum*	Stegostomatidae	Vulnerable (VU)
63	*Taeniurops meyeni*	Dasyatidae	Vulnerable (VU)
64	*Thunnus obesus*	Scombridae	Vulnerable (VU)
65	*Urogymnus asperrimus*	Dasyatidae	Vulnerable (VU)

Source : 1. Froese, R. and D. Pauly. Editors. 2017. FishBase. World Wide Web electronic publication. www.fishbase.org.

2. The IUCN Red List. 2017: www.iucnredlist.org

Applications of Geophysical Data Sets in Marine Ecology

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1. Numerical models and their potential application to marine fish and invertebrate larval transport

The benefit of numerical modelling is that the necessary state variables can be simulated at each grid point of the study domain. Advanced techniques such as finite element mesh and curvilinear contours have made modelling of irregular coastline easier and decreased the complexities involved in formulating the numerical equations.

Biological processes such as fish larval transport can be modelled based on a clear understanding of the physics of a water body. Knowledge of local hydrodynamics is a pre-requisite to modelling coastal processes,given that physical drivers such as tides and currents control them. There is a major role of diffusion and related physical processes in dispersal and recruitment of marine populations (Okubo, 1994). Tidal flows can move larvae passively in peak tidal velocities (Levin, 1990; Gross *et al*.1992). Physical processes influence the distribution of larval fish on a variety of scales, ranging from few meters to thousands of kilometers (Bruce *et al*. 2001; Hare *et al*. 2002). There are few larval transport studies in the coastal waters in particular regions (Moser and Smith, 1993; Oliver and Shelton, 1993; Grothues and Cowen, 1999; Hare *et al*. 2001). Tworelated studies are discusssed in the following section.

2. Geo-Physical datasets from SRS in the context of marine fisheries research and management

SRS datasets are often used in empirical or semi-analytical validated models, either to extrapolate regional datasets in space or to generate derived geo-physical products. A simple example for this can be the summation of thermal signals from different wavelengths for generation of SST. In a similar way, some of the most useful and relevant environmental properties in fisheries research such as sea surface salinity (SSS), WS and WD, sea surface height (SSH), chlorophyll-a (Chl-a) and Chl-a derived primary production (PP) are available online as processed and unprocessed geo-physical datasets. These datasets can be used to advantage in various fisheries research and management programmes. A few such case studies are illustrated in this section:

3. SRS chlorophyll data providing cues on fish stock variability

Variations between years in the seasonal cycle of SRS Chl-a have been implicated in fluctuations in fish stock variability (Platt *et al*.,2003). In this section, we describe the results of an analysis of Chl-a with Indian oil sardine in the coastal waters of India. Fishing effort in the coastal waters of India changed little in the period 1998-2006, with 238,772 fishing craft in 2005 (CMFRI, 2005) in comparison

with 239,000 craft in 1997 (Sathiadhas, 2006). Thus, the variability in sardine landings during the study period, despite steady fishing effort, indicates that other factors such as environment or food to the sardines are involved. A correlation analysis between available environmental factors (SST, sea bottom temperature, surface salinity, surface dissolved oxygen, bottom dissolved oxygen, pH, nutrients, chlorophyll, zooplankton, rainfall, multivariate El Niño Southern Oscillation index, coastal upwelling index, and derived SST) and sardine catch from the study area emphasised the high significance of chlorophyll compared with other environmental factors in explaining the variability in sardine catch (Krishnakumar and Bhat 2008). Using their fine branchial apparatus, sardines feed predominantly on phytoplankton and zooplankton.In a given area, Chl-a is a good index of the food availability to sardines. Summer surface Chl-a from the study area lies in the range 0.1 to 5 mg/m^3, and can be very high, from 5 to 10 mg/m^3, during bloom periods. Given the wide dynamic range of chlorophyll concentration in the coastal waters of southwest India and the dominant role of chlorophyll as a determinant of variability in sardine stocks, it seems likely that much will be gained in studying this link in detail.

Algal bloom in the study area often occurs during upwelling. Upwelling in the waters of the southwest coast of India (5 to 15^0N latitude)and the variability in local physical parameters drives changes in the chlorophyll concentration(Smitha et al. 2008). Physical processes affect not only the magnitude of the plankton biomass, but also its species composition (Huntsman *et al*. 1981), which may in turn affect larval fish feeding and survival (Lasker 1975; Simpson 1987). According to the Hjort-Cushing match-mismatch hypothesis (Hjort 1914; Cushing1974; 1990), the survival rate of fish larvae is a function of thematch between timing of hatching of eggs and initiation of spring phytoplankton bloom. The advent of SRS provides information at the appropriate temporal and spatialscales for testing this hypothesis (Platt *et al*. 2007). With SRS, it is possibleto characterize the spring bloom objectively based on the timing of initiation, amplitude and duration. The statistical moments of all of these properties, and their inter-annual variation, can be calculated and the results used to analyze the effect of ecosystem fluctuations on exploited fish stocks (Platt *et al*. 2003).

The case study presented below deals with the interannual variability of Indian oil sardine (*Sardinella longiceps*) stock in the southwest coastal waters of India and its relationship with the phytoplankton bloom characteristics computed from SRS,with a view to explain larval survival and inter annual variability at the synoptic scale (Grinson *et al*. 2012). The life cycle of sardines includes an active breeding season from May to September. This coincides with the high chlorophyll concentration seen during May to September every year.Thus, we find a probable connection between the life history of sardines and phytoplankton bloom dynamics. This supports the finding that thefish itself times its breeding and adjusts its migration to exploit the productive southwest monsoon period. In this study, magnitude of the bloom during initiation month is selected for characterization of bloom, which naturally falls in the month of May every year. May is the most critical month for sardines because both bloom initiation and the beginning of sardines' active breeding phase occur during this month. A delay in the initiation of bloom in the area results in a delay in the onset of suitable conditions for survival of sardine larvae (Grinson *et al*. 2012).

4. Reef Health Advisories Using SRS Derived SST

Globally, there are several instances of mass coral bleaching incidents leading to heavy reef mortality (Krishnan *et al*. 2011). The application of SRS providessynoptic views of the global oceans in near-real-time for monitoring the reef areas (Liu *et al*. 2003; Bahuguna et al. 2008; Mahendra *et al*. 2010). SST during night time is an important parameter for assessment of the thermal conditions inducing the bleaching. SRS provides SSTinformation during day and night routinely, facilitating the development of a coral reef bleaching warning system to generate early warning advisories/bulletins in near realtime.The estimation of monthly maximum mean using night time SST climatology retrieved using NOAA, AVHRR is used for generating reef health advisories to eliminate the effect of solar glare and reduce the variation in SST caused by the heating during day time. Threshold hotspot (HS) and daily heating week (DHW) values for a region are calculated the advisory (Mohanty *et al*. 2013). Depending on the intensity of HS and DHW there can be advisories such as 'no stress'; 'watch'; 'warning' and 'alert levels-I & II' which progressively indicate the severity of a potential bleaching event. Based on this study INCOIS offers reef stress advisories to alert the reef managers to take appropriate measures to reduce the damage caused to reefs during bleaching events.

5. SRS Data for cyclone tracks creating productive fishing grounds

Even though cyclones are devastating, there are some positive effects of cyclones on the fishery. Study of the effect of tropical cyclones on biological processes has gained momentum in the recent past. In thermally-stratified coastal waters, cyclones trigger the breaking up of nutrient-depleted surface waters and bring in nutrient-rich sub-surface waters inducing sudden algal blooms and enhancing the regional scale PP. The effect of physical forcings on PP, its variation and associated hydrography in the south western Bay of Bengal during the southwest monsoon (July) and post-cyclone period (November) of 1999 was studied by Madhu *et al*. (2002). In the postcyclone period, the combined effects of well-mixed coastal waters and freshwater injection from the land runoff associated with the cyclone brought nutrients to the mixed layer, which enhanced PP. Potentially, such enhancement of PP results in improving the regional fishery. But cyclone tracks alone will not provide the information on enhanced PP. SRS is able to detect the environmental changes caused by tropical cyclones. Geo-physical data sets from SRS are useful in such studies for indicating possible productive fishing grounds after a lag following the cyclone (Rao *et al*. 2006).

6. Demarcation of ecological provinces in support of an ecosystem approach to fisheries management

Globally, the ecosystem approach to fisheries management (EAFM) is preferred as a basis for sustainable management of fish stock (Garcia *et al*. 2003). In this context, it is usefulto have a spatial structure for global oceans defined on the basis of ecological provinces rather than geo-political considerations. There are various approaches for classifying the global oceans into ecological provinces (Ekman 1953; Margelef 1961; Yentsch and Garside 1986; Cushing 1989; Fanning 1992; Sathyendranath *et al*. 1995). The classification by Longhurst *et al.*, (1995) is the most comprehensive, identifying some 50 biogeochemical provinces globally (Longhurst *et al*. 1995).Some other methodologies require huge data sets for demarcating ecological provinces (Hooker *et al*. 2000; Li *et al*. 2004; Alvain *et al*. 2005; Sherman

et al. 2011). Butthere is lack of *in situ* data to suppport these approaches. As oceanic realms are dynamic, there are logistic issues in sampling. Consequently, SRS data are very useful to clasification protocols. PP derived from SRS can be a very useful input as PP provinces subsume many oceanographic forcing mechanisms on synoptic scales (Platt and Sathyendranath 2008). These ecological provinces are useful in fisheries management as the physical processes and the ecosystems in each province support characteristic fisheries different from those in nearby provinces (Stuart *et al*. 2011). Beyond static partitioning, there is a further goal for dynamic bio-geography at regional scales that would incorporate complexities of a dynamic marine environment and their effect on the phytoplankton. SRS will be an invaluable source of inputs in case of such partitioning. Changes in spatial extent of the ecological provinces arising from temporal variations in physical forcing can be captured in a SRS climatology of ocean colour.

7. Coupling modelled and SRS data for effective fishery management

So far in this chapter, we have discussed the usage of environmental data sets from models and SRS for various aspects in fisheries research and management. But lack of environmental time series data sets pointed to the need for more data. Coupled with SRS, numerical modelling is an alternative tool to generate environmental and biological datasets, which can help to mitigate problems arising from data gaps.

7.1. Trophic modelling using SRS data as an ecosystem approach to fisheries management

Trophic levels in the marine ecosystem are similar to those in terrestrial systems starting with primary producers and ending in scavengers. But,the trophic structure in marine systems is web like, rather than a linear food chain. Fishing often alters the ecosystem structure. Trophic webs will respond differently to fishing depending on whether the target species is a predator or prey species. Single-species fish stock-assessment models ignore food web interactions. Ecosystem based fish stock assessement is offered as another option. EAFM models often resort to SRS-based PP as an input for forcing at the base of the food web to investigate energy transfers and biomass in an ecosystem without fishing, from lower to upper trophic levels (Chassot et al. 2011).

7.2. Generating potential fishing zones (PFZ) and their dissemination along with ocean state forecasts (OSF)

Identification of PFZ involves an understanding of oceanic processes and interaction of hydro-biological parameters (Desai *et al*. 2000). The forage base and the physical gradients of temperature and Chl-a help the predatory fish to locate their prey and the same cues are used by fishermen. A number of studies have examined the use of SRS as an aid to locate more productive fishing areas (Waluda *et al*. 2001). Indian Remote Sensing Satellite P4 Ocean Colour Monitor (IRS P4 OCM) derived chlorophyll concentration and National Oceanographic Aerospace Administration Advanced Very High Resolution Radiometer (NOAA AVHRR) derived SST images have been used to characterise the relationship between the biological and physical variables in coastal waters and it was observed that chlorophyll concentration and SST were inversely correlated with each other (Solanki *et al*. 1998). The relationship

between these two parameters was estimated by a clustering technique called ARNONE (NCAER, 2010) and the matching features were selected for generating integrated PFZ forecasts from the composite images on the basis of latitude and longitude (Solanki *et al*. 2005; NCAER 2010).

Validation of studies of PFZ forecasts have shown that the forecast may lead to substantial increase in fish catch (Solanki et al. 2001; 2003; Nayak *et al*. 2003). PFZ forecasts in near-real time indicating the likely availability of fish stocks for the next 2days are disseminated in the Indian EEZ by INCOIS to about 225 nodes for operational use (Nayak *et al*. 2003). A significant increase in total catch by following PFZ forecasts has been documented from ANI (Grinson-George *et al*. 2011, 2013).

7.3. Detection of meso-scale features such as eddies and fronts that may Indicate productive fishing grounds

Oceanographic features such as eddies, currents and meanders are pervasive features in the world's oceans. These conspicuous hydrographic features influence the horizontal and vertical distributions of the chemical (e.g. nutrients), physical (e.g. SST) and biological (e.g. Chl-a) properties in pelagic systems (Yoder *et al*. 1981, Seki *et al*. 2001). Eddies have been found tobe localized regions of higher PP leading to aggregation and development offorage species base communities. The presence of mesoscale eddies and their detection by the fishing fleet is an important factor in fishery performance, leading to increased catch per effort for most pelagic species (Laurs *et al*. 1984).The influence of mesoscale processes at fronts, such as the formation ofrings, meanders and streamers arising or breaking off from these dynamic current systems, has also been shown to be important in shaping the distribution of pelagic fish and shellfish (Waluda *et al*. 2001). Studies linking the physical oceanographic processes with fish have been carried out around the major boundary currents and related mesoscale processes, such as in the fishing grounds associated with Kuroshio frontal regions (Yokouchi *et al*. 2000), mesoscale eddies and pelagic fisheries off Hawaiian waters (Seki *et al*. 2001), upwelling and longline fishery of Portuguese waters (Santos et al. 2006), Atlantic tuna and Gulf of Mexico circulation (Block *et al*. 2005), oceanographic conditions of spawning grounds of bluefin tuna in the NE Indian ocean (Matsuura et al. 1997), bluefin and frigate tunaspawning along the Balaeric archipelago (Garcia *et al*. 2003) and tuna exploitation near the mesoscale processes near the Sechelles (Fonteneau *et al*. 2006).

The chlorophyll-SST based advisories depend on the surface manifestation byalgal blooms and thermal fronts which result from eddies and upwelling. Using altimetry data however, one would be able to follow the evolution of feature from inception to maturation and dissipation with time. There is a time lag between physical upwelling of nutrients to the ocean surface and development of phytoplankton blooms, and subsequently the aggregation of planktivorous and piscivorous fish. Altimetry data helps to identify the fish-aggregating meso-scale features from the outset giving valuable time to forecast and exploit the consequences. Difficulties in getting cloud free imageries sometimes limits the scope of this approach. Altimetrydata, especially the SSH have been useful to study the physical oceanography and mesoscale circulation. Advances in SRS altimetry are making it possible toextend the information to the coastal areas where the fishermen are most active. Inputs from the altimetry data on the mesoscale features can be used to augment the PFZ advisories and also provide data during cloud cover.

7.4. Forecasting cyclones and ocean state to reduce Impacts on coastal fisher folk and resources

Apart from elucidating the areas of likelihood of fish/ shellfish distributions during the PLD phase, the wind models used for generating wind inputs in simulation of physical process can be utilized for studying cyclone tracks. Fisheries is one of the sectors with high occupational hazard. The extent ofdirect mortality caused by storms at local or regional scales is severe (Gardner *et al*. 2005; Done 1992). OSF derived as products of numerical models are provided as input to fishermen to mitigate this risk. OSF provides wave and swell height as well as period, WS as well as wind direction (WD), Tsunami and rough sea warnings and coastal current details. To ensure safe navigation and operations at sea, and to forewarn the fishermen community, INCOIS started the OSF service in 2005 by issuing forecasts seven days in advance and at three hourly intervals, with daily updates. Fishermen utilize these forecasts to guide their daily operational activities and to ensure safe navigation. Though international agencies such as National Centres for Environmental Prediction (NCEP), USA and European Centre for Medium-Range Weather Forecasts (ECMWF) and UK issue sea state forecasts based on models such as WAVEWATCH III and WAM, these forecasts are for the open ocean. The INCOIS model provide accurate location-specific forecast in the coastal waters using high resolution local bathymetry, and tuning them using observed wave measurements. Real-time and on-line validation of the forecast products is disseminated through various means by INCOIS (Nair *et al*. 2013).

Cyclones also render coastal resources vulnerable.The ecological effects of cyclones on coral reefs have been reviewed by Harmelin-Vivien (1994). Tropical storms cause severe damage to the reefs; their impacts include the removal of reef matrix, scouring and fragmentation (Rogers *et al*. 1991;Done 1992), deposition of loosenedmaterial onto beaches above sea level or transporting it into deeper sub-reef environments (Done 1992).The reefs in Andaman and Nicobar Islands (ANI) suffered severe damage following a tropical cyclone in the Bay of Bengal off Myanmar coast during13–17 March 2011 (Krishnan *et.al*. 2012).The investigation exposed the vulnerability of the reefs to oceanographic features which generally remain unnoticed unless they directly affect the life or the property of coastal inhabitants. The wind tracks of cyclone were generated using weather research and forecasting (WRF) models which clearly indicated the passage of cyclone where reefs suffered damage.

7.5. Estimation of potential fishery resources of an Exclusive Economic Zone (EEZ) for fishing fleet management

Global marine fish production increased from less than 20 million tons per year in early 1950's to average around 90 million tons per year during the last decade. If the unreported and discarded catches are also taken into account, the global catches will be around 120 million tons per year (Zeller et al. 2005). The general trend in shortfall from traditional fishing grounds in the EEZ's of developed countries is compensated by the increasing exploitation of resources in developing countries. The United Nations Convention on the Law of the Sea (UNCLOS) bestows the coastal states with the right to exploitation and responsibility for management of fishery resources of their EEZs. Observations are of paramount importance for managing the resources, and there is a need to establish acccurate catch data collection systems. Fish captured are considered to reflect fish abundance in coastal waters. From marine fish

catch data, we can estimate the potential harvestable fish by plotting the catch effort curve, and estimate the maximum sustainable yield (MSY). But, mere post-mortem analysis of landed fish may lead to imperfect estimates as fish catch data without geotags of catching locations may not provide samples representative of the stock in the sea. Therefore, an estimate of harvestable fish based on *in situ* water productivity, taking into account the tropho-dynamics in the EEZ may afford very useful complimentary information.

Chlorophyll, which is an index of algal biomass (ML^{-3}) present in a water column (L) is a prerequisite for primary production and subsequent fish production ($ML^{-2}T^{-1}$) which is the annual rate of production of fish biomass per unit area of sea bed. The importance of the potential link between PP and fish was understood decades ago (Ryther 1969), but the advent of SRS Chl-a and modelled PP data sets now available on global and meso-scale prompted policy planners to utilize this for estimation of fishery potential in the EEZ. Past studies relied on *in situ* datasets resulting from different sampling and processing methods and were generally characterized by low spatiotemporalsampling coverage. SRS Chl-a data are now basic to cross-trophic-level analyses of ecosystem production,structure, and function because of the easy and free availability of a wide-ranging, high resolution, and consistent sampling framework (Platt *et al*. 2007) at a reliable accuracy.

Climate Change Impact on Fisheries and Aquaculture

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Introduction

Increasing atmospheric greenhouse gas concentrations as a consequence of anthropogenic activities have resulted in warming of climate systems or global warming. Over the past 100 years the average global air temperature near the earth's surface has been estimated to increase at the rate of 0.74 ± 0.18°C (IPCC, 2007). In the 5th Assessment Report by the Intergovernmental Panel on Climate Change report (IPCC, 2014), climate model projections indicated that the global surface temperature during the 21st century is likely to rise a further 0.3 to 1.7°C for the lowest emissions scenarios and 2.6 to 4.8°C for the most severe emissions scenarios. Fifteen of the sixteen warmest years have occurred since 2001 in the instrumental record of global surface temperature since 1850. Climate change and its associated impacts are increasingly being felt in many parts of the globe, and are predicted to lead to adverse, irreversible impacts on the earth and the ecosystem as a whole. Although it is difficult to connect specific weather events to climate change, increases in global temperature has been predicted to cause broader changes across the globe including glacial retreat, arctic shrinkage and worldwide sea level rise (Mohanty*et al.*, 2010).

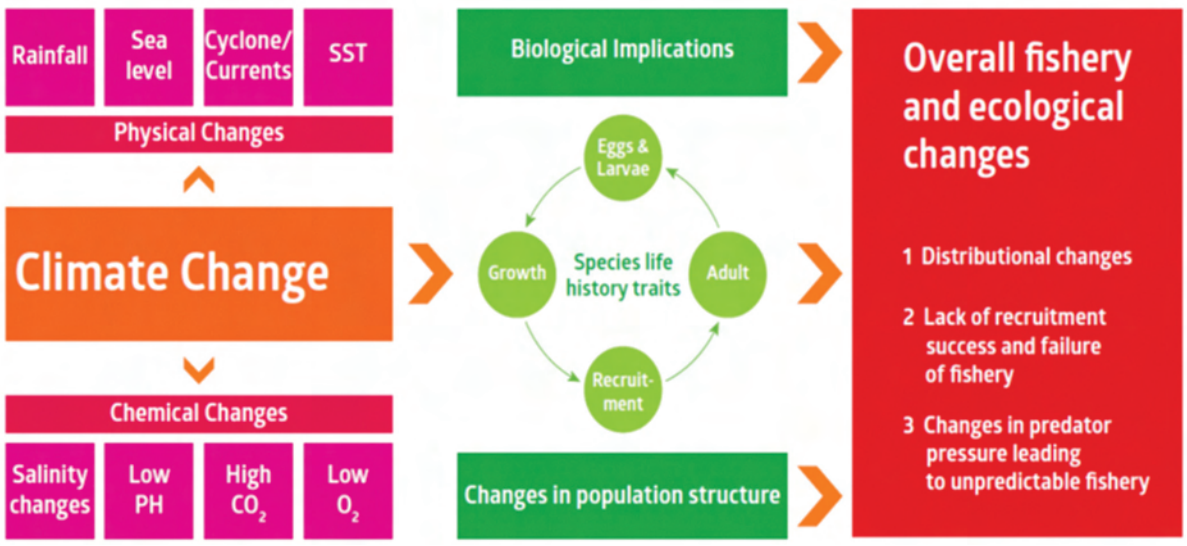

Fig. 1. Flow chart of climate change impacts on fisheries

Impacts of climate change on fishery habitat

Marine ecosystems are not in a steady state, but are instead in constant flux, affected by the environment, which varies on many spatial and temporal scales. Fish populations respond to variation in different ways. Variations may have unforeseen impacts, including cyclic changes in the production level of marine ecosystems that favor one species or group over another. Wetlands of the nation are in great threat due to climate change. The hydrology and influx of wetlands are largely affected due to climate change induced rainfalls, floods and droughts. The physico-chemical and microbiological profiles of wetlands are also significantly affected, thereby changing the suitability of wetland for fish farming practices.

Sea Surface Temperature (SST) increase

Temperature is likely the single most important factor in among the environmental variables affecting the growth and development of aquatic organisms. Earth has been in radiative imbalance since at least the 1970s, where less energy leaves the atmosphere than enters it with most of this being absorbed by the oceans (IPCC, 2014). Northern Indian Ocean has been identified as one of the 17 climate change hotspots among world oceans. These areas will warm faster than 90% of the world oceans. Long-term climate change is likely to impact marine environments and their capacity to sustain fish stocks. Variation of Sea surface Temperature (SST) along Indian seas from 1976 to 2015 revealed that SST increased along all coasts with the highest increase along the southwest coast of India (SWI). The rate of change in SST, though, was highest in northwest India followed by southwest India. The rate of change in SST over Indian Seas revealed that west coast has suffered a higher impact than in the east coast of India.

Ocean acidification

The ongoing reduction in the pH of the Earth's oceans presents a significant challenge to the survival of marine fish. Seawater, by absorbing carbon dioxide and forming carbonic acid, is slowly dropping in pH from its natural, slightly basic state towards pH neutral conditions. The pH of the oceans has dropped to around 8.069 from a pre-industrial age state of 8.179. A total change of -0.355 to 7.824 by 2100 has been estimated by various studies.

Studies indicated an increasing trend in the annual number of instances when pH of surface waters off Kochi was less than 6. Analysis of the instances of low pH values of surface waters in three depth zones *viz*., 10m, 20m and 30m during the period 2005 to 2012 has indicated that in the year 2012, pH of surface water at 10m depth zone was low for a considerably longer period than in the previous years (CMFRI-NICRA, 2013).

Coral bleaching

Elevated water temperatures result in coral bleaching that result in the expulsion of the symbiotic zooxanthellae from the tissues of coral. Between 1979 and 1990, sixty major episodes of coral bleaching were recorded, and in 2016 the longest coral bleaching event on record was observed. Several studies relate bleaching events with global warming and climate change during the last few decades (Lix*et al*.,

2016), and 70% of the reports of coral bleaching at that time were associated with reports of warmer than normal conditions (Glynn, 1991).

Observations on bleaching events have shown that individual species respond differently to this change in thermal environment, with higher degrees of mortality typically seen in branching corals such as *Acropora*(Mohanty*et al*., 2013). Successive bleaching events could lead to a reduction in the species richness of corals in certain global warming hotspots.Coral reef ecosystems support a great diversity of benthic organisms, of which zoanthids, commonly found among degraded reef ecosystems, compose the dominant fauna in the rocky intertidal regions. On the Saurashtra coast, in Gujarat, studies carried out on the distribution and community structure of Zoanthids indicated higher adaptive capacity to changes in environmental and abiotic conditions in comparison to their counterparts. Coral reefs continue to suffer due to high nutrient input, bleaching and other anthropogenic activities, leading to shift in reef patterns towards more aggressive and rapidly growing benthic communities such as zoanthids (Kumari *et al*., 2015).

Sea level rise

Sea level rise on long time scales is mainly due to thermal expansion and exchange of water between the other reservoirs (glaciers, ice caps, etc.) including through anthropogenic change in land hydrology and the atmosphere. The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. The rate of rise in sea level accelerated during 1993 to 2003, to 3.1 mm per year. The total 20th century rise is estimated to be 0.17 m. The movement of the saline water further inland will cause degradation of estuarine associated habitats that are common nesting and breeding grounds for a wide variety of marine fish.Sea-level rise estimates for the Indian coast are between 1.06–1.75 mm per year, with a regional average of 1.29 mm per year, when corrected for GIA using model data (Unnikrishnan and Shankar, 2007). These estimates are consistent with the 1–2 mm per year global sea-level rise estimates reported by the IPCC.

Changes in wind speed and direction

As winds are generated by differences in temperature, rising surface temperatures on the earth's surface are causing winds worldwide to slow dramatically. Reductions in wind speed by 1-3% are expected over the next 50 years, and as high as 4.5% over the next 100 years.

Changes in rainfall

Changes in average precipitation, potential increase in seasonal and annual variability and extremes are likely to be significant drivers of climate change in aquatic systems. Analysis of historical rainfall data in the Andaman and Nicobar islands revealed that while there has been no change in the amount of rainfall received, the patterns of rainfall have changed with increase in number of extreme rainfall events (Velmurugan *et al*., 2015). Variations in annual rainfall intensity, dry season rainfall and the resulting growing season length are likely to create impact on fish farming and could lead to conflict with other agricultural, industrial and domestic users in water scarce areas.

Impact on fish stock

A metabolic increase of 10% corresponds to a 1°C increase in temperature, implying change in seawater temperature as low as 1°C could affect the distribution and life processes of fish. This constraint in physiology will result in changes in distribution, recruitment and abundance. Changes in timing of life history events with climate change are well documented. Species with short-life span and high generational turnover such as plankton and small pelagic fishes are most likely to experience such changes. At intermediate time scales of a few years to a decade, the changes in distribution, recruitment and abundance of many species will be acute at the extremes of species ranges. Changes in abundance will alter species composition and result in changes in the structure and functions of the ecosystems. On longer multi-decadal time scales, fundamental changes in the net primary production and its transfer to higher trophic levels are possible.

Life history is also likely to be affected by the warming of the Earth's waters. Many tropical fish stocks are already exposed to high extremes of temperature tolerance, facing localized extinction, while others may move towards higher latitudes. Shifts in spawning periods of fishes have already been observed in a number of commercially important fish stocks, such as threadfin bream (Zacharia *et al*., 2016). Changes in distribution patterns of two key species in Indian fisheries have already been established – migration patterns of the Indian oil sardine and Indian mackerel have changed greatly over the past 50 years (Vivekanandan *et al*., 2009).

Ocean-atmospheric coupled climate models predict changes in the ocean circulation and subsequent stimulation of phytoplankton biomass production in nutrient depleted areas in the open ocean. Most models show decreasing primary production with shifts in assemblages of phytoplankton to smaller forms, although with high regional variability. Plankton distribution has also been influenced by changes in sea surface temperature. These changes may affect the distribution of fish stocks that predate on plankton. Ocean acidification is believed to have negative consequences for marine denizens, particularly calcifying organisms, subjecting them to the risk of dissolution. Declines in primary productivity have also been forecast. Vulnerability assessment of marine species along Indian coast based on climate change impacts categorized fishes as high, medium and low vulnerable species.

Impact on fish stock availability

Evidence exists for increasing damage by extreme weather events, particularly cyclones, over time. There are various explanations for this, ranging from greater population densities to the wider effects of climate change (IPCC, 2013). Until mid-1980s, the restricted distribution of oil sardine ensured that the entire catch of oil sardine was obtained from the southwestern coast of India. North of 14°N, little to no oil sardine was caught previously. In the last two decades, however, the oil sardine catch from 14°N to 20°N has gradually and consistently increased, contributing 15% to the all-India oil sardine catch by 2006 (Vivekanandan *et al*., 2009). Since the catch in the Southwestern regions has not decreased in overall terms, this represents an extension of the distributional boundaries of the oil sardine.

Studies on the seasonal distribution of skipjack tuna reveal that during winter months, when sea surface temperature is lower, migration occurs towards offshore areas, and during warmer months,

migration occurs towards inshore areas during warmer months. Changes in sea surface temperature due to global warming could result in changes in the seasonal distribution of certain species, and ultimately disruption in their harvest, which is usually based on indigenous knowledge and longstanding cultural practices (Zacharia *et al.*, 2016). Changes in distributional boundaries also bear the potential to bring up delicate questions of fishing rights, especially within the context of geopolitics and exploitation of the resources found within neighbouring exclusive economic zones.

Implications on harvesting sector

Climatic change induces stock fluctuation, species distribution and abundance which shall affect the fishing methods used to harvest affected fish stocks. Species migration, both in horizontal and vertical affects the fishing effort. In a case study of the Bay of Bengal, it was observed that sea surface temperature rise resulted in species migrating to lower layers which forced the fisher folk to increase the depth at which nets are cast. Studies have shown increase in recruitment and catch of oil sardine and Indian mackerel during the post southwest monsoon season as a result of increased temperatures (Zacharia *et al.*, 2016). A mild positive correlation between SST and catch per unit effort in hour was observed, which indicates that greater amount of energy need to be spent to harvest a particular quantity of fish (CMFRI-NICRA, 2016). Studies confirm that the impact of fishing pressure is very high and wider spread as compared to that of sea surface temperature on the fish abundance. However, as 14% of species are also vulnerable to changes in SST.

Wind direction and speed too have implication on fish abundance of many species. It was understood that yellowfin tuna fishery of southeastern coast of India was adversely affected by the change in wind direction and speed. While the north to south winds during October-January was found to be favorable for tuna fishery as the species move along with wind and current from offshore deeper waters to near shore shallower waters. Prominent among the severe climate change induced phenomena are extreme climate change events such as depression induced heavy rainfalls and cyclones which negatively affects the fishing sector operations. A potential impact from climate change is the increase in frequency of extreme weather events and the associated damage to the fishing equipment, facilities, harvest operations and cumulative loss to fishing sector. Vulnerability assessments carried out through surveys of 8000 households from coastal villages in India have revealed that the level of knowledge on the effects of climate change is inadequate, and requires further input, both from government institutions as well as stakeholders (CMFRI-NICRA, 2013).

Life cycle assessments (LCA) of major fishing harbours of the nation revealed that the majority of emissions originating from the fishing sector are generated during the actual harvesting phase, followed by the processing phase(CMFRI-NICRA, 2014). Increase in scouting time shall result in elevated harvest phase emissions.

Aquaculture implications

The contribution to food fish supply from aquaculture grew from 20 % to nearby 50% during 1970 to 2006.To meet the Sustainable Development Goals (SDGs) and to ensure food and nutrition security, aquaculture sector shall have key roles to play. Major aquaculture producing countries are in tropical

and subtropical regions of Asia namely China, Indonesia, India and Vietnam (DeSilva and Soto, 2009). Species reared under aquaculture are poikilothermic and accordingly any temperature change of the associated habitats would significantly influence metabolism and growth which in turn shall have implications on productivity and income. Rising sea temperatures, would, up to a point, increase the production of mariculture. However, these benefits will likely be superseded by adverse effects of growth at higher temperatures. Studies carried out on the growth of silver pompano revealed that fingerlings raised at higher temperatures underwent a higher rate of growth up to ambient temperatures of 31°C. At elevated temperature, however, significant defects in growth were observed, particularly in the musculoskeletal system. Internal abnormalities including bile duct hyperplasia and acute tubular necrosis in the kidneys was also noticed at higher temperatures.

Temperature increase may favour the algal blooms and red tide occurrences due to changes in characteristics of water bodies. Temperature change shall play as a limiting factor for the choice of species that could be successfully cultured. Additionally, increased water temperatures and other associated physical changes, such as shifts in dissolved oxygen levels, have been linked to increases in the intensity and frequency of disease outbreaks (Goggin and Lester, 1995; Harvell*et al.*, 2002; Vilchis *et al.*, 2005). Algal blooms, depletion of dissolved oxygen (oxygen minimum zones) and consequent production losses were observed in inland coastal and mariculture farms.

The upwelling system and ocean circulation is related to climate change fluctuations. In case of Northern Indian Ocean and other regions experiencing strong wind driven upwelling episodes, profound effect are anticipated on future gaseous emissions from oceans. Several cultured species are sensitive to salinity variation. Climate change induced rainfall pattern change shall alter the salinity of the waterbodies and affects the cultured species. In summer months, lack of rains results in salinity increase, which may rise beyond the tolerable limits of farmed shrimps. However in case of high rainfall, the salinity levels shall drop rapidly and such situation were found to be lethal for *Penaeus japonicus*, causing mass mortality of the farm crop (Preston *et al.*, 2001). During droughts the salinity within culture ponds shall be higher eventually making it unbearable for cultured species.

Another impact of climate change is ocean acidification phenomena where the pH of the water body dips due to mixing of CO_2. The scenario of ocean acidification is detrimental to calcareous organisms such as molluscs as it thins the outer shells of the species. Ocean acidification was found to adversely affect the size of larvae of shrimps and mussel. (Bechmann *et al.*, 2011). Besides, low pH values lead to dissolution of the thin exoskeleton of several zooplankton including larval forms of shrimps, molluscs and fishes.This has implications on secondary productivity of the early life stages and also low survival rates of commercially important species, which in turn can affect the fish catch (CMFRI-NICRA, 2013).

The intensity and frequency of climate change induced extreme events such as floods, droughts and cyclones can adversely affect the aquaculture practices and loss in 20-40% loss in production were found as consequence of seasonal variations in coastal states of India. Cyclones viz., *Nisha* in coastal Tamil Nadu (2008), *Aila* in West Bengal (2009), *Laila* in Prakasam District, AP (2010), *Thane* in Cuddalore Dist, TN (2012), *Phailin* in Odisha (2013); Krishna River Flood in AP (2009) and *Tsunami* (not an ECE) in

2004 caused damage to infrastructure and escape of shrimp stock (Ponniah and Muralidhar, 2009; Muralidhar and Vijayan, 2016). The farms were inundated almost one meter above bund level and the damage included erosion of bunds, heavy siltation and damage to electrical installations, sluices, shutters and screens associated negative impacts such as changes in salinity, heavy siltation and introduction of disease and predators into aquaculture facilities along with the flooded water resulted in yield reduction and losses.

Effect on fishing communities

Coastal communities are highly vulnerable to climate change as they are risked with sea level rise based erosion. Change in weather results in loss of fishing days, low catch, income loss and livelihood insecurity. Due to easier influx of water areas with large number of creeks and backwaters are at high risk of inundation. In some coastal areas of Asia, a 30 cm rise in sea level can result in 45 m of landward erosion. The east coast of India is considered more vulnerable due to its flat terrain and the numerous deltas. Estimates show that the inundation area will be about 4.2 km^2 for a 1.0 m rise in sea level in the region surrounding Nagapattinam (Shetye*etal*., 1990). Recent studies indicate net decrease in coastal area due to erosion. Loss of coastal area even in smaller fractions results in significant loss of income and livelihood for associated communities.

Recent cyclonic events such as *Ockhi* and *Vardha* wreak havoc on fishing communities. Damages include infrastructure loss, habitat change, halt of fishing operations and damages to key equipments of the craft. Direct impact of climate change on society is income loss and small scale fisheries sector including artisanal and subsistence fishers are affected the most. Low and irregular income has created livelihood stress coupled with poor adaptability to economic effects of climate change, which is a serious threat to national fisheries economy demanding prioritized interventions of government machineries.

Influence on market and trade

The stock fluctuations and increase in fishing efforts shall results in increased prices for consumers. Additional inputs for fishing operations shall also contribute towards cost increase. The species composition change in catch shall have implications in market as per the availability of high value and low value fishes. Commercial fisheries shall be severely impacted due to shift in fish stocks and increased scouting time. Climate change is expected to change future fisheries production patterns, either by shifting production as species move to new habitats, or as a result of changes in net marine primary production (Brander, 2007). The effects of climate change on the output and reliability of aquaculture practices, however, present a significant hurdle to the food security of states dependent on aquaculture. Ensuring that fisheries are efficiently governed and that aquaculture continues to grow in a sustainable manner will be the main constraints to the sustainability of global fish production (Merino *et al*., 2012).

Potential positive impacts

Climate change has favourable effects as well. Warmer temperature could lead to quicker growth and earlier maturity for some species and shall be beneficial. Silver pompano fingerlings were found to

grow at a greater pace at slightly higher temperatures, though once the temperature exceeded the optimal maximum, abnormalities in growth were noticed (CMFRI-NICRA, 2016).Elevated temperatures of coastal waters also could lead to beneficial impacts with respect to growth rate and feed conversion efficiency (Lehtonen, 1996), and increased production.

Certain species, such as oil sardine and mackerel, have undergone range extensions over the past few decades in response to the warming waters of the Indian Ocean (Vivekanandan *et al.*, 2009). This is distinct from a distributional shift, which could cause disruptions in traditional fishing practices and knowledge. Range extensions on the other hand allow the usage of a particular stock in a greater number of areas. For stocks capable of being utilized at sustainable levels, this is unlikely to be detrimental. Upwelling episodes and ocean mixing could be favourable in some cases as it enables more nutrients and thereby increases the ocean productivity.

Conclusion

Climate change has multilevel impacts on species, habitat as well as on society. The climatic variations are a threat to food and nutritional security of the nation. Rise in sea surface temperature was observed around 0.5–1.3^{o}C along Indian coasts along with precipitation changes and changes in wind pattern. Changes in phenology, trophodynamics, abundance and catch of fish species were established. Changes in SST, Chlorophyll and precipitation make the fish habitat more vulnerable. Extreme events results in loss of fishing days, low catch and income loss. Owing to wide level variations of impacts, regional level impact assessment need to be focused so as to develop effective resilient strategies.

Sampling Methodology Employed by CMFRI for Collection and Estimation of Marine Fish Landings in India

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Fisheries sector plays a key role in Indian economy. The sector supports livelihood, nutritional security, and subsistence to large number of people as well as foreign exchange earnings. India's coast line stretches about 8129 km. There are 1511 landing centres scattered along the coastline of the main land as per the records from National Marine Fisheries Data Centre at Central Marine Fisheries Research Institute (CMFRI). Marine fish landings take place almost all along the coast line throughout the day and sometimes during night. Under these circumstances, collection of statistics by complete enumeration would involve a very large number of enumerators and a huge amount of money apart from the time involved in collection of data. Therefore, a possible solution for quantifying marine fish landings is adoption of a suitable sampling technique. As, monitoring and assessment of the exploited marine fishery resources of India is one of the important mandates of the CMFRI, institute made attempts to evolve the scientific methods for collection of data on catch and effort, since its inception in 1947. Pilot surveys were conducted along the coastline of India and different sampling designs were tested.

CMFRI introduced collection of marine fish statistics through a stratified sampling design along the west coast of India in the year 1959 and extended to other states over the years. Keeping in pace with the changing marine fisheries scenario, the sampling design has been modified over the periods. Presently, CMFRI estimate marine fish landings based on a multi-stage stratified random sampling technique, stratification is done over space and time. Each maritime state is divided into suitable, non-overlapping zones on the basis of fishing intensity and geographical considerations (Fig. 1). The number of landing centres varies from zone to zone.

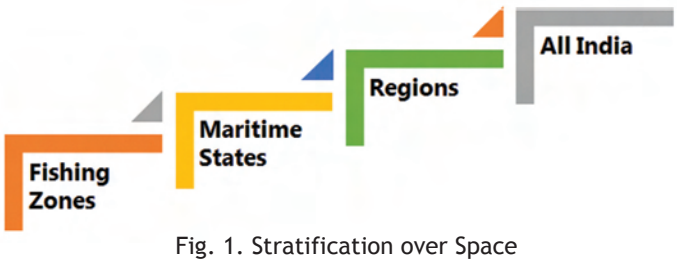

Fig. 1. Stratification over Space

Over space, each zone is regarded as a stratum and over time, a calendar month is considered as a stratum. Consequently, a zone and a calendar month constitute a space-time stratum. Suppose, in a zone, if there are 5 landing centres and 30 fishing days in the month; then 5 x 30 = 150 landing centre days, combination of centre and day constitute the primary stage units (PSU). The fishing craft that land on a landing centre day forms the second stage units (SSU). Furthermore, the fish landings vary considerably among the landing centres in a multi-centre zone, mainly in different seasons and hence a

zone is further stratified into substrata *viz.*, major, minor and very minor. The centres in which either mechanised crafts or 100 or more non-mechanised/motorised crafts are operating are considered as major centres. Likewise, other strata are defined based on the number and type of fishing crafts operating.

Further, a month is divided into three groups each with ten days. A day is selected at random from the first five days of a month and 5 successive days are selected automatically. Three clusters of two successive days are made from the above selected days. To illustrate the selection of landing centres and days, let us consider a fishing zone in a month. Initially, select a date at random from the first five days, let it be 3. Then from the first 10 day group, three clusters of 2 days (3,4) (5,6) and (7,8) can be formed. From the second group of 10 days, the clusters are systematically selected with an interval of 10 days. The clusters of days formed are (13,14) (15,16) and (17,18). Similar selection can be done for the next group of ten days. Accordingly, 9 clusters of two days can be formed in a month. Afterwards, 9 centres are selected with replacement from the total number of landing centres in a zone and allotted to the 9 cluster days as explained before. Thus, a combination of a landing centre and a day (landing centre day) forms the Primary Stage Units. A landing centre day has been divided into 3 periods as given in the infographic. That means a landing centre day is 24 hour duration which starts at noon of the first day and ends at noon of the following day.

The marine fish landings data collection is done by the technical staff of CMFRI. Usually, one staff is identified to collect data from each zone. Data collection starts from period 1 on each selected landing centre day. The staff will be present throughout the periods 1 and 2 at the centres. The data on landings during period 3 (night landings) is usually collected from the landing centre by enquiry on the following day morning. The observations on the 3 periods contribute the data for one landing centre day (24hrs). So, in a 10 day period, data from 3 centre-days are sampled and thus in a month 9 landing centre days are sampled.

After reaching the landing centre, if the landed number of crafts is large, it may not be practical to record the catches of all crafts landed during an observation period. In that situation, sampling of crafts become essential. When the total number of crafts landed is 15 or less, the total landings from all the crafts are enumerated for catch composition and other particulars. When the total number of crafts exceeds 15, the following procedure is followed to sample the number of crafts.

The catches are normally removed in baskets of standard volume from the crafts. The weight of fish contained in these baskets being known, the total weight of the fish in each boat under observation has been obtained. The procedures of selection of the landing centre days and the crafts landed on the selected day for single centre zones are the same as in the case of a stratum in a multi-centre zone. From the landings of the observed fishing units, the landings for all the units landed during the observation period are estimated. By adding the quantities landed during the two 6- hour's periods and during the night (12-hours) the quantity landed for a day (24-hours) at a centre that is the landings for each centre day included in the sample is estimated. From these, the monthly zonal landings are obtained. From the zonal estimates, district-wise, state-wise and all India landings are arrived. The corresponding sampling errors are also estimated. The estimation procedure is detailed in Srinath *et. al.,* (2005).

Administration of the Survey

The survey staff is given 10-12 weeks training course immediately after recruitment and is posted to the survey centres. Each survey centre each centre is provided with literature connected with the identification of fish, a reference collection of local fish species, crustaceans and molluscs, field notebooks and registers. The programme of work for the following month is carefully designed by the staff of Fishery Resources Assessment Division at the CMFRI headquarters. Generally one field staff is allotted to each zone to collect the fish landings data. At the end of every month, the survey staff receives the programme of work for the next month by post, that includes the names of landing centres to be observed and details such as dates and time for observations at each landing centre. The field staff are instructed to send the data collected during every month to reach the Institute's headquarters at least by the end of first week of the subsequent month.

Surprise inspections are carried out by the supervisory staff of the Institute and the enumerators are inspected while at work in the field and their field notebooks and diaries are scrutinised. The estimated zonal landings are always compared with the previous year's survey figures, and if any variation which cannot be explained is observed, the technique of interpenetrating sub-samples is adopted to detect observational errors. Zonal workshops are held periodically to review the progress of work and update the sampling frame and to impart refresher courses to the field staff. Non-response occurs when the regular field staff is not available to observe the centre-day included in the sample. Usually, arrangements are made at the Headquarters/Research/Regional Centre to minimise the non-response.

In the existing sampling methodology, the interest is to estimate gear-wise, species-wise landings for the state in a month, fishing effort according to different types of fishing crafts and also in terms of man hours. The analysis is carried out at CMFRI headquarters. Before the data is processed for analysis it will be ensured that the data collection is made as per the approved schedule, by checking the appropriate proforma. The responsibilities and functions of staff at the headquarters are data coding, estimation and database management. The data analysis is computerised and estimates are made using the software developed by the Fishery Resources Assessment Division of the Institute. The processed data are again counter- checked for errors. When discrepancies are detected, the estimation procedure is scrutinised in detail.

Statistical Methods

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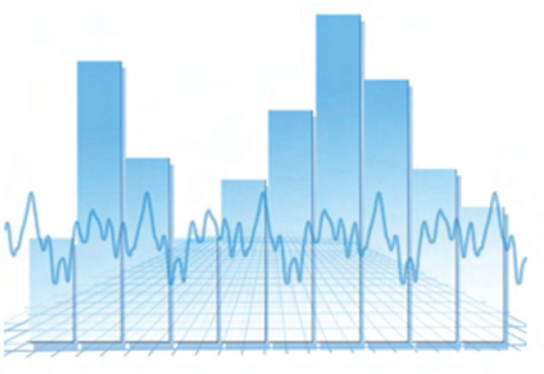
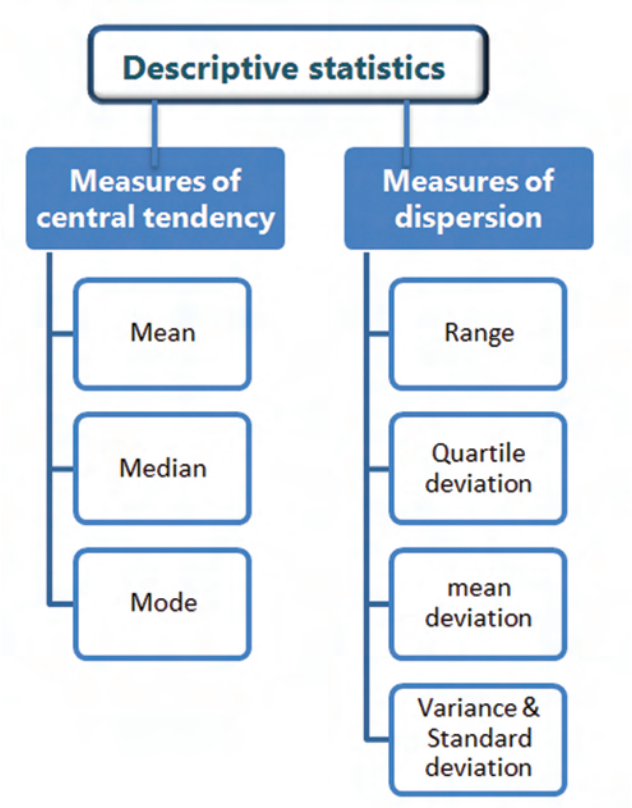


Statistics plays a central role in research, planning and decision-making in almost all natural and social sciences. It is the Science of collecting, organizing, analyzing, interpreting and presenting data. It deals with all aspects of this, including not only the collection, analysis and interpretation of such data, but also the planning the collection of data, in terms of the design of surveys and experiments. Two types of statistical methods are used in analysing data: descriptive statistics and inferential statistics. **Inferential statistics** makes inferences and predictions about a population based on a sample of data taken from the population in question. **Descriptive statistics** uses the data to provide descriptions of the population, either through numerical calculations or graphs or tables. Descriptive statistics therefore enables us to present the data in a more meaningful way, which allows simpler interpretation of the data.



Measures of central tendency

Description of a variable usually begins with the specification of its single most representative value, often called the measure of central tendency. The best way to reduce a set of data and still retain part of the information is to summarize the set with a single value. A measure of central tendency is a single value that attempts to describe a set of data by identifying the central position within that set of data. Measures of central tendency are sometimes called measures of central location or summary statistics. Measures of central tendency are measures of the location of the middle or the center of a distribution. There are several measures for this statistic.

Measures of central tendency

Arithmetic mean

The arithmetic mean of a set of values is the quantity commonly called the mean or the average. For a data set, the mean is the sum of the values divided by the number of values. The mean of a set of numbers x_1, x_2, ...,x_n is typically denoted by $\bar{x}$ pronounced "x bar".

Arithmetic Mean = $\bar{x} = \frac{x_1 + x_2 + ... + x_n}{n}$ Or $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$

Arithmetic Mean from a grouped data

i) Discrete frequency distribution

Data arising from organising 'n' observed values into a smaller number of disjoint groups of values, and counting the frequency of each group; often presented as a frequency table. In this case the values of the variable are multiplied by their respective frequencies and this total is then divided by the total number of frequencies.

Arithmetic mean, $\bar{x} = \frac{f_1 x_1 + f_2 x_2 + ... + f_n x_n}{f_1 + f_2 + ... + f_n}$ $\bar{x} = \frac{\sum_{i=1}^{n} f_i x_i}{\sum_{i=1}^{n} f_i}$

where x_1, x_2, … x_n are values of the variable x and f_1,f_2,…f_n are their corresponding frequencies.

ii) Continuous frequency distribution

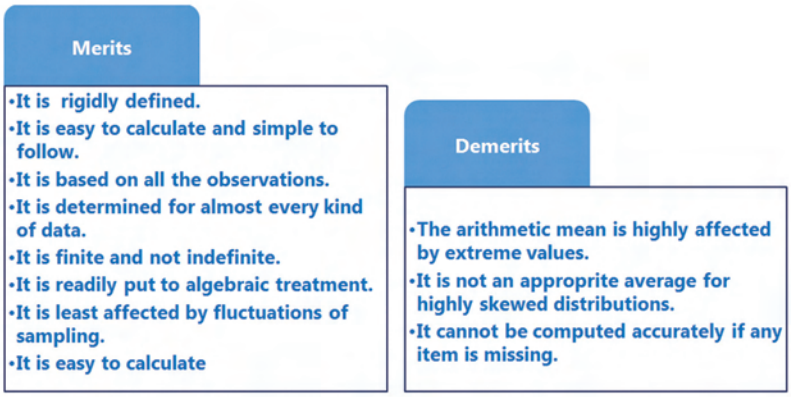
We take mid values of each class as representative of that class, multiply this mid values by their corresponding frequencies, total these products and divide by the total number of items. If x_1,x_2…..x_n represent the mid values of classes and f_1, f_2,…f_n the frequencies, then

$$\text{Arithmetic Mean} = \frac{f_1 x_1 + f_2 x_2 + ... + f_n x_n}{f_1 + f_2 + ... + f_n} = \frac{\sum_{i=1}^{n} f_i x_i}{N}$$

$$\text{Where } N = \sum_{i=1}^{i=n} f_i$$

The mean is valid only for interval data or ratio data. Since it uses the values of all of the data points in the population or sample, the mean is influenced by outliers that may be at the extremes of the data set. The mean uses all the observations and each observation affects the mean. Even though the mean is sensitive to extreme values (*i.e.*, extremely large or small data can cause the mean to be pulled toward the extreme data) it is still the most widely used measure of location. This is due to the fact that the mean has valuable mathematical properties that make it convenient for use with inferential statistics analysis. For example, the sum of the deviations of the numbers in a set of data from the mean is zero, and the sum of the squared deviations of the numbers in a set of data from the mean is minimum value. The following are the merits and demerits of arithmetic mean.

Merits and Demerits of Arithmetic Mean



Median

Median is the value in the middle of the data set, when the data points are arranged from smallest to largest. If there are an odd number of data points, then just arrange them in ascending or descending order and take the middle value. If there is an even number of data points, you will need to take the average of the two middle values. Hence median is determined by sorting the data set from lowest to highest values and taking the data point in the middle of the sequence. There is an equal number of points above and below the median.

Calculation of median in a grouped data

i) Discrete series

In this case also, data should be arranged in ascending or descending order of magnitude and find out the cumulative frequencies. Now find out the value of $(n+1/2)^{th}$ item. It can be found by first locating the cumulative frequency which is equal to (n+1/2) and then determine the value corresponding to it. This will be the value of median.

ii) Continuous series

For computing the value of the median in a continuous series, first determine the particular class in which the value of the median lies. Use N/2 as the rank of Median where N= total frequency. Hence it is N/2 which will divide the area of the curve into two parts. The following formula is used for determining the exact value of the median.

$$\text{Median} = l + \frac{(\frac{N}{2} - m) * c}{f}$$

where N= $\sum fi$ = Total frequency, l- the lower limit of the median class, m -cumulative frequency up to the median class, f- frequency of the median class and c- class width.

Median

The median can be determined for ordinal data as well as interval and ratio data. Unlike the mean, the median is not influenced by outliers at the extremes of the data set. Generally, the median provides a better measure of location than the mean when there are some extremely large or small observations (*i.e.*, when the data are skewed to the right or to the left). For this reason, the median is often used when there are a few extreme values that could greatly influence the mean and distort what might be considered typical. Note that if the median is less than the mean, the data set is skewed to the right. If the median is greater than the mean, the data set is skewed to the left. Median does not have important mathematical properties for use in future calculations.

Merits and Demerits of Median

Merits	Demerits
•Median is rigidly defined. •It is simple to understand and easy to calculate. •Median is not affected by extreme observations. •Median can be computed even for open-end classes. •Median can sometimes be located by inspection. •Median value is real value and is a better representative value of the series compared to arithmetic mean. •Median can be obtained graphically. •Median is only the average to be used while dealing with qualitative characteristics such as intelligence, beauty etc.	•Arrangement of data according to magnitude is necessary. •Median is not based on all observations: •For an ungrouped data, if the number of observation is even, median cannot be determined exactly. •Median is not suitable for further mathematical treatment. •For a small size sample, median is affected by fluctuation of sampling.

Mode

Mode is the most common value or most frequently occurring value in the data set. For finding the mode, just look at the data, count how many of each value you have, and select the data point that shows up the most frequently. If no value occurs more than once, then there is no mode. If two values occur as frequently as each other and more frequently than any other, then there are two modes. In the same way, there could also be more than two modes.

Merits and Demerits of Mode

Merits	Demerits
•Compared mean, mode is less affected by marginal values in the series •Mode can be located graphically, with the help of histogram. •The calculation of mode does not require knowledge of all the items and frequencies of a distribution.	•Mode is an uncertain and vague measure of the central tendency. •Unlike mean, mode is not capable of further algebraic treatment. •It is difficult to identify the modal value, when frequencies of all items are identical. •It ignores extreme marginal frequencies and is not a representative value of all the items in a series.

Mode is very simple measure of central tendency. Because of its simplicity, it is a very popular measure of the central tendency. The mode can be very useful for dealing with categorical data. The mode also can be used with ordinal, interval, and ratio data. However, in interval and ratio scales, the data may be spread thinly with no data points having the same value. In such cases, the mode may not exist or may not be very meaningful. Following are the various merits and demerits of mode:

Weighted Mean

When two or more means are combined to develop an aggregate mean, the influence of each mean must be weighted by the number of cases in its subgroup.

$$\overline{X}_w = \frac{n_1\overline{X}_1 + n_2\overline{X}_2 + n_3\overline{X}_3}{n_1 + n_2 + n_3}$$

Geometric mean (GM)

The geometric mean is an average that is useful for sets of positive numbers that are interpreted according to their product and not their sum (as is the case with the arithmetic mean) e.g. rates of growth.

$$\bar{x} = \left(\prod_{i=1}^{n} x_i\right)^{1/n}$$

Harmonic mean (HM)

The harmonic mean is an average which is useful for sets of numbers which are defined in relation to some unit, for example speed (distance per unit of time).

$$\bar{x} = n \cdot \left(\sum_{i=1}^{n} \frac{1}{x_i}\right)^{-1}$$

Relationship between AM, GM, and HM

AM, GM, and HM satisfy these inequalities:

$$AM > GM > HM$$

Equality holds only when all the elements of the given sample are equal.

The mean (often called the average) is most common measure of central tendency, but there are others, such as, the median and the mode. The mean, median and mode are all valid measures of central tendency but, under different conditions, some measures of central tendency become more appropriate to use than others.

Measures of Dispersion

Measure of variation describes how spread out or scattered a set of data. It is also known as measures of dispersion or measures of spread. Measures of variation determine the range of the distribution, relative to the measures of central tendency. Measures of average such as the mean and median represent the typical value for a dataset. Within the dataset the actual values usually differ from one another and from the average value itself. The extent to which the mean and median are good representatives of the values in the original dataset depends upon the variability or dispersion in the original data. The measures of central tendency are specific data points, measures of variation are lengths between various points within the distribution. It provide us with a summary of how much the points in our data set vary, e.g. how spread out they are or how volatile they are. Measures of variation together with measures of central tendency are important for identifying key features of a sample to better understand the population from which the sample comes from. Datasets are said to have high dispersion when they contain values considerably higher and lower than the mean value. The most common measures of variation are Range, Quartile déviation or semi Interquartile Range, Mean deviation, Variance, Standard deviation and Coefficient of Variation.

Range

The range is the distance between the lowest data point and the highest data point. In other words, it is difference between the highest value and the lowest value.

Range = Highest value–lowest value

The range is the simplest measure of variation to find. Since the range only uses the largest and smallest values, it is greatly affected by extreme values, that is - it is not resistant to change.

The range is simple to compute and is useful when you wish to evaluate the whole of a dataset. It is useful for showing the spread within a dataset and for comparing the spread between similar datasets.

Since the range is based solely on the two most extreme values within the dataset, if one of these is either exceptionally high or low (sometimes referred to as outlier) it will result in a range that is not typical of the variability within the dataset. The range does not really indicate how the scores are concentrated along the distribution. The range only involves the smallest and largest numbers, and is affected by extreme data values or outliers. In order to reduce the problems caused by outliers in a dataset, the inter-quartile range is often calculated instead of the range.

Quartile Deviation or The semi inter-quartile Range

The inter-quartile range is a measure that indicates the extent to which the central 50% of values within the dataset are dispersed. If the sample is ranked in ascending order of magnitude two values of *x* may be found, the first of which is exceeded by 75% of the sample, the second by 25%; their difference is the interquartile range. It is based upon and related to the median. In the same way that the median divides a dataset into two halves, it can be further divided into quarters by identifying the upper and lower quartiles. The lower quartile, Q1 is found one quarter of the way along a dataset when the values have been arranged in order of magnitude; the upper quartile Q3 is found three quarters along the dataset. Therefore, the upper quartile lies half way between the median and the highest value in the dataset whilst the lower quartile lies halfway between the median and the lowest value in the dataset. Between Q1 and Q3 there is half the total number of items. Q3-Q1 affords a convenient and often a good indicator of the absolute variability. Usually one half of the Q3-Q1 is used and given the name semi-interquartile range or quartile deviation.

$$Quartile\ deviation = \frac{Q3 - Q1}{2}$$

The relative measure of quartile deviation is known as the coefficient of Q.D.

$$Coefficient\ of\ Q.D. = \frac{\frac{Q3 - Q1}{2}}{\frac{Q3 + Q1}{2}} = \frac{Q3 - Q1}{Q3 + Q1}$$

The larger the semi – interquartile range, the larger the spread of the central half of the data. Thus the semi –interquartile range provides a measure of spread. Thus it indicate how closely the data are clustered around the median.

Mean deviation

Mean deviation is the average of the absolute values of the deviation scores; that is, mean deviation is the average distance between the mean and the data points. It is calculated as

$$\sum \frac{|\overline{X} - X_i|}{n}$$

Closely related to the measure of mean deviation is the measure of *variance*.

Variance

The variance is the most commonly accepted measure of variation. It represents the average of the squared deviations about the mean. Variance also indicates a relationship between the mean of a distribution and the data points; it is determined by averaging the sum of the squared deviations. Squaring the differences instead of taking the absolute values allows for greater flexibility in calculating further algebraic manipulations of the data. It is the average of the squared deviations between the individual scores and the mean. The larger the variance the more variability there is among the scores. When comparing two samples with the same unit of measurement (age), the variances are comparable even though the sample sizes may be different. Generally, however, smaller samples have greater variability among the scores than larger samples.

The average deviation from the mean is:

$$\textit{Average Deviation} = \frac{\sum(x - \mu)}{N}$$

The problem is that this summation is always zero. So, the average deviation will always be zero. That is why the average deviation is never used. So, to keep it from being zero, the deviation from the mean is squared and called the "squared deviation from the mean". This "average squared deviation from the mean" is called the variance. The formula for variance depends on whether you are working with a population or sample:

The formula for the variance in a population is where $\sigma^2 = \frac{\sum(X-\mu)^2}{N}$ where μ is the mean and N is the number of scores.

When the variance is computed in a sample, the statistic $s^2 = \frac{\sum(X-M)^2}{N-1}$ where M is the mean of the sample and gives an unbiased estimate of σ^2.

Standard deviation

Standard deviation is the most familiar, important and widely used measure of variation. It is a significant measure for making comparison of variability between two or more sets of data in terms of their distance from the mean.

The standard deviation is the square root of the variance. It is denoted by σ and is computed as

$$\sigma = \sqrt{\frac{\Sigma (x_i - \bar{x})^2}{n}}$$

The standard deviation has proven to be an extremely useful measure of spread in part because it is mathematically tractable. Many formulas in inferential statistics use the standard deviation. It possess the majority of the properties which are desirable in a measure of dispersion and is based on all observations. Because of these merits SD should always be used as the measure of dispersion unless there is some definite reason for selecting any other measure of dispersion.

Coefficient of Variation

The coefficient of variation is the ratio of the sample standard deviation to the sample mean. It is calculated as

$$Coefficient\ of\ variation\ (C.V.) = \frac{\sigma}{\bar{x}} * 100$$

It expresses the standard deviation as a percentage of the mean, so it can be used to compare the variability of two or more distributions even when the observations are expressed in different units of measurement. The coefficient of variation is a dimensionless number. So when comparing between data sets with different units or widely different means, one should use the coefficient of variation for comparison instead of the standard deviation. A standard application of the Coefficient of Variation is to characterize the variability of geographic variables over space or time. Coefficient of Variation is particularly applied to characterize the interannual variability of climate variables or biophysical variables. When coefficient of variable is lesser in the data, it is said to be more consistent or have less variability. On the other hand, the series having higher coefficient of variable has higher degree of variability or lesser consistency. When the mean value is close to zero, the coefficient of variation will approach infinity and is hence sensitive to small changes in the mean. Unlike the standard deviation, it cannot be used to construct confidence intervals for the mean.

Correlation

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. The correlation analysis enables us to have an idea about the degree & direction of the relationship between the two variables under study. It is used to assess the possible linear association between two variables. If there is any relation between two variables *i.e.* when one variable changes the other also changes in the same or in the opposite direction, we say that the two variables are correlated. Thus correlation is the study of existence, magnitude and direction of the relation between two or more variables. The measure of correlation called the correlation coefficient. If the ratio of change between two variables is uniform, then the correlation is said to be linear. If the amount of change in one variable does not bear a constant ratio to the amount of change in the other variable, then the correlation is said to be non-linear or curvilinear. The nature of the graph gives us the idea of the linear type of correlation between two variables. If the graph is in a straight line, the correlation is called a "linear correlation" and if the graph is not in a straight line, the correlation is non-linear or curvi-linear.

Positive and negative correlation

If two variables change in the same direction *i.e.*, if one increases the other also increases, or if one decreases, the other also decreases), then this is called a positive correlation. If two variables change in the opposite direction *i.e.*, if one increases, the other decreases and vice versa), then the correlation is called a negative correlation. Through the coefficient of correlation, we can measure the degree or extent of the correlation between two variables. On the basis of the coefficient of correlation we can also determine whether the correlation is positive or negative and also its degree or extent.

If two variables changes in the same direction and in the same proportion, the correlation between the two is **perfect positive**. According to Karl Pearson the coefficient of correlation in this case is +1. On the other hand if the variables change in the opposite direction and in the same proportion, the correlation is **perfect negative** and its coefficient of correlation is -1. In practice we rarely come across these types of correlations.

If two variables exhibit no relations between them or change in variable does not lead to a change in the other variable, then we can say that there is **no correlation** between the two variables. In such a case the coefficient of correlation is 0.

Methods of Determining Correlation

The following are the most commonly used methods of determining correlation.

(1) Scatter Plot

(2) Karl Pearson's coefficient of correlation

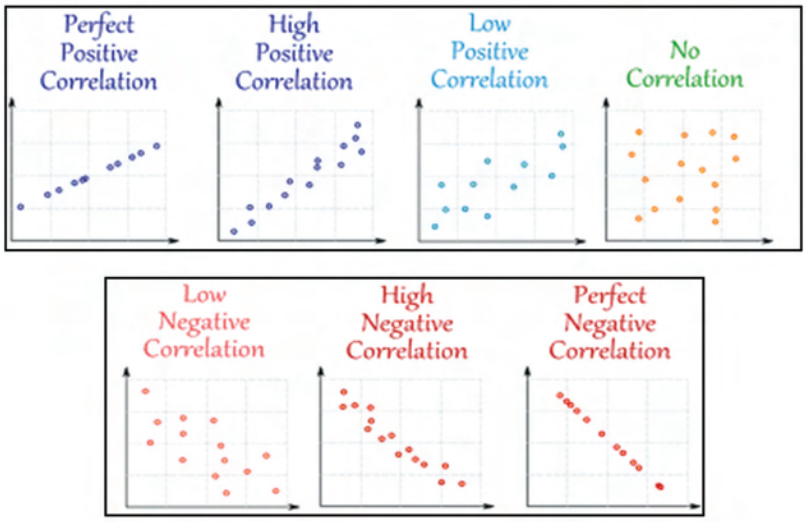
Scatter Plot (Scatter diagram or dot diagram)

The scatter diagram may be described as the diagram which helps us to visualize the relationship between two phenomena. This is the simplest method for finding out whether there is any relationship present between two variables. In this method the values of the two variables are plotted on a graph paper. One is taken along the x-axis and the other along the y-axis. By plotting the data, we get points on the graph which are generally scattered and hence the name 'Scatter Plot'. The manner in which these points are scattered, suggest the degree and the direction of correlation. The greater the scatter of the points on the chart, the lesser is the relationship between the two variables. The more closely the points come to a straight line, the higher the degree of relationship. The degree of correlation is denoted by 'r' and its direction is given by the signs positive and negative. Scatter diagrams will generally show one of five possible correlations between the variables:

- *Strong Positive Correlation :*The value of Y clearly increases as the value of X increases.
- *Strong Negative Correlation:* The value of Y clearly decreases as the value of X increases.
- *Weak Positive Correlation :* The value of Y increases slightly as the value of X increases.
- *Weak Negative Correlation:* The value of Y decreases slightly as the value of X increases.
- *No Correlation:* There is no demonstrated connection between the two variables.

Though this method is simple and provide a rough idea about the existence and the degree of correlation, it is not reliable. As it is not a mathematical method, it cannot measure the degree of correlation.

Illustrations



Karl Pearson's coefficient of correlation:

The most widely-used type of correlation coefficient is *Pearson r*, also called *linear* or *product-moment* correlation. It gives the numerical expression for the measure of correlation. The value of ' r ' gives the magnitude of correlation and sign denotes its direction. It is defined as

$$r = \frac{\sum XY}{n\sigma_x\sigma_y}$$

Where $X = (X_i - \bar{X})$, $Y = (Y_i - \bar{Y})$, σ_x = s.d.of X, σ_y = s.d.of Y and n is the number of pairs of observations

Properties of Correlation coefficient

- The value of correlation does not depend on the specific measurement units used; for example, the correlation between height and weight will be identical regardless of whether *inches* and *pounds*, or *centimeters* and *kilograms* are used as measurement units.
- The value of correlation coefficient lies between -1 and +1, -1 means perfect negative linear correlation and +1 means perfect positive linear correlation.
- The correlation coefficient r only measures the strength of a linear relationship. There are other kinds of relationships besides linear.
- If the two variables are independent, then the value of the correlation coefficient is zero. If the value of the correlation coefficient is zero, it does not mean that there is no correlation, but there may be non-linear correlation.

- The value of r does not change if the independent (x) and dependent (y) variables are interchanged.
- The correlation coefficient r does not change if the scale on either variable is changed. You may multiply, divide, add, or subtract a value to/from all the x-values or y-values without changing the value of r.
- The correlation coefficient r has a Student's t distribution.

Assumptions to use the Pearson product-moment correlation

- The measures are approximately normally distributed
- The variance of the two measures is similar (homoscedasticity)
- The relationship is linear
- The sample represents the population
- The variables are measured on a interval or ratio scale

Testing the Significance of the Correlation Coefficient

The correlation coefficient, *r*, tells us about the strength and direction of the linear relationship between *x* and *y*. However, the reliability of the linear model also depends on how many observed data points are in the sample. We need to look at both the value of the correlation coefficient *r* and the sample size *n*, together.

We perform a hypothesis test of the "significance of the correlation coefficient" to decide whether the linear relationship in the sample data is strong enough to use to model the relationship in the population. The sample data are used to compute *r*, the correlation coefficient for the sample. If we had data for the entire population, we could find the population correlation coefficient. But because we have only have sample data, we cannot calculate the population correlation coefficient. The sample correlation coefficient, *r*, is our estimate of the unknown population correlation coefficient. The hypothesis test lets us decide whether the value of the population correlation coefficient σ is "close to zero" or "significantly different from zero". We decide this based on the sample correlation coefficient *r* and the sample size *n*.

The correlation coefficient r has a t distribution with n-2 degrees of freedom. The test statistic used is

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

If the test concludes that the correlation coefficient is significantly different from zero, we say that the correlation coefficient is significant and there exists a linear relationship between the two variables. If the test concludes that the correlation coefficient is not significantly different from zero (it is close to zero), we say that correlation coefficient is not significant and there is insufficient evidence to conclude that there is a significant linear relationship between the two variables.

Regression analysis

Regression analysis is a statistical tool used for the investigation of relationships between variables. It is the study of *linear*, *additive* relationships between variables. Correlation gives us a measure of the magnitude and direction between variables. It is a technique used for predicting the unknown value of a variable from the known value of another variable. When there is only one independent variable then the relationship is expressed by a straight line. This procedure is called simple linear regression or bivariate regression. More precisely, if X and Y are two related variables, then linear regression analysis helps us to predict the value of Y for a given value of X. Multiple regression is an extension of bivariate regression in which several independent variables are combined to predict the dependent variable. In multiple regression analysis, the value of Y is predicted for given values of X_1, X_2, …, X_k. This technique is used for forecasting, time series modelling and finding the causal effect relationship between the variables.

Dependent and Independent Variables

By simple linear regression, we mean models with just one independent and one dependent variable. The variable whose value is to be predicted is known as the dependent variable and the one whose known value is used for prediction is known as the independent variable. Similarly for Multiple Regression the variable whose value is to be predicted is known as the dependent variable and the ones whose known values are used for prediction are known independent variables.

The Regression Model

The line of regression of Y on X is given by Y = a + bX where a and b are unknown constants known as intercept and slope of the equation. This is used to predict the unknown value of variable Y when value of variable X is known.

The Simple Linear Regression model is

$$Y = a + bX$$

The **Regression Coefficient** is the constant 'b' in the regression equation that tells about the change in the value of dependent variable X corresponding to the unit change in the independent variable Y and can be represented as:

$$b = r\frac{\sigma_x}{\sigma_y}$$

Where r is the correlation coefficient σ_x is the standard deviation of x, σ_y is the standard deviation of y.

In general, the multiple regression equation of Y on X_1, X_2, …, X_k is given by:

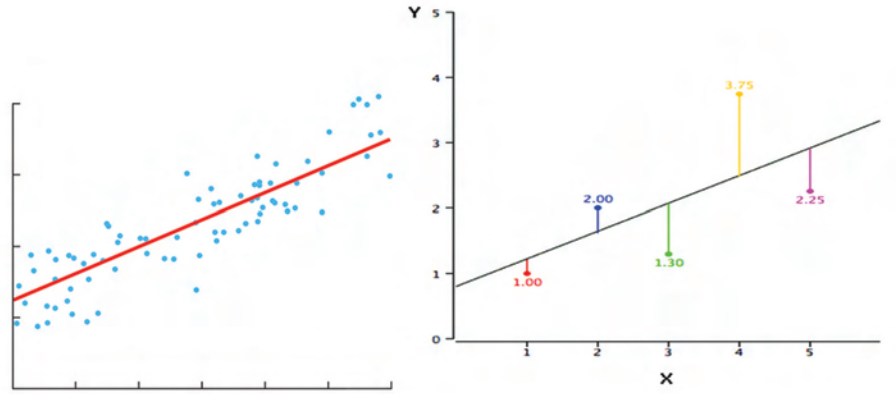
$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots\ldots + b_k X_k$$

Here b_0 is the intercept and b_1, b_2, b_3, …, b_k are analogous to the slope in linear regression equation and are also called regression coefficients. They can be interpreted as the change in the value of dependent variable (Y) corresponding to unit change in the value of independent variable X_i.

Fitting of regression line

In scatter plot, we have seen that if the variables are highly correlated then the points (dots) lie in a narrow strip. If the strip is nearly straight, we can draw a straight line, such that all points are close to it from both sides. Such a line can be taken as an ideal representation of variation. This line is called the line of best fit if it minimizes the distances of all data points from it and also called as the line of regression. Now prediction is easy because all we need to do is to extend the line and read the value. Thus to obtain a line of regression, we need to have a line of best fit.

The problem of choosing the best straight line then comes down to finding the best values of a and b. By 'best' we mean the values of a and b that produce a line closest to all n observations. This means that we find the line that minimizes the distances of each observation to the line. Choose the values of a and b that give the line such that the sum of squared deviations from the line is minimized. This method of estimation of parameters is called least square method. The best line is called the regression line, and the equation describing it is called the regression equation. The deviations from the line are also called residuals.



R^2 - coefficient of determination

Once a line of regression has been constructed, one can check how good it is (in terms of predictive ability) by examining the coefficient of determination (R^2), which is defined as the proportion of variance of the dependent variable that can be explained by the independent variables. The coefficient of determination is a measure of how well the regression equation y = a + bX performs as a predictor of y. Its value represents the percentage of variation that can be explained by the regression equation. R^2 always lies between 0 and 1. Higher values of this are generally taken to indicate a better model. A value of 1 means every point on the regression line fits the data; a value of 0.5 means only half of the variation is explained by the regression. The coefficient of determination is also commonly used to show how accurately a regression model can predict future outcomes.

Estimation of Length Weight Relationship in Fishes

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Organisms generally increase in size (length, weight) during development. The key factors that influence the growth of fish are the quantity of food available, the number of fish utilizing same food source, temperature, oxygen and other water quality factors besides the size, age and sexual maturity of the fish. Every animal in its life exhibit growth both in length and in weight and the relationship between these two has both applied and basic importance. The length-weight relationship is one of the standard methods that yield authentic biological information and is of great importance in fishery assessments. It establishes the mathematical relationship between the two variables, length and weight, and helps in assessing the variations from the expected weight for the known length groups. This is particularly useful for computing the biomass of a sample of fish from the length-frequency of that sample. The parameter estimates of the relationship for a population of fish can be compared to average parameters for the region, parameter estimates from previous years, or parameter estimates among groups of fish to identify the relative condition or robustness of the population. Relationship between length and weight is required for setting up yield equation and sometimes it may be useful as a character to differentiate "small taxonomic units". It also helps in converting one variable into another. Of the two, length is easier to measure and can be converted into weight in which the catch is invariably expressed. The length weight relationship also provides means for finding out the "condition factor" and the seasonal changes in the condition factor are useful to determine the biological changes in the fish.

The relationship between weight (W) and length (L) in fishes has the form:

$$W=aL^b$$

In this equation, the parameters ***a*** and ***b*,** usually termed as length weight parametersare to be estimated with the available length-weight data. Each species of fish will have a specific length-weight relationships or specific length-weight parameters. It may also differ between sexes and between stocks or those belonging to different geographical regions. The parameter ***a*** is a scaling coefficient for the weight at length of the fish species. The parameter ***b*** is a shape parameter for the body form of the fish species.

- to convert growth-in-length equations to growth-in-weight, for stock assessment models;
- for the estimation of the biomass of a species from length frequency distributions
- to calculate a estimate of the condition of fish; and
- for life history and morphological comparisons of life histories of a certain population from different regions

The length of a fish is often measured more accurately than the weight.

In theory, one might expect that the exponent ***b*** would have a value of roughly ***b*** = 3 because the volume of a 3-dimensional object is roughly proportional to the cube of length for a regularly shaped solid. Length is one dimensional whereas weight which depends on volume is three dimensional. Hence, there is thinking that weight of a fish is proportional to cube of the length of the fish. That is, there exists cubic relationship between weight and length of a fish.For an ideal fish which maintains the same shape b=3. Most species of fish do change their shape as they grow and so a cube relationship between length and weight would hardly be expected. It has also been found that while b may be different for fish from different localities, of different sexes, or for larval, immature and mature fish, it is often constant for fish similar in these respects. The length-weight relationship may thus be a character for the differentiation of small taxonomic units, like any other morphometric relationship. It may also change with metamorphosis or the onset of maturity.

In practice, fish that have thin elongated bodies will tend to have values of ***b*** that are less than 3 while fish that have thicker bodies will tend to have values of ***b*** that are greater than 3. Thus this also help to determine whether somatic growth is isometric (b=3) or allometric. Values of *b* smaller, equal and larger than 3 indicate isometry, negative allometry and positive allometry respectively. When *b*>3, large specimens increase in height or width faster than in length, either as the result of a change in body shape with size, or because the large specimens in the sample are in better condition than the small ones. Conversely, when *b*<3, either the large specimens have changed body shape, i.e., become more elongated, or the small specimens were in better nutritional condition at the time of sampling.

Thus the growth of fish length and weight is not proportionate or the relationship between length and weight is not linear. This means that when the length is increased the increase in weight is not proportionate to it. It is rather non-linear type of relationship. The estimation procedure for length – weight relationship is through linear regression. Since the above model of length-weight relationship is not linear it has to be transformed into linear type by applying logarithmic transformation.

If we take logarithm (*natural logarithm with base e*) the above model will become linear as

$\ln (W) = \ln (a) + b \ln (L)$ or $Y = A + b X$

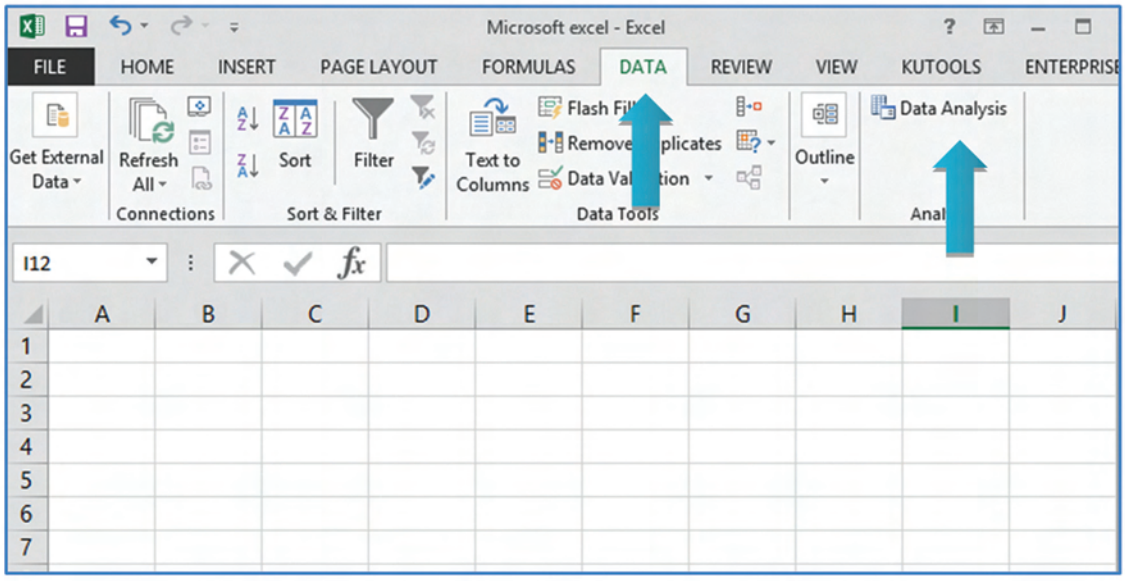
where ln(*a*) is the intercept and (*b*) the slope or regression coefficient. The above relationship is now linear and we can use the ordinary linear regression method for estimating the parameters of the relationship.

Data for fitting the length-weight relationship is collected randomly from the commercial catches and should represent fishes of all sizes, smallest to the biggest, and there should be enough samples for the analysis and estimation through regression. If our aim is to examine difference in length weight relationship between different sexes then data should be collected separately for males and females.

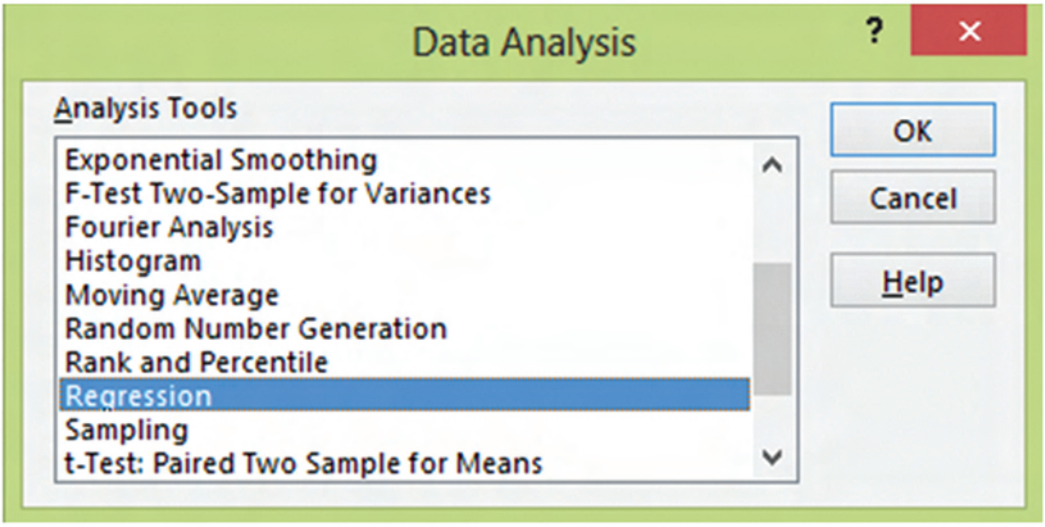
Regression analysis for estimation of length weight parameters

We can use Microsoft Excel to do the analysis using the regression analysis tool.

Select Data from the Main Menu and Select Data Analysis



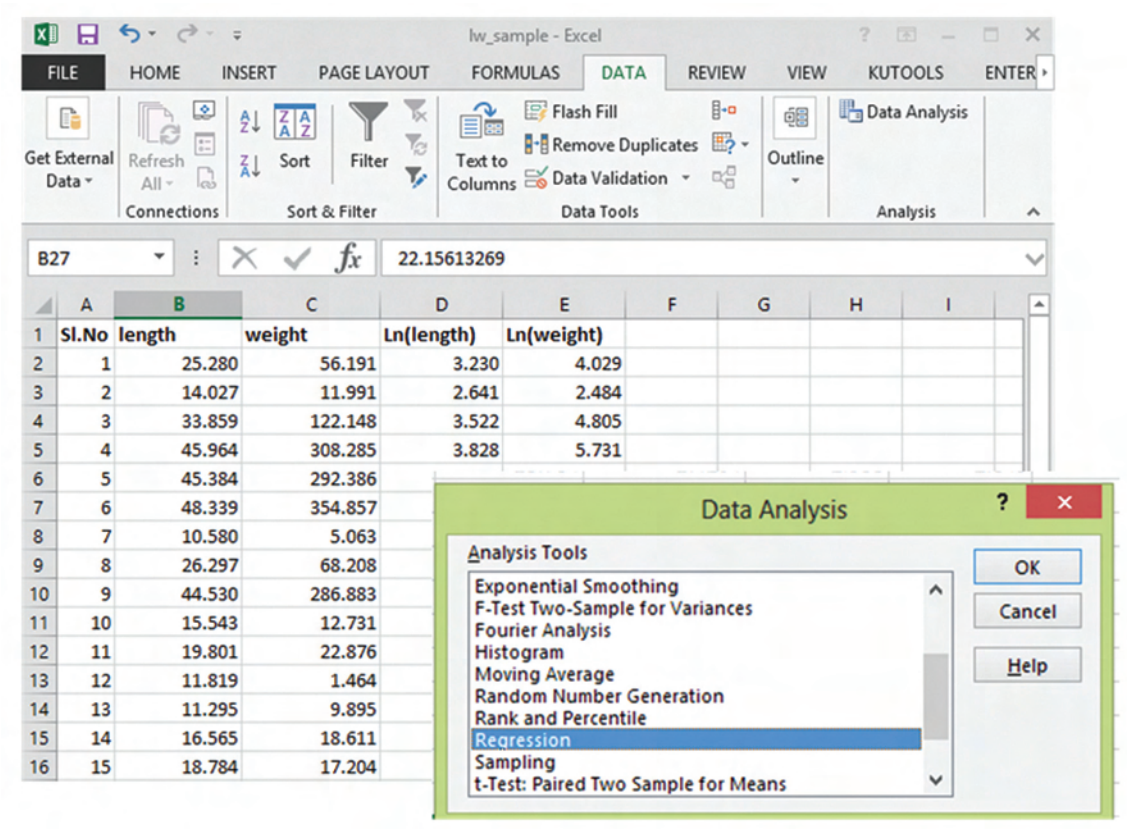
Select 'Regression' from the 'Data Analysis' dialog box and click OK.



The following example demonstrates the use of this tool for estimation of length weight parameters.

Enter the data on length and weight of samples in two columns as shown in below. Generate two columns as the logarithmic values of the length and weight by using the natural logarithm function 'ln'. The transformed data will be used for estimation of parameters. To run the regression routine select

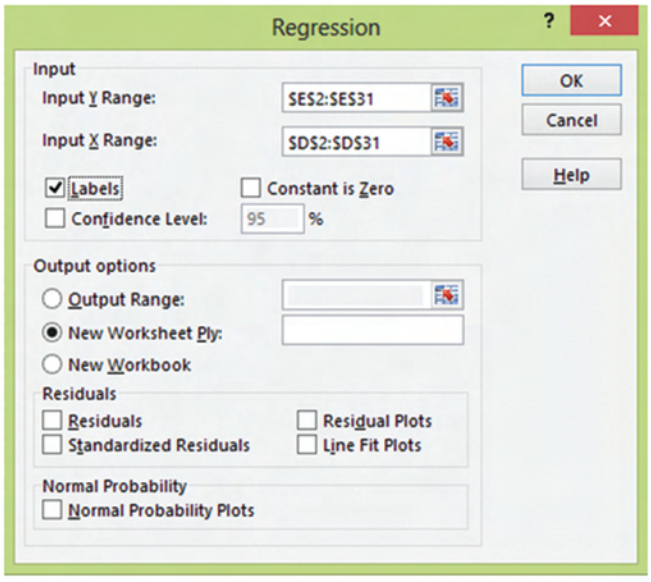
Data from the main menu, and select **Data Analysis**. Again select Regression from the dropdown menu.



	A	B	C	D	E
1	Sl.No	length	weight	Ln(length)	Ln(weight)
2	1	25.280	56.191	3.230	4.029
3	2	14.027	11.991	2.641	2.484
4	3	33.859	122.148	3.522	4.805
5	4	45.964	308.285	3.828	5.731
6	5	45.384	292.386		
7	6	48.339	354.857		
8	7	10.580	5.063		
9	8	26.297	68.208		
10	9	44.530	286.883		
11	10	15.543	12.731		
12	11	19.801	22.876		
13	12	11.819	1.464		
14	13	11.295	9.895		
15	14	16.565	18.611		
16	15	18.784	17.204		

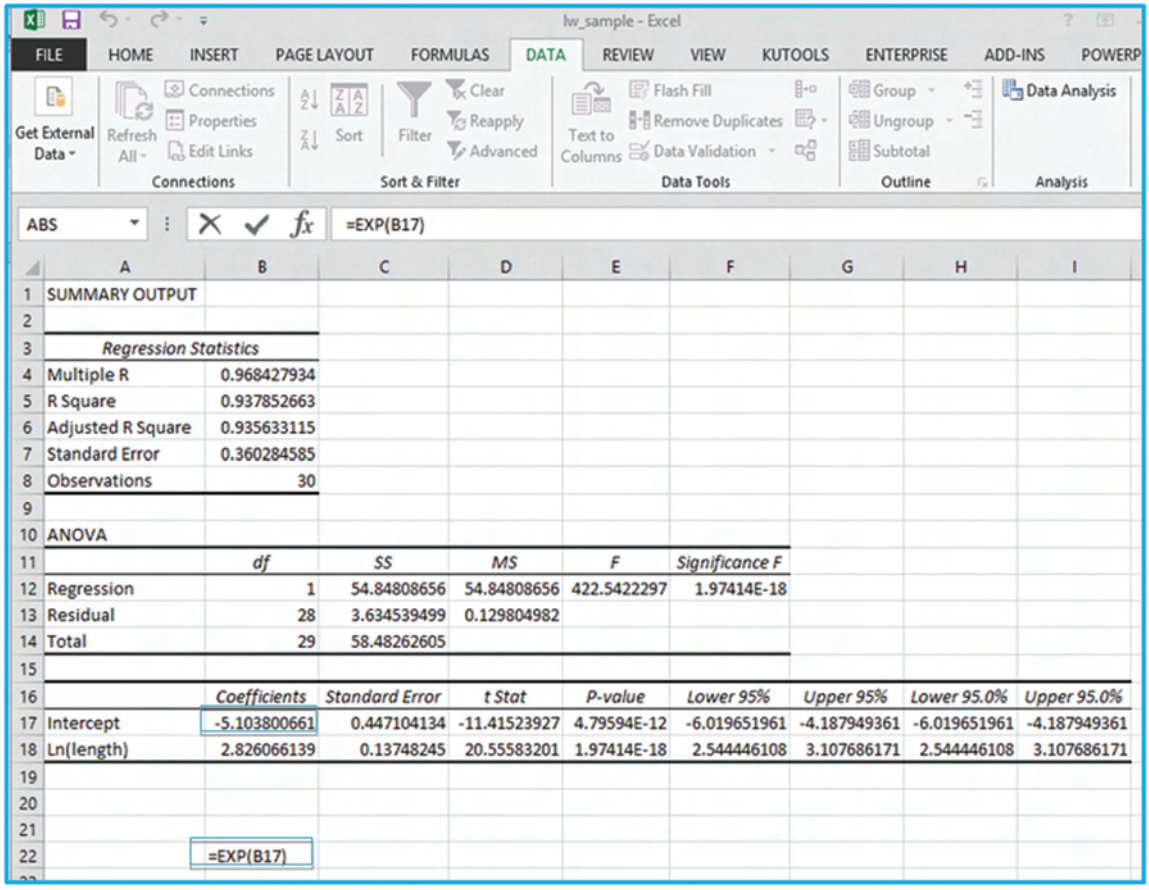
You will be presented with the following dialog box:

Specify the cells containing log transformed weight data and label for “Input Y Range:” (E21:E31). For “Input X Range:” specify the cells containing log transformed length data and label (D21:D31). Check the “Labels” box (since you included data labels in your input ranges), select the New Worksheet Ply under “Output options” and click OK.



The output will be obtained in a new sheet as given below.

The output will give regression statistics, ANOVA and the estimates of coefficients. The estimate of parameter ‘a’ is calculated from the value given against intercept and the estimate of



lw_sample - Excel

FILE HOME INSERT PAGE LAYOUT FORMULAS DATA REVIEW VIEW KUTOOLS ENTERPRISE ADD-INS POWERP

Get External Data | Refresh All | Connections | Properties | Edit Links | Sort | Filter | Clear | Reapply | Advanced | Text to Columns | Flash Fill | Remove Duplicates | Data Validation | Group | Ungroup | Subtotal | Data Analysis

Connections | Sort & Filter | Data Tools | Outline | Analysis

ABS =EXP(B17)

	A	B	C	D	E	F	G	H	I
1	SUMMARY OUTPUT								
2									
3	*Regression Statistics*								
4	Multiple R	0.968427934							
5	R Square	0.937852663							
6	Adjusted R Square	0.935633115							
7	Standard Error	0.360284585							
8	Observations	30							
9									
10	ANOVA								
11		*df*	*SS*	*MS*	*F*	*Significance F*			
12	Regression	1	54.84808656	54.84808656	422.5422297	1.97414E-18			
13	Residual	28	3.634539499	0.129804982					
14	Total	29	58.48262605						
15									
16		*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
17	Intercept	-5.103800661	0.447104134	-11.41523927	4.79594E-12	-6.019651961	-4.187949361	-6.019651961	-4.187949361
18	Ln(length)	2.826066139	0.13748245	20.55583201	1.97414E-18	2.544446108	3.107686171	2.544446108	3.107686171
19									
20									
21									
22		=EXP(B17)							

parameter 'b' is that given against Ln(length) coefficient (here it is the value against 'ln(Length)' which is 2.826). The estimate of 'a' is calculated as the exponent of the intercept value which can be obtained by using the **'exp'** function. For example here the intercept value is in cell B17 and to obtain the estimate of 'a' in a blank cell use the function '=exp(B17)' and we get the value of a as 0.00607.

The goodness of fit of the regression model is indicated by the 'R square' value in the output. It should be high for the relationship fitted to be good. In the example it is 0.96 indicating a good fit. The maximum value of 'R square' is 1.0 and the minimum is zero.

Using the estimated values of the parameters and the original data we can calculate the expected values of weight for the lengths in the sample data. This is done by substituting the estimated values in the relationship $W = a\,L^b$ and calculating the weights corresponding to each length in the sample.

Statistical Test for b=3 (Isometric Relationship)

In statistical test of hypothesis this is testing for the null hypothesis H_0 : b=3 against the alternative hypothesis H_1 : b "3. The test criterion for this statistical test is a Student's t statistic with (n-2) degrees of freedom where n is the total number of observations.

Since this test criterion is for a linear regression, for the length-weight relationship situation we should use the log transformed values for the X and Y variables. Therefore, X values are the log transformed values of length and Y values are the log transformed values of the weights.

The test statistics for this is

$$t_{n-2} = \frac{(b-3)\sqrt{(n-2)\sum_{i=1}^{n}(x_i - \bar{x})^2}}{\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2 - b^2\sum_{i=1}^{n}(x_i - \bar{x})^2}}$$

This value has to be compared with the table value of t-distribution with n-2 degrees of freedom for making inferences about the null hypothesis.

If the value of Student's t is higher than the calculated value, we accept the null hypothesis that b=3. In that case we infer that the length weight relationship is said to be isometric or there is cubic relationship between length and weight.

The length-weight relationship in fishes can be affected by a number of factors including season, habitat, gonad maturity, sex, diet, and stomach fullness, health and preservation techniques, and differences in the length ranges of the specimen caught. The exact relationship between length and weight differs among species of fish according to their inherited body shape, and within a species according to the condition (robustness) of individual fish. Condition sometimes reflects food availability and growth within the weeks prior to sampling. But, condition is variable and dynamic. Individual fish within the same sample vary considerably, and the average condition of each population varies seasonally and yearly.

Responsible Fisheries in India- A Prelude to the Concept, Context and Praxis

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The concept of Responsible Fisheries is synonymous with the FAO Code of Conduct for Responsible Fisheries (CCRF). CCRF is an international instrument for fisheries management which was developed and released by Food and Agriculture Organisation (FAO) functioning under the United Nations on 31 October 1995 after a series of international deliberations that began in 1992. More than 160 countries, including India are signatories to this international instrument which is considered as a landmark document symbolizing the international consensus achieved on the necessity for providing guidelines to ensure sustainable utilization of fisheries resources of the world**.** The most salient feature of this global instrument is its voluntary nature. The Code is often referred to as the Bible of Fisheries Management.

Why the Code?

The term "Responsible Fisheries' may evoke a doubt whether we have been irresponsible in the way we have been developing or managing our fisheries resources. In fact such a doubt is the stepping stone to understand the concept of Responsible Fisheries.

In common parlance the term "responsibility" is immediately read with the notions of rights or ownership. We tend to have a better sense of responsibility to things we own. Thus, we feel responsible in taking care of our properties or assets like land or house or vehicle. The lesser the sense of our ownership lesser will be our sense of responsibility. Thus we feel less responsible for the affairs of our ecosystem or political system because we deem them as owned by all. A property belonging to everyone tends to be no body's property though nobody is excluded from its utilization. This is an important point because in the case of fisheries what we are talking about is a Common Property. Or more correctly an Open access resource. An important question here is "Who actually owns the fish or who actually owns the sea? The *de jure* owner of the fisheries is the State or the government. But by all practical sense the fish, once caught by the fisher, becomes his or her property. If so, what about his or her sense of responsibility to ensure its conservation? It may sound a bit puzzling. That is why the Code makes it very clear in the very first article which is given under the general principles of the Code.

" *States and users of living aquatic resources should conserve aquatic eco systems. The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources"* (Article 6.1).

What is in principle a property of every one, becomes the property of none in practice. This is the

most fundamental challenge in scientific fisheries management. There is a notion that if a sense of ownership is assured, the likelihood of it being taken care of in a responsible manner is more. There are people who argue that it is a misplaced notion. The above-mentioned article of the Code, in fact, is a preemptive answer to this common misunderstanding. It is for the same reason that, of the more than 230 clauses in the Code classified under 12 articles, a large number vest the responsibility with the State. This, in a way also, helps to clear the doubts regarding the real meaning of implementing the Code.

Another doubt could be on the real meaning of the voluntary nature of the Code. Being a voluntary instrument the question could be, "Is it something like a "barking dog that seldom bites"?. The code answers this question in its fundamental philosophy called the Precautionary Approach, which is enshrined in Article 7.5.1."*The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures."*

In simple words what it means is "Better *safe than sorry"*. It also has a deeper meaning which implies that when a person is given the license or permission or right to fish, what is being transferred is part of the stewardship obligation of the State. One needs to clearly understand this because, when individuals operate in a common property with the sole objective of making profitable livelihoods, the sustainable utilization of such a resource becomes an impossible task in the absence of mutually respected and endorsed regulations. The precautionary principle is further elaborated under the Foundations of the Code below. Being a global guideline there is much practical sense for keeping it as a voluntary instrument too. Each nation can contextualize the code in sync with its own local realities and requirements at the same time respecting the globally agreed principles and norms. However there are scholars who argue for making the CCRF as a binding instrument given the sorry state of fisheries governance in most parts of the world.

Foundations of the Code

That the sustainability of marine capture fisheries at the current level of harvesting is at stake is no longer a moot point. It is being realized that fisheries anywhere in the world is more a socioeconomic process with biological constraints than anything else. The open access nature of the resource coupled with unregulated penetration of advanced, but not necessarily eco-friendly, harvesting technologies (a phenomenon called *technological creep*) has enacted a virtual "tragedy of the commons" in our seas. Making the issue still more complex, especially in the context of the Millennium Development Goals, is the rampant poverty existing among our fisher folk though the capture fisheries make significant foreign exchange contribution in our country. The plateauing of the resource as revealed by recent trends in landings doesn't augur well for the ecologic and economic sustainability of the marine fisheries sector.

If there are no technological magical bullets for the current impasse what is the way out? This is precisely the question the FAO code is trying to answer. "*The right to fish carries along with it an obligation to do it responsibly*" is the cardinal principle of the code. This principle is built on the foundation of what is known as a Precautionary Approach. Precautionary approach, which originally was

proposed as Principle 15 of Agenda 21 the Rio Earth Summit meeting in 1992, enunciates that "*where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*".

While in simple terms the precautionary approach means "better safe than sorry", it clearly recognizes that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to changing environment and human values. As Restrepo et al define in fisheries, the precautionary approach is about applying judicious and responsible fisheries management practices, based on sound scientific research and analysis, proactively (to avoid or reverse overexploitation) rather than reactively (once all doubt has been removed and the resource is severely overexploited), to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future as well as current generations".

It involves the application of prudent foresight. It is about applying judicious and responsible fisheries management practices, based on sound scientific research and analysis proactively rather than reactively to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future as well as current generations.

Taking account of the uncertainties in fisheries systems and the need to take action on incomplete knowledge, it requires, *inter alia:*

a. consideration of the needs of future generations and a voidance of changes that are not potentially reversible;
b. prior identification of undesirable outcomes and of measures that will avoid them or correct them promptly;
c. that any necessary corrective measures are initiated without delay, and that they should achieve their purpose promptly, on a timescale not exceeding two or three decades;
d. that where the likely impact of resource use is uncertain, priority should be given to conserving the productive capacity of the resource;
e. that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource, and that increases in capacity should be further contained when resource productivity is highly uncertain;
f. all fishing activities must have prior management authorization and be subject to periodic review;
g. an established legal and institutional framework for fishery management, within which management plans that implement the above points are instituted for each fishery, and
h. appropriate placement of the burden of proof by adhering to the requirements above.

The reversal of burden of proof means that those hoping to exploit our marine resources must demonstrate that no ecologically significant long-term damage will result due to their action. Or in other words human actions are assumed to be harmful unless proven otherwise.

Contents of the Code

The code provides a necessary framework for national and international efforts to ensure sustainable exploitation of aquatic living resources in harmony with the environment. It is achieved through 12 articles covering areas like

a. Nature and scope of the code (article 1)
b. Objectives of the code (article 2),
c. Relationship with other international instruments (article 3),
d. Implementation, monitoring and updating (article 4),
e. Special requirements of developing countries (article 5),
f. General principles (article 6),
g. Fisheries management (article 7),
h. Fishing operations (article 8),
i. Aquaculture development (article 9),
j. Integration of fisheries into coastal area management (article 10),
k. Post-harvest practices and trade (article 11), and
l. Fisheries research (article 12).

(The full text of the FAO CCRF (hereafter referred to as the Code) translated into Malayalam was published by CMFRI in 2002 under an agreement with the FAO (Ramachandran, 2002). Thus, Malayalam became the second language, after Tamil, to have a translated version of the most important international fisheries management instrument. You can access it at www.cmfri.org.in. The pdf of the English full text is supplied with the Winter school CD rom.)

Characteristics of the Code

As we have seen, the most salient feature of the code is that it is *voluntary* in nature. Unlike other international agreements like UN Agreement to Promote Compliance with International Conservation and Management Measures by Fishing vessels on the High Seas or the Straddling Stock Agreement,1995, it is not legally binding and violation of the code cannot be challenged in a court of law.

It would be tempting to castigate it as an Achilles' heel and thus the futility of the code. But it should be remembered, "open acces simbroglios'' cannot be resolved through attempts that fail to recognize altruistic spirit of the human actors. In a situation where "you and your enemy belong to the same eco-system", solutions must be found in managing relationships of the actors that make or move the ecosystem. It doesn't mean that the code is impractical or ineffective. What it demands is to construe responsible fisheries management as a *political process* rather than a *technical process*. This insight is a significant contribution of social scientists studying natural resource management. (Wilson *et. al*. 2006)

A fundamental objective of the Code is "to serve as an instrument of reference to help states to establish or to improve the legal and institutional framework required for the exercise of responsible fisheries and in the formulation and implementation of appropriate measures". The policies of the state for managing the fisheries resources should be based on the provisions of the code.

If world fisheries are to be sustainable in the long term, structural adjustment within the fisheries sector is required. Although policy decisions in this regard must be made by national governments, effective implementation of the code requires the participation and cooperation of a wide range of stakeholders, including fishers, processors, NGOs and consumers. Implementation of the code is primarily the responsibility of states. The code will require regional and sectoral implementation in order to address the particular needs of fisheries in different regions or sub-sectors.

Relevance of the Code in our context

Before analyzing the relevance of the code in our context it is necessary to have an inkling of the historical context in which the code was developed.

The code was unanimously adopted on 31 October 1995 after lengthy deliberations and negotiations spanning about four years. One of the major triggers for the idea behind the code is the international concern over the serious decline noted in the global catch of marine fish. The iconic cod fish of the Canadian waters collapsed in 1992. The famous Science magazine at that time wrote in its editorial that "Fisheries is five per cent protein and 95% politics". It was realized that the command and control regime of fisheries management banking mainly on scientific advice has come of age. Fisheries management was perceived more as fisher management or managing the behavior of human beings rather than that of the fish. No effective management was possible without the active participation of stakeholders. It was this realization that led to the concept of responsible fisheries. It is worth noting that the global production of marine fish after reaching a peak of 86.4 million tons in 1996 from a mere 20 million tons of the 1950s started stagnating or even plummeting down to 79.7 million ton in 2012.

The Lessons of the Code

In order to better understand the lessons we can garner from the code which is an international instrument a comparative key word analysis of the Code with the instrument we currently have namely the Marine Fisheries Regulation Acts of the maritime states in India. (Kerala MFRA is considered for the analysis here). Also given is the famous Magnuson –Stevenson Fisheries Conservation and Management Act 1976, 2007 of USA for a comparative understanding.

Table 1. A comparative Key word analysis of three instruments

Key word	FAO CCRF 1995	KMFRA 1980	MS Act 2007
Sustainability	5	0	8
Over fishing	0	0	45
Conservation	70	1	>200
Management	10	0	>200

Food security	4	0	0
Gender	0	0	0
Regulation	19	37	152
Research	46	0	64
Penalties	0	0	22
Mesh size	1	2	0
Over capacity	0	0	0
MSY	1	0	5
Fisherman	15	0	43
Justice	0	0	6
Discard	9	0	18
By catch	1	0	68
Participation	4	0	32
Fisheries development	0	0	1
Poverty	1	0	2
Conflicts	3	0	3
Rights	33	0	0
Safety	11	0	26
ecosystem	27	0	13
Code of conduct	NA	0	0

The table reveals certain interesting things. The greater importance given to Resource Conservation both by the CCRF and the MS Act compared to KMFRA is indicative of the nature of exploitation in our waters. Remember that the KMFRA was developed in 1980. Today the situation has definitely changed given the declining trends we have witnessed in recent times. Another key word to take note of is MSY. Maximum Sustainable Yield is the most fundamental creed of fisheries stock assessment science. MS act of USA has given much more importance to MSY indicating the extent to which scientific stock assessment has influenced the fisheries management regime in that country. FAO CCRF has mentioned MSY only once (Article 7.2). It indicates the lesser global applicability of MSY as a management reference point. All the three instruments give importance to fisheries regulations. CCRF obviously does not deal with penalties. But what is relevant here for us is the fact that out of the 24 keywords used in this analysis only three keywords appear in KMFRA. They are conservation, regulation and mesh size. (What are your impressions over this finding?). The absence of these key words in our Act indicates that there is a need for reforming it taking into cognizance the new ecologic and economic realities emerging in our fisheries sector.

Another interesting thing is the fact that the MS Act of USA is silent about the FAO CCRF. But, in an international study published in Nature 2009, which assessed the extent to which the FAO CCRF is being complied by different nations USA got second rank. Out of the 53 countries where the assessment was made India got 27th position. The lesson we have to draw from this study is the importance accorded by

Nation States in adopting problem-based management measures in ensuring sustainable utilization of their marine fisheries resources and the kind of policy significance these countries bestow to the importance of sustainable fisheries in the economy of those nations. It is worth noting that all of the 10 highly ranked countries belong to temperate regions of the world. The issues like overfishing are more visible in these countries and hence there is no wonder that these countries are ahead of other nations in adopting conservation oriented- fisheries management and regulations in their waters. In this context a question may creep in our minds. Should we also follow these nations where overfishing has become a reality? Can we continue our business as usual attitude in the absence of fisheries collapses or severe decline in our resources? It indeed is a challenging poser.

It is here that the science of fisheries management and the knowledge base we have accumulated so far regarding the status of our marine resources become relevant. There are only two fundamental questions in fisheries management anywhere in the world.

i) "How much fish we can safely catch?"

ii) "How much is the fish available?"

These questions are very simple. But answers are not so simple to come. That is precisely the reason why Precautionary approach has become the driving philosophy of the global thinking over sustainable or responsible fisheries. We should not fail to see the intellectual humility enshrined in this approach. It is the deep ecological insight that in the face of the excruciating uncertainty and ignorance attached to our fisheries management knowledge base we need to respect the self rejuvenating capacity of the ecosystem. This realization is the basic idea behind new approaches like Ecosystem based Fisheries Management. And of course this demands new approaches in fisheries research and governance.

What is the Problem?

The most important problem a fishery faces is what is known as Over Fishing. It takes place over time as the fishing is intensified. It is the stage where a stock of fish loses its capacity to keep on providing the Maximum Sustainable Yield. It is at this stage that the fishery is at the verge of an almost irredeemable loss, economically and biologically. MSY as a logic is easy to understand. But as a quantitative reference point, MSY is a methodological challenge especially in our multi- species tropical water scenario. This is still considered as the Holy Grail in fisheries stock assessment science. Remember, this should not be construed as a weakness of the scientist. It is the epistemological challenge the fisheries scientists all over the world share, lament and endeavour to overcome.

MSY is like a *Laxman Rekha*. The most frightening aspect about this *Laxman Rekha* is that we need to cross it to realize that we have trespassed it. Hence we can build our defense against the specter of overfishing only on the basis of a stronger understanding and contextual analysis of its symptoms.

Will our waters also witness collapses like that of the Canadian Cod? That such a tragedy has not happened so far is not a guarantee that it will not happen here. But we have a better sense of optimism thanks to the resilience of our marine ecosystem which is mainly due to the rich bio diversity. However, we need to be concerned if recent events like pelagic fatigue in Kerala are of any indication. The

decline experienced by our fishers vouch for a serious rethinking on our laid back attitude. Our fishers also share the veracity of different ways in which symptoms of overfishing are being manifested. They are:

a) Severe decline or total absence in those fish which used to be abundant,

b) Decline in the size range of major species ,

c) Excessive catch of juveniles,

d) Increase in fishing time and distance,

e) Frequent fluctuations in the total catch, and

f) Changes in species composition.

Our Tool Box

There are five types of remedies for the disease called “over fishing”.

1. Based on the total catch of the fish (yield or Output)
2. Based on fishing effort or input
3. Based on time or season (temporal)
4. Based on space or depth (spatial)
5. Based on technical things

A typical example of the first type of remedies is the Quota system of fisheries management which is common in countries like EU, USA . This demands the assistance from a very precise stock assessment science. These measures which are similar to rationing of the catch, can be considered as the last ditch effort feasible in areas of lower species diversity that makes determination of MSY much less cumbersome. The second type of measures aims rationalizing the fleet size. Licensing based on an optimum fleet size is an example here. The next type of measures based on time and space is well known to us through the Monsoon Trawl Ban. Other examples are Marine sanctuaries, and no- fishing zones. Technical measures include Mesh size regulations, and Minimum legal size.(For an overview of the status of the tool box (interpreted in a slightly different mode) in our context see Shinoj and Ramachandran 2017).

As long as a fishery remains a common property resource, a regulated fishery is more profitable than an unregulated fishery in the long run. Our fishers have started accepting this truism. But they are helpless to avoid competitive fishing due to two main reasons. One is the increase in fuel cost. And the other is the high demand for fish which has led to a situation where you are economically rewarded whatever be the catch. So fishers tend to do indiscriminate fishing. This has resulted in an illusion of super abundance which again drives more fishing effort. This is leading to a very dangerous situation. There are fishers (like Mr. Jossy Palliparambil, Munambam Kerala) who characterize this ugly scenario as a phase of “Foolish Fishing”. It is high time each fisher take more care in analyzing the fluctuations observed in the economics of their operations.

Challenges in the praxis

Sustainable Management of resources is no different from fisheries development. They are no longer considered as dichotomous. There will be no fisheries development if there is not enough fish in the sea. There won't be enough fish in the sea, if human beings, both as harvesters and consumers, do not act in a precautionary manner which is nothing but to nurture a feeling of "better safe today than sorry tomorrow". It means to understand clearly the limits to which nature can be tapped. The requirements of both the present generation and future generation are to be given equal importance. It is also about respecting the co-evolutionary culture of a fisheries-resource dependent community. Thus Responsible Fisheries management takes place at the dynamic interface between the behavior of man and that of fish. So the knowledge base for responsible fisheries ought to be a convergence of different disciplines like fisheries biology, socio-politics, ecology, economics, engineering, law and communication. The aim of fisheries management is to ensure optimum utilization of a common pool resource without jeopardising the inherent regenerative ability of the resource leading to livelihood security of the dependent community.

Much has been said about rights-based fisheries, fisheries co-management and ecosystem-based fisheries management with fisheries managers, policy-makers, scientist and researchers racking their brains about the meaning of each of these fisheries management approaches. In trying to find definitions and formulating "how-to" guidelines and handbooks on such fisheries management approaches, their essential ingredient often is overlooked, namely dialogue. Whether talking of co-management and partnerships between fisheries stakeholders or of the adaptive nature of ecosystem-based fisheries management the fundamental nature of any fisheries management effort is the communication process among its various protagonists. Neither a partnership between fishing communities, fisheries managers, researchers and other stakeholders, nor the merging of the development goals of human well-being with that of ecological well-being through an ecosystem-based fisheries management approach would be possible without free-flowing information among the various partners in the management process.

These communication processes can take many different forms and can be designed according to a diversity of purposes: (1) to meet specific fisheries management objectives, needs and aspirations for the fisheries sector; and 2) to generate new information about local fisheries systems through participatory (eg. catch-reporting) mechanisms. The experiences from these activities should encourage fisheries managers, scientists, and fishing communities to actively seek such dialogue and information exchange as a basis for improving fisheries management on an ecosystem approach.

The efforts to engender a scientifically- informed fisheries management or governance regime are always challenged by the inherent uncertainty that characterizes the epistemology of fisheries science. The complexity of an otherwise resilient tropical marine ecosystem adds fuel to the fire. And on the Human dimension we have a plethora of challenges despite promising perspectives from Hardin to Ostrom.

It is here that we need to fully appreciate the multitude of challenges we face in a precautionary and participatory framework. We have the instruments/tool box. But the credo of responsible fisheries

is yet to become part of the community ethos. What could be the reasons and how we can overcome the barriers? As a concerned stakeholder each one of us has a responsibility to be part of a collective process to not only decipher the answers but also translate them into pragmatic ameliorative strategies.

The Code and CMFRI Initiatives

Our fisheries have undergone tremendous changes during the past six decades. Before the advent of modernization, (motorization, mechanization , refrigeration, export orientation and transportation) the access to sea was limited to a few skillful and adventurous people who were by birth fishers. The community could afford to have self regulations oriented towards resource conservation which were arrived through the ecological experience of the community over generations. These concerns were institutionalized too. An example of such an institution still, surprisingly, surviving in Kerala is the *Kadakkody* of the Malabar coast (Ramachandran, 2006). The self regulations and community regulations which were rooted in the traditional wisdom have given way to technological skills. These skills, unleashed by what we generally refer to as an era modernization, most often take a dehumanized manifestation thus weakening the hold of the community. This is where the crucial role of the State comes into play in the management as well as development of the fishery. This is better known as fisheries governance.

Fisheries governance is dependent on the particular stage of economic development and local ecological status of the fishery resources. This varies with each country. It is because of this contextual nature that the Code has been made as a voluntary tool. Each government is free to make its own rules, regulations and strategies based on the guidelines and principles elaborated in the Code. Thus article 4.3 says "FAO through its competent bodies, may revise the code, taking into account developments in fisheries as well as reports to COFI on the implementation of the Code. (But in recent times an argument against this position has also emerged).

It is in this context that the actions and initiatives being taken by CMFRI, mainly through an NATP funded research project titled "Designing and validation of communication strategies for responsible fisheries –a co-learning approach" become relevant. A Responsible Fisheries Extension Module (RFEM), which consists of 13 tools including a Malayalam translation of the code, animation films in all maritime languages etc. developed have been widely used to create awareness among the fisher folk. A state-wide campaign on Responsible Fisheries was launched and the RFEM was released for further scaling up by the respective State Fisheries Departments. These mass communication tools have the potential to reach almost 85 % of the fisher folk and other stakeholders in the country. It is reasonable to conclude that CMFRI has made a pioneering initiative in the cause of popularization of the concept of Responsible Fisheries in India (Ramachandran, 2004).

Though the voluntary nature of the code has been necessary in garnering the all-nation agreement when it was drafted in the early 1990s, our attitudes to the oceans have changed since then (Pitcher *et al.*, 2009). There is now widespread scientific consensus on the ecological impacts of continued over-fishing and the threats to seafood security and broad agreement on policy issues such as curtailing illegal catches and minimizing the impacts of fishing on marine ecosystems. The basic requirement for adoption of Ecosystem Approach is a dynamic knowledge base on stock assessment. The stock assessment

knowledge base generated and continuously maintained by CMFRI is a unique achievement among the developing tropical context countries. But the utility of this Knowledge base in translating into management praxis is less appreciated. There still exists a communication divide between the research system and the fisheries management system in the country.

Though the communication tools and strategies already developed by the institute have been useful in creating awareness on the need for sustainable /responsible fisheries there is a need to develop and scale up specific communication interventions to sensitize the stakeholders in making a transition towards ecosystem based approaches that ensure responsible management of our waters. Fisheries management is fisher management and participatory approaches informed/initiated by a proactive research system taking place in a democratic and decentralized civil society space is globally accepted as the key to Ecosystem Based Fisheries Management. The future is decided by the capacity we build today amongst the different stakeholders responsible for sustainably utilizing the marine fisheries resources of our country. It is with this objective that we are continuing the efforts in this line through innovative research projects in Capacity Development for compliance to Ecosystem Based Responsible Fisheries Management in India through Co-Learning and Multi-disciplinary action research under the leadership of Extension scientists in CMFRI.

Pathways before us

Taking into consideration the inherent epistemological limitations of the Fisheries science, it is essential to make a transition towards more participatory efforts fisheries governance and research. There cannot be any management without measurement. What our fishers lack is the big picture on the status of our fisheries resources. The science has the tools to draw this picture. But its precision depends on the accuracy of the data on landings. We badly need a National Marine Fisheries Data Acquisition Plan. The active and informed participation of fishers in providing the catch data needs to be encouraged through proper incentive mechanisms.

Engendering a scientifically informed fisheries management governance system is the need of the hour. As recent events like the Kochi Initiative (Ramachandran and Mohamed 2015) is of any indication, formation of multi stakeholder platforms of responsible fisheries co-governance is not an impossible task in our context. The response of the State in facilitating this transition is essential. With the landmark promulgation of insisting Minimum Legal Size for 55 species of fish by the Government of Kerala (GoK, 2017) done based on the recommendation of CMFRI (Mohamed et al 2014), the State of Kerala has shown an instance of proactive engagement with responsible fisheries governance which is worthy of emulation by other maritime states. It is, however, worth remembering that regulatory measures like MLS would become impotent in the absence of strong arm efforts to eliminate (or at least rationalize) external drivers like demand for the juveniles either for reduction or consumption. As scholars of regulatory politics argue, legislative coercion though necessary can not be open totendencies for inefficient rent seeking in a public good.

Economics of Marine Fishing Methods and Management at a Glance

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Introduction

Economics is the basis for life. Every one of us is a practicing economist in himself/herself in life. The principle of economics, when applied to fields like agriculture, animal husbandry, fisheries, poultry and other enterprises becomes more valuable. Initially fisheries did not consider economics as a component. But later in course of time, the fishery biologists realized that economics is a vital component of fisheries management. In this lecture we will see how the concepts of economics are applied to assess the economic performance of various fishing methods and fisheries management.

Economics: A few basic concepts

Wants are unlimited but the means to satisfy them are limited. This is the basis of scarcity definition of Economics. In the wider sense, the resources at our disposal to meet our requirements are limited. We have to allocate the resources among the competing alternatives, for which the economic theory helps us. Optimization of resource use to obtain maximum profit is one of the aims for applying economic principle in entrepreneurship.

In fisheries also, the economic principles are allocated for formulating fisheries management measures. In fisheries, the point of optimum harvest occurs where the average revenue cost cuts the average revenue curve, contrary to the other fields, where the optimum occurs where marginal cost cuts the marginal revenue curve.

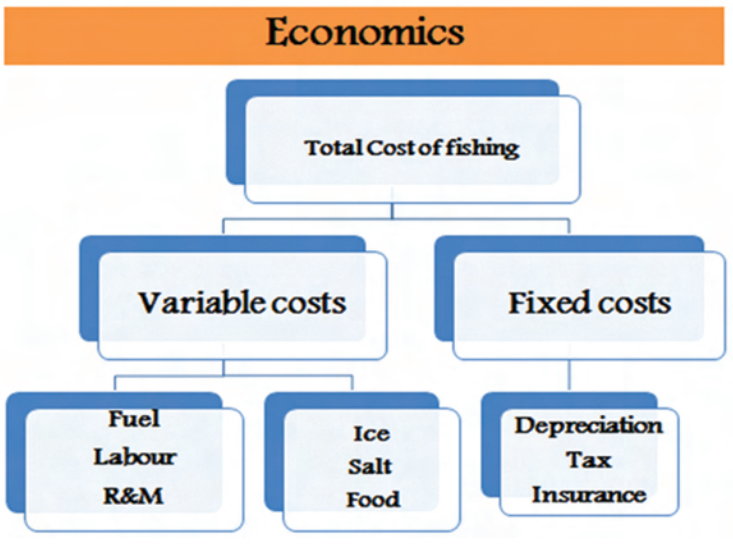


Fig. 1. Types of costs and its components

**Presently at Madras Research Centre of CMFRI, Chennai - 600 028*

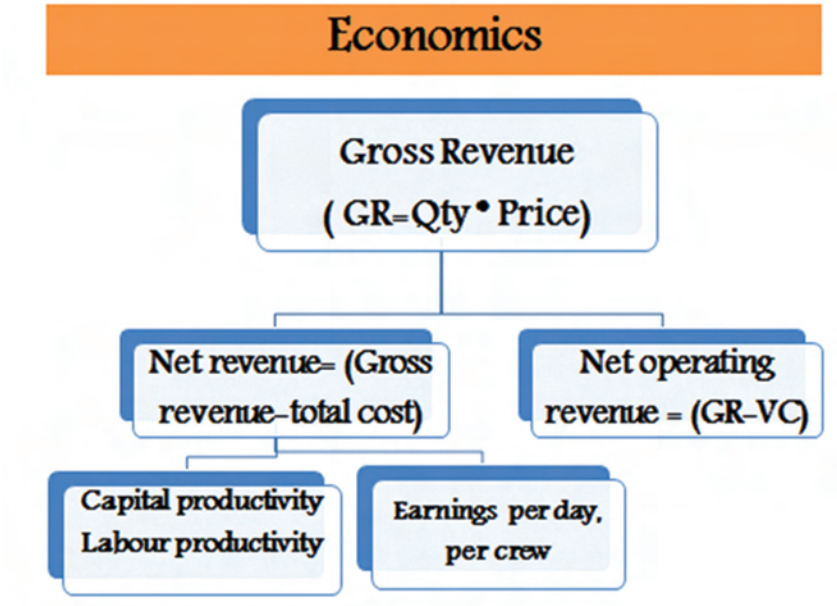


Fig. 2. Types of revenue and its components

Economics of marine fishing methods

Marine fish production in India reached 3.63 million tonnes in 2016. The country had exported marine products worth 5.78 billion US$ in 2016-17 (MPEDA, 2017). Nearly one million active fisherfolk are engaged in marine fishing in the country and the sector provides employment to a significant number of coastal population in fishing allied activities. The marine fish production has been stagnant in the past decade owing to the dwindling catch of many of the marine resources. However, the consistent rise in prices of many of the marine fish resources contributed to increase in the gross revenue both at landing centre and retail levels. The estimated value of marine fish landings during 2016 at landing centre level was Rs.48,381 crores, and at retail level was Rs.73,289 crores. The Government of India has taken several measures for augmenting fish production through promotion of mariculture activities in the maritime states of the country.

The economic analysis in marine fisheries focus on developing macroeconomic indicators for guiding the policy makers, micro level indicators for investment decisions for stakeholders, financial feasibility analysis and marketing efficiency analysis. The economic and financial indicators act as decision making tools for investment decisions for the marine fisherfolk and fish farmers at microlevel.

The macro level indicators developed include gross value added in the marine fisheries sector, percapita earnings of marine fisherfolk, gross earnings at landing centre and retail levels and Fishermen's Share in the Consumer's Rupee. Financial ratios such as Operating Ratio, Input-Output ratio, gross ratio and discounted measures like Net Present Value (NPV), Internal rate of Return *(*IRR) and Benefit-Cost Ratio (BCR) were used to analyze the financial feasibility at micro level.

The various macro and micro level financial indicators are as follows.

Net profit = [Gross revenue **minus** all costs including operational expenses, depreciation and interest on fixed capital] .....(1)

$$Gross\ Revenue\ per\ trip = \sum_{i=1}^{n} Q_i \times P_i \ \ldots\ldots\ldots\ldots\ldots (2)$$

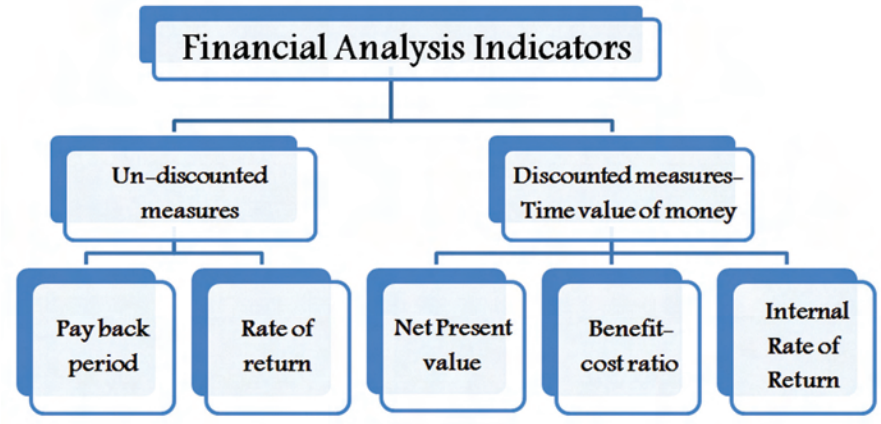
where Q_i is the landings of the resource and P_i is the price (Rs./kg) of the resource.

Operating ratio = Operating costs/ Gross revenue .....,(3)

Input-output ratio= Input cost/ Gross revenue .....(4)

Gross value added= Net operating profit + Labour wages .....(5)

Data on operational costs, fixed cost and prices and quantities of resources landed per fishing trip are collected by following multistage random sampling method covering all the fishing seasons. The operating costs in marine fishing consists of expenses on fuel, (diesel/kerosene), ice, food for the crew, crew bata, crew share, repair and maintenance of crafts, gears and engine, water charges, auction charges, landing charges and other miscellaneous expenses. The input costs consist of operational costs excluding the crew wages. The crew wages are paid either as fixed monthly payments or as a share of the net income earned per fishing trip. The crew share varied from 35-50% of the net income for mechanized fishing units.



Financial feasibility and economic viability

The financial feasibility and economic viability indicators are required to evaluate the financial worthiness of any enterprise. Especially the financial institutions evaluate the applications for loans using these indicators only. The financial feasibility indicators are evaluated by estimating the Net present value (NPV), Benefit-Cost ratio (BCR) and Internal Rate of Return (IRR) as detailed below.

(i) Payback period ***(in number of years)*** = {Initial Investment /Average annual net cash flow or net profit}.....(6)

$$(i) \quad Rate\ of\ return\ (in\ percent) = \left\{\frac{Gross\ revenue}{Initial\ investment}\right\} \times 100 \ \ldots\ldots\ldots\ldots (7)$$

$$Net\ Present\ Value\ (NPV) = \frac{\sum_i Bi}{(1+r)^i} - \frac{\sum_i Ci}{(1+r)^i} \ldots\ldots\ldots\ldots (8)$$

Where NPV is the net present value and r is the internal rate of return

(iv) Benefit Cost Ratio(BCR) is the ratio of present discounted benefits to the discounted cost.

$$BCR = \frac{\{\sum_i Bi/(1+r)^i\}}{\{\sum_i Ci/(1+r)^i\}} \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where ,

"B_i" is the total revenue earned at year i,

"C_i" is the total costs at year i,

"i is the average number of years of operation of fishing units and

" r" is the discount rate.

(v) Internal Rate of Return (IRR) of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.

Economic performance of marine fishing: Results of Case studies

The Socio Economic Evaluation and Technology Transfer Division (SEETTD) is regularly conducting research project on the assessment of economic performance of marine fishing methods across the country. The analysis of the economic performance of such fishing methods are given below

(i) The macroeconomic indicators of marine fishing in India

The macroeconomic indicators of marine fishing were arrived from the costs and revenues per fishing trip for various types of fishing units operating in different maritime states. The gross value realized from marine fish landings in India (2016) was Rs.48,381 crores with a net operating income of Rs. 21,288 crores. The gross value added in marine fishing was Rs. 22,899 crores (Table1).

Table 1 Macro indicators for marine fisheries sector in India (2016)

Macro indicators	Value
Value at landing centre level(in Rs.crores)	48,381
Total operating cost(in Rs.crores)	27,093
Net operating income(in Rs.crores)	21,288
Total value of inventories(in Rs.crores)	23,668
Gross ratio	2.04
Capital productivity	0.56
Gross value added(in Rs.crores)	22,899

Source: CMFRI Annual report, 2016-17

(ii) Economic performance of marine fishing methods

The fishing units operating in the Indian coastal waters are categorized as mechanized, motorized and the non-motorised sectors based on the method of propulsion and types of engines used for fishing. In the mechanized sector, trawlers are the dominant units followed by gillnetters, dol netters and purse seiners. The motorized sector consisted of gillnetters, ring seiners and hooks and lines. The mechanized sector contributed 82% of marine fish landings followed by 17% by motorized sector and 1% non-mechanized sector in 2016. The mechanized sector undertook single day fishing trips to multiday fishing trips up to 20 days duration. The economic performance varied with type of fishing unit, types of engines used and duration of fishing trips. The economic performance of different mechanized units indicated the lowest input-output ratios for trawlers operated in AP. The gross value added was maximum for the multiday gillnetters operating in Kerala and the labour productivity was highest for multiday trawlers in Maharashtra (Table 2).

Table 2 Economic performance mechanized fishing units in selected coastal states (2016)

Particulars	Kerala			Maharashtra		AP		Odisha	
	Trawl MD (2-5D)	Trawl MD (>6D)	Gillnet (MDF>6D)	Trawl MD (>6D)	Purse seine (SD)	Trawl MD (2-5D)	Trawl (SD)	Trawl MD (>6D)	Purse seine (MD)
Total Operational cost(in Rs)	78903	280913	351658	223201	42635	66348	18891	181496	172885
Gross Revenue (in Rs.)	125132	490586	632092	629756	154590	137313	39718	404912	292724
Net operating income (in Rs.)	46228	209672	280434	406555	111955	70965	20827	223416	119839
Capital productivity	0.63	0.57	0.56	0.35	0.28	0.48	0.48	0.54	0.59
Labour productivity (kg/crew)	99	252	240	392	71	270	151	304	327
Input-output ratio	0.29	0.25	0.31	0.30	0.20	0.18	0.18	0.25	0.33
Gross value added (in Rs.)	88962	366748	437510	442393	124205	112158	32741	304410	292725

Source: CMFRI Annual report 2016-17

Note: *MD: Multiday fishing; 2-5D: fishing trips of 2-5 days' duration and >6D: fishing trips of more than 6 days' duration*

The motorized category consisted of small wooden/FRP canoes with outboard or inboard engines and these are operated mainly in the states of Kerala, Tamil Nadu, Andhra Pradesh and Gujarat. Eventhough the contribution of motorized sector to the total marine fish landings has declined drastically in the recent years it still contributes 62% of the active fisherfolk workforce in the marine fishing sector. The non-motorised sector consisted of traditional boats without engine. The motorised and non-motorised units undertook single-day fishing trips only and a comparative analysis of the economic performance of various non-mecahnised fishing units indicated the highest capital productivity, gross value added and labour productivity for motorized gillnetters in Andhra Pradesh (Table3).

Table 3 Economic performance of selected motorized and non-motorized fishing units (2016)

Particulars	Andhra Pradesh		Tamil Nadu		Kerala	
	Mot GN	Mot.BSGN	NM BSGN	Mot. GN	Mot. H&L	Mot RS
Total Operational cost(in Rs)	8967	1415	302	5179	8306	3584
Gross Revenue(in Rs.)	18154	2148	3621	6207	9423	4082
Net operating income (in Rs.)	9187	733	319	1028	1117	498
Capital productivity	0.49	0.74	0.49	0.83	0.88	0.88
Labour productivity(kg/crew)	80	4	2	17	10	10
Input-output ratio	0.19	0.49	0.25	0.18	0.37	0.22
Gross value added(in Rs.)	14633	1092	469	5056	5970	3197

Source: CMFRI Annual report 2016-17

Note: Mot.GN: Motorised gillnet, Mot.BSGN: Motorised bottomset gillnet, Mot.H&L: Motorised Hooks& Line, Mot. RS: Motorised Ring seine

Fishery Resources

Fishery resources are renewable natural resource but are not inexhaustible extinct if the rate of harvest or exploitation is higher than the rate of regeneration or reproduction. Here the size of the stock (population) depends on the biological, economic and social considerations. Fisheries come under Common Property Resource (CPR), due to which a comprehensive management measure could not be exercised. "In an open access regime like fishery, negative externalities are many, which implies that uncontrolled fishery will bound to end up in what is called tragedy of commons". (Grafton *et.al*, 2006)

Sustainable Fisheries Yield

The sustainable yield in fishing commonly referred to as "Maximum Sustainable Yield (MSY) is a biological phenomenon. MSY means that level of fish catch or yield that can be harvested from a given system in perpetuity without affecting the stock of the system (or the sea). In other words, a catch level is said to be sustainable whenever it equals the growth rate of the population since it can be maintained for ever. As long as the population size remains constant, the growth rate will remain constant as well.

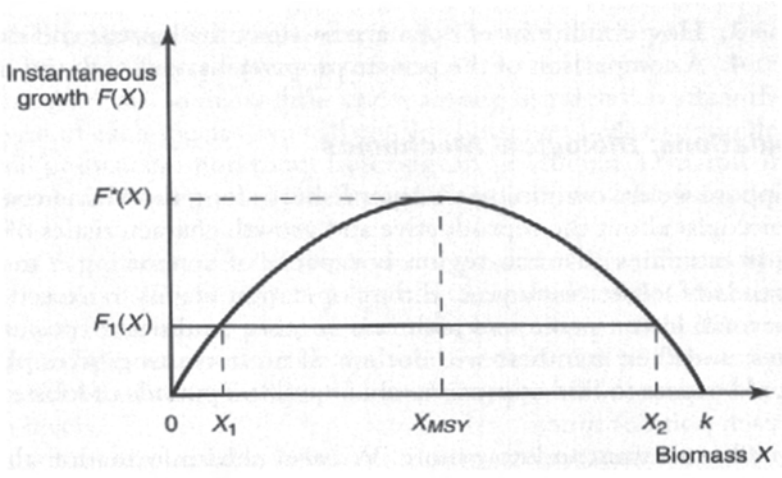


Fig. 3. Sustainable Yield Curve

Economics of fisheries management

Economics play a vital role in fisheries management. In the earlier stages, fisheries management focused on controlling the effort to maintain the fish stocks. The common assumption is that if the control measures are strictly implemented, the further increase in effort is prevented and thus a sustainable harvest can be expected. But by 1970 it was found that such measures fail to control the fishing effort and capacity as the fishers substituted from regulated to unregulated inputs (Wilen, 1979) and further remedies suggested also failed to prevent the increase in fishing effort (Townsend, 1990).

"An economic perspective of fisheries management is that marine resources should not only be managed sustainably but also in a way that they contribute to and provide net benefits for the nation as a whole. Indeed the economists argue that sustainable and economically profitable fishery is complimentary. A level of harvest that maximizes the sustainable returns from fishing is often at a stock size that is greater than that which would maximize the overall yield from a fishery. Moreover, if there are other costs associated with fishing like habitat damage or environment loss etc., the economic optimum level of harvest that accounts for these costs would be even less, and the desirable fish stock even larger. In other words, a fishery that is economically optimum in the long run is also likely to be an ecologically sustainable fishery" (Grafton, *et al.*, 2006).

Maximum Economic Yield (MEY) is realized at that level of effort in which the sustainable net return from the fishery is maximum. The difference between the total revenue (TR) and the total cost (TC) is maximum. This difference is also referred to as **resource rent.**

Total revenue (*TR*) = Price (*P*) × Catch (*H*)

- TC = Unit cost (*c*) × Effort; Rent = TR – TC

The resource rent is maximized at the point E*. Here

MEY is left of MSY

- Optimal harvest (*H**) is less than the *MSY* harvest
- But rent is larger than at *MSY*

The marginal analysis can show that the MEY occurs at the point where MC=MR. It is observed that for marginal unit of effort, marginal rent is = 0 and average rent >1.

The point **E* is that effort level at which the MEY occurs.**

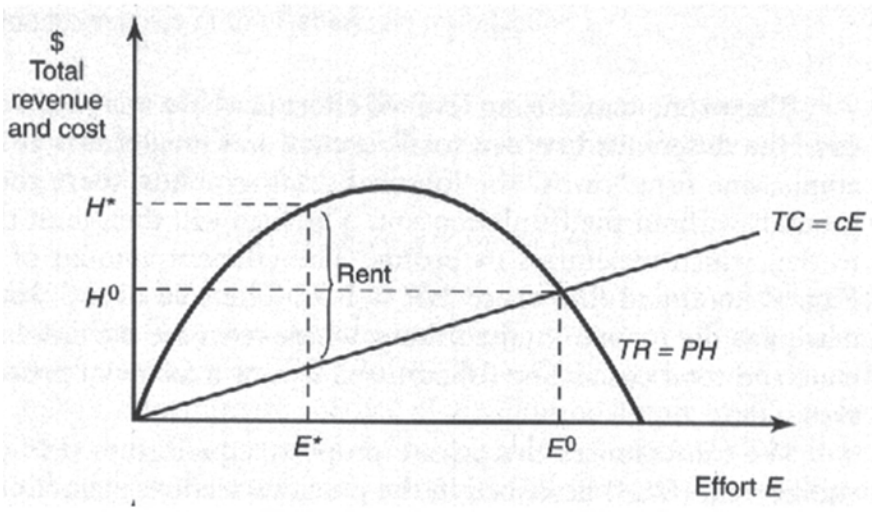


Fig. 4. Maximum Economic Yield

At this point of effort only the **difference between the total revenue from fishing and total cost of fishing is the maximum.** This difference is also referred to **as resource rent.**

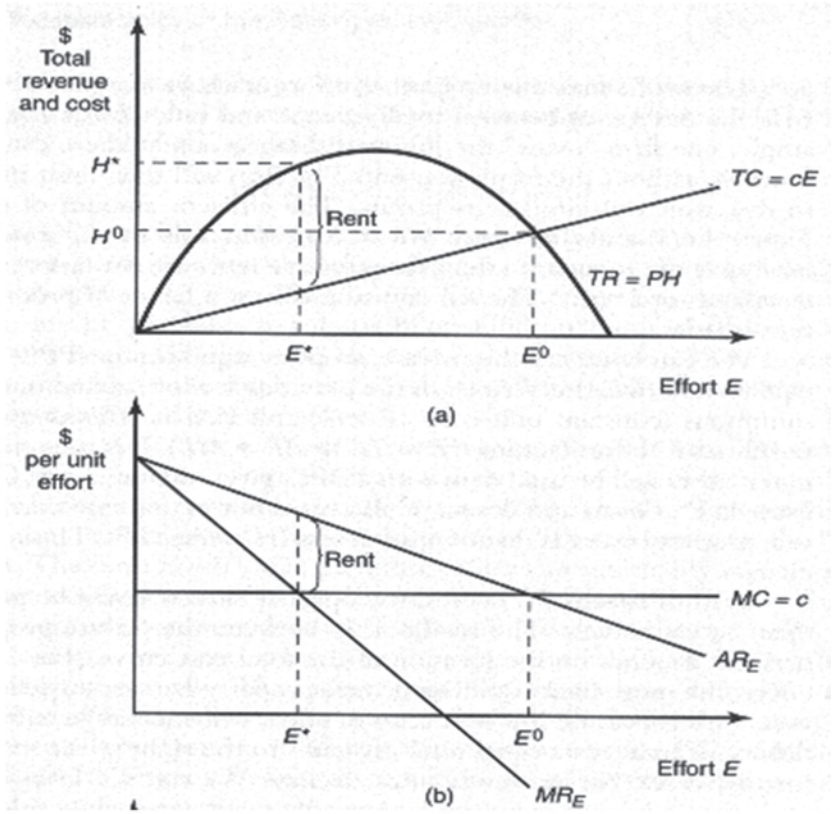


Fig. 5. Maximum Economic Yield (MEY)

"Goal of traditional fisheries management: achieve *MSY*. However the economists aim for MEY in contrast to MSY. AT MEY, compared to MSY, the fish catch is lower, fishing profit is higher, fishing effort is lower and the fish stock is higher. Thus MEY is where more fish is conserved and economic is the friend of conservation. (Dixon, 2005 and Grafton et.al, 2006)

MEY is affected by the changes in **price of fish and the costs of fishing.** When the price of fish increases, the total revenue curve shifts upward at all effort levels, leaving the intercepts unchanged and the point of MEY moves closer to MSY but never beyond MSY so long as the cost of fishing increases with effort. On the other hand, if the cost of fishing increases, the total cost curve moves upward to the left, thus the new point of MEY is to the left of the previous MEY. This will lower the optimal fishing effort (E*) because with a more costly harvest, it pays more to have larger stocks from which to catch. In total, a fall in fish price or an increase in cost of fishing will lead to lower harvest with a less fishing effort and a larger stock size in order to maximize the economic profits (Grafton *et.al.,* 2006)

Conclusion

The economic performance of the fishing methods or vessels is the basis of any management measure. Unless the economic performance is in favour of the fishermen, he will not be interested to continue the business. The excess fishing capacity existing now is an indication of poor economic performance of the fishing methods.

It is time, we find out a middle point between biological and economic optimum involving all stakeholders so that practically implementable management measures can be formulated. We can even revisit the traditionally community based management practices followed sometimes back and scrutinize them for modification to the present needs and incorporate them into our present day management regimes.

Status of Mariculture in India and Major Technologies

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A globally competitive, technologically appropriate and diverse mariculture sector that meets increasing demand for seafood and products that are affordable and meet high standards for safety, quality, and environmental stewardship, with maximum opportunity for profitability and economic growth is the need for the coming years. Over the coming years aquaculture tends to face many challenges in combating diseases, broodstock improvement and domestication, hatchery production of more species, development of appropriate feeds, supplementation of fishmeal and fish oil, feeding mechanisms, innovative grow-out technologies and water-quality management. To tackle such issues we have to be proactive in research and development activities.

Mariculture involves the cultivation of marine organisms in seawater for food and other products either in the open ocean, an enclosed section of the ocean, or in tanks, ponds or raceways. About 600 aquatic species are cultured all over the world in a variety of farming systems and facilities of varying input intensities and technological sophistication. Mariculture activities other than for human consumption include live bait farming for fishing, live ornamental animal and plant species and ornamental products (pearls and shells), fishes cultured as feed for certain carnivorous farmed species, culture of live feed organisms such as plankton, Artemia and marine worms for use as feed in hatcheries and grow-out systems, aquaculture hatchery and nursery outputs for on-growing in captivity or stocking to the wild and capture based aquaculture. Asia accounted for 89% of world aquaculture production by volume in 2010, up from 87.7% in 2000. Mariculture represents an opportunity to provide a sustainable supplement to the marine capture fishery. Mariculture has a relatively long history, while, the modern intensive mariculture is only 35 years old, producing a steadily increasing proportion of the world's seafood during this period. Aquaculture production currently makes up almost half of the marine capture fisheries. Moreover, aquaculture production has more than doubled over the last fifteen years and this trend is continuing whilst traditional fishing production is declining as a result of overexploitation. But aquaculture, both in inland waters and marine and coastal areas, has problems, including habitat degradation, disruption of trophic systems, depletion of natural seed-stock, transmission of diseases, and reduction of genetic variability. To solve these problems it is needed to diversify aquaculture and improve its sustainability. In particular, we need to better understand possible interactions between mariculture and natural environments to minimize the potential for habitat degradation, introduction of invasive alien species, etc.

Sea cage farming

The cage culture which initiated in Norway during 70s got developed into a high tech industry in many countries all over the world for high value fishes. The major advantage in countries where cage culture has been commercialized is that they have large, calm and protected bays to accommodate the cages safely against any unfavourable weather conditions. Recent technological advance is in cage design and with new species. In the past, the industry had typically used steel-framed rectangular support structures for the net cages, with walkways around them as work platforms. After that HDPE cages came into existence. Of recent submersible cages which can overcome rough oceanic conditions are being designed and used. Farming was mostly in the inshore waters and since the commercial aquaculture of marine finfish will continue to expand in future, it will take place more in offshore locations than have traditionally been used. By integrating the cage culture system into the marine aquatic ecosystem, the carrying capacity per unit area is optimized because the free flow of current brings in instantaneous exchange of water and removes metabolic waste and excess feed. Thus economically speaking, cage culture is a low impact farming practice with high economic returns and with least carbon emission activity. In view of the high production attainable in cage culture system and the presence of large sheltered coastal waters in many countries, marine cage farming can play a significant role in increasing fish production.

Recirculating Aquaculture Systems (RAS)

A notable technology-based development in the farming sector has been a significant expansion in fish production using closed-recirculation systems. Recirculation aquaculture systems (RAS) are systems in which water is (partially) reused after undergoing treatment. Each treatment step reduces the system water exchange to the needs of the next limiting waste component. RAS have been developed to respond to the increasing environmental restrictions in countries with limited access to land and water. RAS offer advantages in terms of reduced water consumption, improved opportunities for waste management and nutrient recycling and for a better hygiene and disease management, biological pollution control (no escapees), and reduction of visual impact of the farm. These systems are sometimes referred to as 'indoor'or 'urban' aquaculture reflecting its independency of surface water to produce aquatic organisms. In addition, the application of RAS technology enables the production of a diverse range of (also exotic) seafood products in close proximity to markets, thereby reducing carbon dioxide (CO_2) emissions associated with food transport.

Integrated Multi-Trophic Aquaculture (IMTA)

Integrated multi-trophic aquaculture (IMTA) has emerged recently, where multi-trophic refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system. Interestingly this practice has been defined based on pilot studies in marine habitats involving joint aquaculture of fed species, usually fish, together with extractive species such as bivalves and/or macroalgae. IMTA can also allow an increase in production capacity for harvesting of a particular site when regular options have established limitations.

Ecosystem approach to aquaculture (EAA)

In recent years, FAO has been working on the implementation of the ecosystem approach to aquaculture (EAA) as a way to improve the governance of the sector; an Integrated mariculture – A global review ecosystem approach to aquaculture is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity and resilience of interlinked social and ecological systems. The EAA promotes the efficient use of nutrient resources as well as the opportunity of diverse products and benefits (and beneficiaries) while reducing impacts, and therefore integrated aquaculture becomes a very important practical way to implement such an approach.

The future expected increases in energy prices, costs for aquafeeds and the strengthening of environmental regulations should facilitate the implementation of integrated systems. However, if integration of e.g. fed species with extractive species (e.g. filter feeders, seaweeds) results in beneficial environmental effects – either locally through waste remediation or at a larger scale with respect to efficiency in resource utilization – such services should be internalized in order to benefit society as a whole (e.g. such as waste mitigation improving coastal ecosystem quality). Integrated aquaculture has many benefits, where bioremediation is one of the most relevant and yet unvalued in its real social and economic potential. Reducing risks is another advantage and profitable aspect of farming multiple species: a diversified product portfolio will increase the resilience of the operation, for instance when facing changing prices for one of the farmed species or the accidental catastrophic destruction of a crop.

Species selection and seed availability

It is well known that availability of seed in adequate quantities is one of the major challenges in the development and expansion of mariculture. Though seed production technologies have been developed for many marine finfish and shellfish species, many of these technologies have not been scaled up to commercially viable levels. The hatchery seed production of many high value marine finfishes and shellfishes is complex and expensive due to the high costs involved in the establishment of broodstock and hatchery facilities and also to the complicated larviculture procedures involving culture of proper live feeds, their nutritional enrichment, feeding protocols, grading, water quality maintenance, nursery rearing and disease management. The production of seed of the concerned species by development of commercially viable technologies is essential for development of sustainable mariculture practices, but many of these technologies are still in the emerging state and may take several years for standardisation on a cost effective level.

Capture Based Aquaculture (CBA) is an alternative for those species for which hatchery technology is not developed. As hatchery technologies remain to be perfected for many species, fish farmers have to depend on 'seed' available from the wild. CBA has developed due to the market demand for some high value species whose life cycles cannot currently be closed on a commercial scale. CBA is a world-wide aquaculture practice and has specific and peculiar characteristics for culture, depending on areas and species.

Nutrition and feed technologies

Currently, one of the most heated debates concerning aquaculture development is the use of fishmeal and other animal proteins in aquafeeds. Although fishmeal is used for its high quality protein content, it has several disadvantages, including high cost and instability of supply. Wild fish catches are on the decline and there are increasing environmental concerns (eutrophication, pollution associated with excess nutrient waste), ethical concerns over feeding fish to non-piscivorous fish, and social concerns over using aquatic protein to feed fish that could be used for human nutrition (especially in nutritionally deficient areas of the world). Plant protein has significant potential for addressing the problem of phosphorus pollution, since plants do not contain the high levels of phosphorus found in animal protein. The use of plant protein in aquafeeds also helps reduce pressure on wild fish stocks. Research in this area is focusing on the investigation of various plant species and plant-animal protein mixes, as new sources for protein for aquafeeds for shrimp. Researchers are looking at the possibilities of dealing with anti-nutritional factors by producing feed enzymes to counteract them. Phytase is one example. This enzyme helps fish make optimal use of the phosphorous available in plant-protein based feeds.

Dependable availability of quality fry to stock grow-out production systems has been one of the most critical factors affecting commercial success of fish and shellfish production. Although nutritional and dietary requirements of most fish and shellfish species have been identified, large-scale hatchery production of most aquatic species still depends on live feeds, such as selected species of microalgae, the rotifer Brachionus and the brine shrimp Artemia. The live feed production systems used in most developing countries are still labour intensive. This lowers cost efficiency and poses many problems for consistent mass production, including optimal nutritional quality and prevention of microbial contamination. These problems have created a whole new area of biotechnological research aimed at finding cost-effective and efficient supplements to live microalgae, commercial production of freeze-dried algae, microencapsulated diets, and manipulated yeasts. Future aquaculture development ultimately depends on the ability of farmers and processors to produce a product acceptable to consumers. Increasing consumer demands for quality and safe products have to be recognised and addressed. Biotechnology also shows promise in this area, especially for assessing and improving safety, freshness, colour, flavour, texture, taste, nutritional characteristics, and shelf-life of cultured food products. Tools are already under development, or commercially available, that can detect and assay toxins, contaminants, and residues in aquatic products. Biotechnology tools can also be used to identify and characterize important aquatic germplasm resources, including those of endangered species. The genetic make-up of aquatic species can now be analysed, characterized and quantitative trait loci identified that code for phenotypic characters that are beneficial for culture (e.g., fast growth, disease resistance and cold tolerance). The study of biotechnology can also improve understanding of gene regulation and expression, sex determination and definition of species, stocks, and populations.

Disease Management

Productions of specific pathogen free (SPF) and specific pathogen resistant (SPR) stocks are two complementary objectives being developed through shrimp broodstock management programmes. The

specific pathogens for these programs are those listed as 'notifiable' by the OIE, representing direct trade concerns, as well as, significant threats to optimal production (OIE, 2000, 2001). Taking this technology beyond specific pathogens, there is exciting potential for this approach to be adapted to selection of lines with high non-specific immunity or high tolerance of physiological stresses that facilitate opportunistic infections or other pathology. Considering the major contribution of many shrimp and finfish species to the global aquaculture production and the economic losses encountered due to both facultative and opportunistic disease outbreaks, it is appropriate and timely to concentrate further research to develop specific and non-specific resistant broodstock for commercially important finfishes and shell fishes.

Transboundary movements of aquatic animals have in some cases lead to the spread of aquatic animal diseases. Reliable and sensitive diagnostic techniques and standards are required to ensure such movements of live aquatic animals do not include the dispersion of their pathogens. Once DNA probes are field validated and refined for non-specialist use, these will be particularly valuable tools for this purpose.

One of the most urgent needs for aquaculture health management is establishment of standards for quantitative assessment of health status in the broad range of species under culture. Progress in this regard is being made for certain finfish, however, knowledge of shrimp and molluscan health (and stress) are still relatively undeveloped. Harnessing the host's specific and non-specific defense mechanisms in an effort to control aquatic animal diseases has considerable potential for reducing the impact and losses from diseases. Immunostimulants and non-specific immune-enhancers are being incorporated into diets to boost protection.

Probiotics are generally administered as live microbial feed supplements which affect the host animal by improving the intestinal microbial balance to optimise the presence of non-toxic species. A stable gut microflora helps the host resist pathogenic invasions, particularly via the gastrointestinal tract. Antibiotics reduce specific or broad-spectrum gut microflora and probiotics may have post-antibiotic treatment potential for restoring the microbial balance. Probiotics are widely used in animal husbandry but their use in aquaculture is still relatively new.

Bioremediation for environmental sustainability

Bioremediation is another promising biotechnological approach for degradation of hazardous waste to environmentally safe levels using aquatic microorganisms, or other filtering macro-organisms. In addition to microbes, bivalves, seaweeds, holothurians (sea cucumbers), etc., have been tested to assess their ability to reduce organic loading, or reduce excess nutrients produced during culture production. Various bioremediation preparations have also been developed with the view to remove nitrogenous and other organic waste in water and bottom sludge, to reduce chemically-induced physiological stress. Concomitant with bioremediation is enhanced feed delivery. Aquaculture development in recent years has, therefore, included investigation into methods for more efficient feeding. Underwater closed circuit television is in use to record when fish are satiated (no longer feeding), so feeding can be halted, and also to monitor the accumulation of wastes under moored cages. Training fish to trigger feeding when hungry offers strong potential to lower feed costs, raise conversion efficiency and reduce wastage and pollution.

Hatchery Technology and Seed Production of Marine Food Fishes

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Introduction

It has long been recognized that a good source of juveniles is the most important prerequisite for fish farming. Non availability of the seed for stocking in quantity and quality at the right time, will affect the production plans. Most of the worlds fish aquaculture still depend on the fry almost comes exclusively from wild. Seed supply from the wild is often unpredictable and seasonal. Hatchery production of seeds of economically important finfish ensures a steady supply of quality seeds for aquaculture operations. The successful hatchery production of marine fin fishes, depends on various factors like proper maintenance of broodstock, efficient live feed production systems, larval rearing protocols including water quality management, feed management and nursery rearing systems.

Broodstock

Availability of adequate number of healthy broodstock is of prime importance in successful induced-breeding operations or artificial propagation, especially of the most important cultured species. There are two sources of finfish broodstock: wild-caught adults and those reared in ponds or cages. It is advantageous to use cultured broodstock as they are acclimatized to captive conditions, free from exogenous pathogens and diseases. The disadvantages of using wild stock are uncertainty of capturing them, the relatively large expenditure needed for their capture and transport, and the limited opportunities of obtaining good quality eggs. The selection bloodstock should based on the following criteria : fish movement should be active, finas and scales shold be complete, and free from diseases and parasites. Upon arrival at hatchery, the fishes should be treated with antibiotic like Acrifalvin with recommended dose of 2mg/L for 2 hours.

Age at maturity

The age at maturity varies for different species of fishes. Knowledge about the age at which the species matures is useful in the selection of right sized brooders for breeding purpose. Rabbitfish begins sexual maturation and spawning in one year of captivity. As Protandrous hermaphrodites, the seabass are mature males on the third year of captivity and became females on the following year. On the other hand, groupers, being protogynous hermaphrodites, are mature females after four years of its growth. It takes longer for them to be transformed to mature males. Both milkfish and snappers take 5 years to attain sexual maturity.

Determination of Sex and Maturity of Spawners

Determination of sex and the maturity of spawners are very important in the artificial propagation of marine finfishes. Determination the sex of spawners through examining the external morphology of the fish is often difficult and unreliable. Ripe males are easy to distinguish during the spawning season since milt oozes out from the urogenital pore as its abdomen is pressed. If fishes are fully matured, the milt will be white and creamy; poor milt is watery and curdled. Milt which is not ripe will demand strong pressure and will be mixed with blood.

The commonly-used method to assess gonadal maturation of broodstock is through gonadal biopsy. Gametes are removed from either an anaesthetized or unanaesthetized fish by using a polyethylene cannula. The inner diameter of the cannula to be used varies with the size of eggs to be sampled. The cannula is inserted 4–15 cm into the gonad through urogenital pore and gametes are drawn into the cannula by aspiration as the cannula is slowly withdrawn. The distance to which the cannula is inserted varies with the length of the gonads. Samples from the middle portion, especially of the ovary, are generally considered to be the most representative.

The eggs collected through cannula are observed for its eggs diameter and the average egg diameter is determined from a batch of 50–10 by using a micrometer and their developmental stage is assessed under the microscope. Gonadal maturation is then expressed in terms of average egg diameter and the developmental stage of the eggs.The milt collected is removed from the cannula by blowing it onto a clean dry Petri dish. A small portion of this is mixed with a drop of seawater or brackishwater, depending upon the species, and examined immediately under the microscope. Sperm motility and vitality are then assessed.

Factors Affecting Gonad Development

Nutrition

Poor nutrition can result in poor or no reproductive performance and that lack of vitamin supplement could affect sperm quality. Mere reliance on natural food may lead to poor or variable reproductive performance. Fish broodstock diets are now formulated to include high levels of n-3 fatty acids which include enhanced levels of both decosahexaenoic acid and eicosapentaenoic acid. Eggs considered to be of better quality have higher content of these fatty acids. Furthermore, successful embryonic development in fish has been shown to be dependant on the balance of aminoacids present in the egg. However broodstock fed on 'natural diet/s' often produce eggs of better quality than those on formulated commercial diets. Thus it appears that different fish species may have different dietary requirements and that diets of broodstock should be tailor made to ensure good egg quality.

Environment

Photoperiod

One of the factors considered being of great importance to the inducement of sexual maturation and spawning is photoperiod. Photoperiod manipulation is now being employed to alter the normal

reproduction of a few cultured species. The greatest advantage of altering the spawning time of the cultured species is the availability of fry for stocking in ponds, pens and cages throughout the year.

Temperature

Water temperature is another important factor which influences the maturation and spawning of fish. In some species of fish functional maturity is directly controlled by temperature; in others, the time of spawning is regulated by the day-length cycle such that it occurs when the temperature is optimum for survival and the food supply is adequate.

Salinity

Salinity is related to maturation and spawning especially for the spawning which shows spawning migrations.

Other environmental factors

In addition to photoperiod, temperature and salinity, there are other less obvious factors which may affect the maturation and spawning of broodstock. These less obvious factors, which include rainfall, stress, sex ratios, stocking density, isolation from human disturbance, dissolved oxygen, social behaviour of fish, heavy metals, pesticides, and irradiation amy also influence maturation in fishes.

Spawning and fertilization

Selection of Spawners

The selection of spawners from the broodstock should be done months before the beginning of natural spawning to allow ample time for the fish to be conditioned to environmental and diet controls. Spawners are normally selected based on the following criteria:

- fish should be active
- fins and scales should be complete
- fish should be free from disease and parasites
- fish should be free from injury or wounds
- males and females of similar size are preferred

Spawning

After the selection of spawners, the fishes are transferred to spawning tanks. The ratio of male : female in spawning tanks 1:2. Water in spawning tanks should be clean and in good condition.

Two major techniques are used in the spawning of finfishes namely natural spawning by environmental manipulations and hormonal induction of spawning.

Natural Spawning by Environmental Manipulation

The method involves the simulation of the natural spawning environment in which temperature, artificial rainfall and tidal fluctuation are manipulated.At the beginning of the new moon or full moon,

the water temperature in the spawning tank is manipulated by reducing the water level in the tank to 30 cm deep at noon and exposing to the sun for 2–3 hours. This procedure increases water temperature in the spawning tank to 31°–32°C. Filtered seawater is then rapidly added to the tank to simulate the rising tide. In effect, the water temperature is drastically decreased to 27°–28°C.The fish spawn immediately the night after manipulation (18.00–20.00 h) or, if no spawning occurs, manipulation is repeated for 2–3 more days until spawning is achieved.

Hormonal induction of spawning

All of the cultured species exhibit spontaneous spawning but this is seasonal and at times unpredictable. Thus induced spawning to ensure availability of eggs, to meet fry demand and as a supplement to natural spawning may be undertaken. Manipulations of various environmental parameters, such as temperature, photoperiod, salinity, tank volume and depth, substrate vegetation, etc. can often improve the reliability of spawning. However, in some species hormonal treatments are the only means of controlling reproduction reliably. Over the years, a variety of hormonal approaches have been used successfully. These methods began with the crude use of ground pituitaries from mature fish—containing gonadotropin (GtH.—which were injected into broodstock to induce spawning Today, various synthetic, highly potent agonists of the gonadotropin-releasing hormone (GnRHa) are available as well as sustained-release delivery systems for their controlled administration These methods have contributed significantly to the development of more reliable, less species-specific methods for the control of reproduction of captive broodstocks.

Agents used for induced spawning in fishes

SPH - acetone-dried pituitary gland homogenate

It was found that pituitaries collected during the spawning season were more effective in inducing spawning. Use of pituitaries for spawning in fishes ,have drawbacks such as the great variability in pituitary LH content; the administration of additional hormones present in the pituitary that may adversely affect the physiology of the treated fish, and the potential for transmission of diseases from donor fish to recipient broodstocks.

Human chorionic gonadotropin (hCG)

Unlike pituitary extract, Human chorionic gonadotropin (hCG) is often given in a single dose, which ranges between 100 and 4000 international units (IU) per kg body weight. The advantage of hCG is that it acts directly at the level of the gonad . hCG acts much faster, via direct stimulation of the gonad, in inducing Final Oocyte Maturation, spermiation and spawning.

Use of gonadotropin-releasing hormone (GnRH) and agonists (GnRHa)

Studies in female broodstocks indicated that GnRH and GnRHa were effective in inducing ovarian development, FOM and ovulation in doses ranging from 1 to 15 mg GnRH kg^{-1} or 1 to 100 mg GnRHa kg^{-1}. GnRH and its agonists can be used again in subsequent spawning seasons with no reduction in their efficacy. GnRH acts at a higher level of the hypothalamus–pituitary–gonad axis. Consequently, GnRH can

provide a more balanced stimulation of reproductive events by directly or indirectly affecting the release of other hormones necessary for successful FOM, spermiation and spawning. Another advantage of GnRHa, is that it can be synthesized and obtained in pure form, and thus does not carry the risk of transmitting diseases. Also, because of the structural similarity of the GnRHs among many fish the same GnRHa can be successfully applied to a wide range of fish species.

Sustained-release delivery systems for GnRHa

Repeated handling of broodstock requires substantial labor, time and monitoring. Also, repetitive handling is stressful to the fish and can often result in pre-spawning mortalities, or at the very least it can adversely affect the maturation process. A variety of GnRHa-delivery systems have been developed and tested for the sustained release of hormones . Cholesterol implants are prepared as solid, cylindrical pellets (3 mm in diameter) and are implanted intramuscularly using an implanter or a scalpel. This GnRHa-delivery system is easy to fabricate and relatively inexpensive, but the GnRHa release from the pellets seems to be extremely variable probably because each implant is prepared individually. The next type of GnRHa-delivery system was fabricated in the form of microspheres (5–200 mm in diameter), using co-polymers of lactic acid and glycolic acid (LGA). The greatest advantage of biodegradable, microspheric delivery systems is that the same preparation can be used to treat fish varying in size from a few grams to many kg. The last type of GnRHa-delivery system used for spawning induction is prepared in the form of a solid, monolithic implant, using a non-degradable co-polymer of Ethylene and Vinyl Acetate (EVAc). Unlike the biodegradable microspheres and similar to the cholesterol pellets, EVAc delivery systems have a long shelf-life and can maintain their effectiveness for up to 3 years if stored desiccated at 20 ºC.

Fertilization and incubation

The fish that are induced to spawn by hormone injection will be ready to spawn within 9–12 hours after the final injection. The schedule of injections for subsequent spawning must be synchronized with the natural spawning time of the fish which occurs in late evening between 18.00 and 24.00 h. On the other hand, in the stripping method, it is still necessary to sample the eggs from gonads by cannulation and examine them under the microscope. The fish has spawned only if at least 40% of the eggs are transparent.

Determination of egg and larval quality

Several parameters are used to assess fish egg and larval quality. These include the rates of egg viability, hatching and normal larvae. Chemical composition of eggs are also analysed and of the egg chemical constituents, fatty acids, amino acids, ascorbic acid, yolk protein and DNA and RNA have been reported to have an influence on egg and larval quality.

Larval rearing

The rearing tanks are usually made of plastic, fibreglass or concrete. The shape of the tanks can be retangular or circular. Volume ranges from 1 to 10m^3. The tanks are usually protected from sunshine and heavy rain. Five hours before hatching, the developing eggs are transferred to larvae-rearing tanks. The

tanks are provided with mild aeration. The larvae start to hatch 16–25 h after fertilization depending on temperature and species. The usual stocking density of developing eggs is 100–200 eggs/l.

Factors affecting mass-rearing of marine finfish larvae

- Type of food
- Food density
- Water quality
- Environmental factors

The most important environmental factors affecting larval growth and survival are: (1) light, (2) temperature, and (3) salinity.

(1) Light. The effect of light intensity and photoperiod on the growth and survival of larvae has received little attention in the past. Generally, fish larvae are reared either under continuous light or under day and night conditions. Light is of primary importance since most marine fish larvae are visual feeders. Nevertheless, the larval eye at first feeding is very simple, with no capabilities of distinguishing between different illuminations. High light intensities of about 1000–2000 lx at the water surface are commonly used in hatcheries. Naas, K., Huse, I. and Iglesias, J., 1996. Illumination in first feeding tanks for marine fish larvae. *Aquacult. Eng.* **15** 4, pp. 291–300 Article | PDF (634 K) | View Record in Scopus | Cited By in Scopus (27)The reflections from surfaces in a tank are very important for the light distribution in the water body. Black tanks are best suited to reproduce natural illumination conditions. White-walled tanks should be avoided since they would be a perfect wall trap due to the phototaxis of the larvae. Green water and dark walled tanks seems to be beneficial, as growth, survival and nutritional condition are usually enhanced.

(2) Temperature. Temperature can be either beneficial or detrimental to fish larvae. Temperature regimes outside the tolerance limits of a particular species will cause mortality of larvae while temperature regimes within the range that give good survival may be used to accelerate or even maximize growth of the larvae. High temperatures will shorten the time from hatching to metamorphosis, and consequently, mortality may be reduced.The effects of temperature on the growth and survival of fish larvae must be determined for each species. Apparently, the eggs and larvae of tropical and subtropical species are generally stenothermal.

(3) Salinity. The effect of salinity on the growth and survival of fish larvae is primarily on larval osmoregulation. Survival of larvae of many species may be better at low salinities than higher salinities since low salinities are isosmotic to body fluids.

Rearing environment

Good quality seawater at 30–31 ppt is required for larvae rearing. Water temperature is also important and should range from 26° to 28°C to promote fast growth of larvae. Larval tanks are prepared one to two days prior to the transfer of newly-hatched larvae. Filtered seawater is added to the tanks and very

mild aeration is provided. After stocking, unicellular algae (Tetraselmis sp. or Chlorella spp.) are added to the tank and maintained at a density of 8–10 × 10 or 3–4 × 10 per ml for Tetraselmis sp. and Chlorella spp., respectively. These algae serve a dual purpose: as a direct food to the larvae and rotifer and as a water conditioner in the rearing tank.

Green water and clear water

Microalgae affect the microbiology, nutrition, feeding and behaviour of larvae. The addition of microalgae to the tanks during early rearing of the larvae may affect rearing performance. Microalgae addition rapidly affects the biochemical composition of the rotifers in the larval tanks. Larvae from green water tanks showed higher survival and growth, and less gut contents than larvae reared in clear water. In the former, the ingested rotifers had higher energy and protein content, suggesting that these variables are important for achieving high growth and survival in the larvae. The growth and survival of fish larvae can also be affected by the type of microalgae used. Interactions between algae and bacteria in the larval tanks might be more important than the nutritional value of the algae. Dead or dying algae would increase the bacterial substrate.

Fish larvae can be reared under stagnant or open-system conditions. Generally, partial water changes are provided and microalgae are supplied to the rearing tanks during the initial stages of culture. Low exchange rates of water may affect the retention time of prey in the larval tanks and changes may occur in the biochemical composition of the prey before being consumed by the larvae. Algal addition is advantageous since the prey can continue feeding. Consequently, in clear water systems, there is a progressive decrease with time in prey quality. This loss of prey quality can be partially avoided by reduction of the prey residence time through an adequate adjustment of the prey density and the prey/larvae ratio.

The day following stocking, the bottom of the larvae-rearing tank should be cleaned and every day thereafter. This is done by siphoning off unfertilized eggs, faeces, dead larvae and uneaten food accumulating on the bottom of the tank. About 20% of the tank water is changed daily for the first 25 days of the rearing period, then increased to 40–60% per day for the remaining culture period. Since seabass can also be cultured in freshwater, it is recommended to reduce the salinity of rearing water when the larvae are still in the hatchery, before transfer to a freshwater environment. Beginning from the twentieth day, salinity can be gradually lowered until freshwater condition is reached on the twenty-fifth day.

Feed and feeding

Prey size

Prey size may affect the prey ingestion by early fish larvae. It has been reported that the use of small sized rotifers significantly improves the initial feeding performance of fish larvae at the earlier developmental stages. The effect on feeding of using small sized rotifers is mainly due to an increase in feeding incidence rather than in ingestion rates. Therefore, small rotifer supply would improve the incorporation of the larvae to the exogenous feeding from mouth opening. In spite of this, only large

rotifers are commonly used in hatcheries for some species. Small sized nauplii of various copepod species were found to very useful for the larval rearing of marine finfishes especially for the species with small larval mouth openings.

Prey density

Maintenance of appropriate feed density in the larval tanks is most important. Since the marine finfish larvae are visual feeders, availability of the prey in the vicinity increases the chances of feeding and saves energy of larvae used for searching the prey.

Larval diets

Most species of marine fish that have been cultured are reared on a sequential diet of rotifers, brine shrimp nauplii and dry supplemental diets. Microalgae are the customary food given to zooplankton that will be fed to larval fish. The type of culture, temperature, nutrients, other conditions and growth phase all can affect the nutritional value of microalgae to zooplankton and to the fish larvae eating them.

Rotifers

The rotifers are considered as an important live feed in hatchery operation due to their planktonic nature, tolerance to a wide range of environmental conditions, high reproduction rate (0.7-1.4 offspring/female/day), small size and slow swimming nature. More over the filter-feeding nature of the rotifers facilitates the inclusion of specific nutrients essential for the larval predators through bioencapsulation into their body tissues. As a result it became a suitable prey for fish larvae that have just resorbed their yolk sac. The availability of large quantities of this live food source has contributed to the successful hatchery production of more than 60 marine finfish species and 18 species of crustaceans worldwide.Two main species of rotifer have been used are *Brachionus plicatilis* (large size) and *Brachionus rotundiformis* (small size).

Health and nutritional quality of rotifers depends on several culture factors: type of culture, water quality, temperature, foods, rotifer density and age of culture. Rotifers are also cultured in many species of algae. These algae should contain significant amounts of DHA and EPA because one or both of theses are essential fatty acids in the diet of marine fish. The ability of rotifers to synthesize these fatty acids is limited and their diet must include a generous portion of these if the requirements of marine fish larvae eating the rotifers are to be met.

The rotifer diet has little effect on the rotifer size and the use of different strains/species of rotifers is required to provide optimal prey size to the larvae.

Artemia

Among the live diets used in the larviculture of fish and shellfish, nauplii of the brine shrimp *Artemia* constitute the most widely used food item. the unique property of the small branchiopod crustacean *Artemia* to form dormant embryos, so-called 'cysts', may account to a great extent to the designation of a convenient, suitable, or excellent larval food source that it has been credited with. In

marine finfish larval rearing, artemia feeding is done when larvae is big enough to capture larger preys. Artemia is usually given after 5-10 days of initial rotifer feeding.

Artemia nauplii are maintained in the larval culture tank at densities of 0.5 to 2 per ml for most species of finfish. To estimate the amount of *Artemia* required one must consider both the volume of the tank and the expected number of *Artemia* the larvae will consume. Based on the stage or the age of the larvae, estimate a daily *Artemia* requirement per ml. The total requirement is calculated by multiplying the predicted requirement per ml by the total volume of the rearing tanks. Each gram of cysts contains approximately200,000 to 300,000 cysts. *Artemia* generally have at least a 50 percent hatch.

Copepods

Copepods were found to be best alternative and most appropriate for marine fish larvae in which rotifers are an unsuitable first feed. Copepod nauplii are a common natural feed for marine fish larvae species. Small size of copepod nauplii make them suitable for small marie fish larvae at first feeding. Copepods has been used in successful production of marine fish larvae of groupers, snappers, etc. However, the ability to produce copepod nauplii on a large scale has yet to be accomplished as successfully as it has been for rotifers.

Trocophores of bivalves have been found to be a good supplement starter food if given with small rotifers and then replaced with rotifers as soon as the fish are ready. Wild planktons can collected with various nets and traps and can be used for feeding larvae. Nutritional quality is likely to be very high but the appreciable chance of introducing pathogens or pests into the system. Another alternative is extensive culture of zooplankton in ponds and impoundments.

Feed quality

Enormous efforts has been done on improving the quality of both live foods and formulated diets for larval fish by better understanding of the nutrient requirements of larval fish. Enrichment of live foods has been a major area of emphasis. Artemia can be low in several fatty acids and various products and protocols have been investigated to improve artemia nutrient quality. Rotifers, a commonly given first food, are often enriched in an attempt to improve their nutrient quality. There are a number of commercial products are now available for fatty acid enrichment of live foods. The appropriate concentration of a specific fatty acid and how it interacts with other fatty acids is to explored for a better management of feed quality.

Amino acids are another important component of the diet of rapidly developing larvae providing the building blocks for protein synthesis, and are important energy substrates.

Enrichment of live feeds

To reduce uncertainty concerning lipid quality of zooplankton, they can be enriched. Some marine oils are reliable sources of EPA and DHA, and mixtures of purified oils are also used. Because rotifers cultured in baker's yeast alone are deficient in DHA and EPA, they can be enriched upto 48hrs with yeast

enriched with oil and sometimes vitamin or with other materials. Addition of cuttle liver oil to bakers yeast fed to rotifers increased both EPA and DHA levels. Brine shrimp nauplii can also be enriched with emulsified marine oil or a micronutrient-fortified marine oil emulsion. A variety of commercial enrichment media for rotifers and artemia are available to improve the nutritional quality of these organisms.

Compound larval feeds

The three main types are microencapsulated, microbound and microcoated diets. early marine fish larvae have difficulty in accepting and digesting microcapsules and microparticulates. Early weaning was the orinal goal of supplementing with compounded feed, but co feeding of compounded feeds with live feeds can at least reduce the live food requirement. Microencapulsted feeds provide ad alternative way to administer vaccines and therapeutic agents to larvae. During early stages, larvae have difficulty in recognizing inert particles as feed. Typically, early marine larvae probably depend on to a greater degree on small colloidal proteins in zooplankton because they donot have the enzymes necessary for digesting and absorbing larger protein molecules. Older larvae have greater capabilities to make more kinds of enzymes and to adjust enzyme production according to the type of food.

As greater understanding of the nutrient requirements of larval fish are gained and weaning protocols are improved, formulated diets will become more widely used and used earlier in the life history for many fish.

Feed management

Newly hatched larvae are usually not given food on the first day because they derived their nourishment from the yolk and the eyes and mouth are still non functional. During the initial days the larvae were given enriched rotifers at a density of 5-20 rotifers/ml depending upon the species and age of the larvae. As the larvae grows bigger, freshly hatched brine shrimp nauplii at a density of 1-10 1induviduals /ml depending upon the species and age of the larvae. As the feeding of brine shrimp progress the rotifer density is slowly decreased and finally stopped. As the larvae grow bigger, compounded feeds were given to larvae at a rate of 1-4g/t.

Water management

Siphoning of the tank bottom to remove dirt, dead larvae, wastes and decaying uneaten food should be done everyday starting from the second day of rearing . Daily water exchange from as high as 70% of the tank volume to as low as 30% is undertaken prior to feeding. The percentage of water exchange is dependant on the age of the larvae.

Fry harvest/packing /transport

At the end of larviculture, fry can be harvested and transported to fish farms. Transport is usually done in cool periods of the day. Fishes are transported in oxygenated bags places inside carton boxes lined with thermocole sheets. The transport densities depend upon the size of the fish, species of the fish, distance to be traveled etc. Reducing the temperature and salinity during transport help to improve larval survival.

Conclusion

The hatchery phase is one of the bottlenecks for aquaculture expansion. Broodstock development and Induced spawning techniques have improved drastically over years for a number of species by administering gonadotropin releasing hormones via injection or implantation. Advances have been made in broodstock diets, specifically in the use of fatty acids to improve egg quality and quantity to equal that of brooders given natural diets. Advances in the larval rearing systems, better understanding of rearing environment has improved the growth and survival of larvae in captivity. Better understanding of nutritional requirements and by improving the larval feed quality made the hatchery production marine finfishes more successful. Improvements in formulated diets for larval fish have reduced the dependence on live foods at earlier and earlier stages in the life history. Co-feeding during the larval stages helps to reduce the need for live foods and facilitates the transition to formulated diets. Recent advances in hatchery management have resulted in a much better control of critical life stages of fish. These advances will continue until the science of aquaculture is on a level with that of the other animal sciences.

Broodstock Development and Breeding of Marine Finfishes

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Introduction

In recent years, mariculture has been growing rapidly on a global basis especially with the development and expansion of sea cage farming. On a global basis, a rapid growth in marine finfish culture is noted. It has increased at an annual average growth rate of 9.3% from 1990 to 2010. Salmonids, amberjacks, sea breams, sea basses, croakers, groupers, drums, mullets, turbot, other flatfishes, snappers, cobia, pompano, cods, puffers and tunas are the major groups which are maricultured. One of the major reasons for the growth of sea cage farming is the availability of breeding techniques that can produce sufficient quantity of seeds of different high value marine finfish. Many countries in the Asia-Pacific Region like Australia, China, Japan, Taiwan, Philippines, Indonesia, Thailand, Malaysia and Vietnam have made substantial progress in the development of commercial level seed production technologies of high value finfish suitable for sea farming. In India, the broodstock development and seed production of sea bass, cobia and silver pompano were developed and standardized for commercial level production.

The major steps involved in marine finfish broodstock development and breeding are the following:

1. Broodstock collection
2. Transportation
3. Quarantine
4. Broodstock development
5. PIT tagging
6. Cannulation
7. Induction of spawning
8. Egg collection
9. Incubation

Broodstock Collection and handling

Broodstock development is the vital and time consuming procedure in marine finfish seed production. It is not easy to obtain broodstock fish directly from the wild and hence broodstock development is to be done in captivity. The main selection criteria to identify suitable adult fish as broodstock fishes are as follows:

- Body shape, age and colour,
- Absence of deformities,
- Absence of wounds, haemorrhages, infections and parasites,
- Behaviours like quick response to feed and fast swimming

It is advantageous to collect sub-adults for broodstock development. Larger fishes would have crossed the reproductive age and very small fishes will take longer time to sexually mature. In the case of cobia, fish weighing between 8 to 15 kg could be procured while silver pompano could be procured in weight range of 750 gm to 1.5 kg. Stress should always be minimised during capturing and handling of broodstock. It is best to collect broodstock fishes from trap nets, hook & line, etc., as they cause minimum stress to the fishes. Adequate dissolved Oxygen (DO) should be ensured during transportation.

Quarantine

Upon arrival at the hatchery, broodstock fishes are released into the quarantine tanks for prophylactic treatment. Fish anesthetics like MS 222 (50-100 ppm) and Aqui-S (4 ml / 100 L), can be used for broodstock handling. The prophylactic treatment is given to limit the risk of introducing parasites or bacterial diseases into the hatchery facility. Short time exposure of brooders (maximum 5 minutes) in freshwater will help to remove the external parasites. The prophylactic treatment in hatcheries includes a sequence of medicated baths in formalin, malachite green and Oxytetracycline (OTC). Prophylactic treatment can be repeated three to four times within a week. It is preferable to have a flow-through water circulation in quarantine tanks when treatments are not underway. Smooth inner surface in tanks allow easy and complete cleaning. The following sequence of treatments can be followed:

Day 1: Fresh water bath for 10 minutes and then Oxytetracycline treatment (50 ppm) in seawater for 30 minutes.

Day 2 to Day 7: Treatment with a mix of 200 ppm formalin and 0.2 ppm malachite green for 1-2 minutes, followed by a freshwater dip for 5 minutes. Before returning the fishes to quarantine tanks with filtered seawater, they can be given an Oxytetracycline treatment at 50 ppm for 30 minutes. The fishes should be closely observed during treatments.

During the quarantine, fish should be closely monitored. If the fishes suddenly become immobile or are found with very less opercular movements or are turning upside down, they should be immediately transferred to filtered seawater. The fishes can be fed during the day time when it is not undergoing treatment. Over feeding should be avoided and the fishes can be transferred to maturation tanks after the treatments are over. Apart from quarantine treatment, the broodstock fishes should be given regular prophylactic treatment with freshwater with or without OTC at least once in a month.

Broodstock development

After quarantine, broodstock fishes are moved into Recirculation Aquaculture Systems (RAS) or sea cages for broodstock development. Broodstock development in sea cages was successfully done for

cobia at Mandapam Regional Centre of CMFRI. Circular cages of 6 m diameter and 3.5 m depth with HDPE frame were employed for the purpose. The major problem in the development and maintenance of the broodstock in sea cages is the risk of contracting diseases and subsequent loss of broodstock. The sudden loss of broodstock will affect the seed production, since loss of broodstock cannot be made good from the wild immediately. Hence, on shore facilities like RAS is advised for development and maintenance of biosecured broodstock.

The vital aspects which affect development of broodstock are the photoperiod, temperature and broodstock nutrition. In a shore based facility, the photo thermal conditioning can be practiced which will accelerate the gonadal maturation. In addition, it is also possible to obtain year round spawning in such a controlled system.

Broodstock nutrition

The viability of the larvae is very much dependent on broodstock nutrition. The nutritional components in the diet, the feed intake rate or the feeding period can all affect spawning, egg and larval quality. In the case of tropical fishes, ovarian development is often asynchronous – oocytes in all stages of development are present at the same time and sometimes independent of season. The ovarian development starts with the formation of primary oocytes. During the primary growth phase, the surrounding granulose and theca cells envelop the oocyte to form the ovarian follicle. In the early stages of secondary growth, cortical alveoli appear and accumulate in the periphery of the oocyte. Even though the oocyte may increase in size several fold during primary and early secondary growth, the most conspicuous size increase occurs during the last part of secondary growth, vitellogenesis. Vitellogenesis is the process of yolk formation and incorporation in the growing oocytes. The yolk protein precursors, vitellogenins, are high molecular weight lipoproteins that are synthesized in the liver and secreted into the blood. The fatty acid composition of the vitellogenins can be affected by long term imbalances in the broodstock diet. It has been well established that feeding broodstock fish with squid, cuttlefish or meals made from cephalopods have beneficial effects. These feed ingredients make the diet more attractive and therefore increase feed intake. Squid and cuttlefish also contain high levels of essential fatty acids.

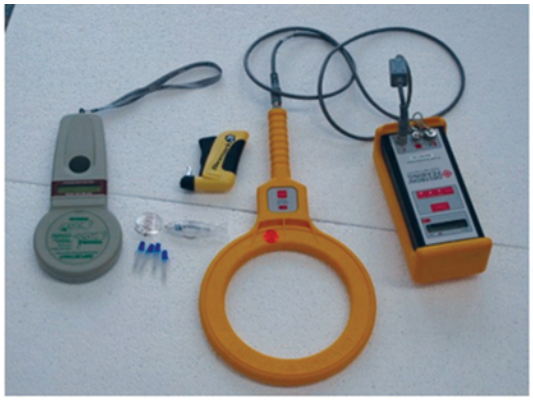
For quicker maturation, the broodstock fishes are to be fed with highly nutritive diet. Diet rich in vitamins, poly-unsaturated fatty acids (n- 3 PUFA) and other micro-nutrients is essential for obtaining viable eggs and larvae. During gametogenesis, female fish require a food, richer than usual, in proteins and lipids to produce the vitellogenin. As the sole source of food for the developing embryo and the early larval stage until feeding on live preys starts, yolk quality and quantity are key factors for a successful reproduction. Both dry pellets and moist food are also employed during maturation. Dry pellets should include essential nutritional components like polyunsaturated fatty acids (n-3 PUFA), in particular EPA (20:5 ù 3) and DHA (20:6 ù 3), which cannot be produced by fish metabolism. Broodstock fishes are fed *ad libitum* once a day with squids, cuttlefish, crabs, shrimps and chopped oil-sardines depending on the availability.

Tagging

Tagging or physical marking of broodstock fishes through easily detectable methods is very much essential for selection of broodstock for identification, selective breeding and segregation. The most popular method is PIT Tagging. Passive Integrated Transponder (PIT) tag, also known as is a radio frequency device to permanently mark fishes internally. The tag is designed to last the life of the fishes providing a reliable, long term identification method. The PIT tag contains a microprocessor chip and antenna. It has no internal battery, hence the term "passive", so the microchip remains inactive until read with a reader. The reader sends a low frequency signal to the microchip of the tag providing the power needed to send its unique code back to the reader and therefore fish is positively identified.

The distance from which a tag can be read is the read range. Most read ranges using hand-held readers are 3 to 9 inches depending on the reader. There are currently three basic tag frequencies. The 400-kHz tag was one of the first developed but it has limited read range. As microchip technology evolved, the 125-kHz and 134.2-kHz tags became available. Compared to the older 400-kHz tags, they have a much better read range and reduced read time. The 134.2-kHz tag was developed to meet international standards for code format. It is very much important that the tag type and reader unit should be compatible. Most readers are capable of detecting both 125-kHz and 134.2-kHz frequencies.

Design engineers' calculations suggest that PIT tags can last as long as 75 years or more. There is no battery to fail and the glass encapsulation is impervious to almost everything. PIT tags can be removed or recovered from a primary location and reused indefinitely. Reducing stress to the fish is the prime factor in ensuring the success of the tagging and safety of the fish. Therefore, the fish should be anesthetized during the implantation of PIT tags. Species, size and age should be considered when making a decision about anesthetization and restraint. Sterile implants are advised but many field conditions do not allow for sterile implants. Equipment can be disinfected prior to use with alcohol and iodine-based solutions. The tag is encased in glass that protects the electronic components and prevents tissue irritation, thereby very much safe to the fish.



Procedure of tagging

The implant site depends upon the species, size of the fish and the size of the tag. It is preferable to implant the tag on the dorsal musculature of the fish which will be convenient.

Stepwise protocol

- Use sterile needle or implanter to tag the fish. In field condition, disinfect all the components prior to use with alcohol and iodine-based solutions.
- Read the tag before inserting into the fish and record the identification code or number.
- Catch the fish and anaesthetize it with suitable anaesthetic. In sea cages, it is easier to restrain the fish inside the catching net.
- Disinfect the site of implantation with alcohol or iodine-based solution.
- It is a better practice to keep a standard site of implantation so that the reading will be easier and quicker.
- The tag loaded inside the implanter has to be inserted into the muscle tissues. It is advisable to insert the tag parallel to the muscle fibres to avoid much damage to the tissues.
- The tag should be released slowly and steadily from the implanter while removing the implanter from the tissue in such a way that the tag fills the space created by the implanter needle.
- Once implanter needle is taken out, the site should be disinfected again with alcohol or iodine-based solutions to avoid secondary infection.
- Release the fish as soon as the tagging is over or once it has recovered from anaesthesia.

Cannulation

At the onset of the spawning season, it is necessary to move selected broodstock fishes from maturation tank to spawning tank after assessing the ovarian development through cannulation. Only females with oocytes in the late-vitellogenic stage, with a diameter around 700m in cobia and 500 mm in pompano, are selected.

Ovarian biopsy can be carried out as follows:

- Female brooders have to be transferred to a small tank containing anaesthesia in sufficient quantity.
- Flexible sterile catheters (1.2 mm internal diameter) can be used for cannulation biopsy.
- Introduce the sterile catheter into the oviduct, up to the ovary for a few cm; then suck carefully a small sample of oocytes up into the catheter and place the sample on a glass slide.
- After sampling, release the animal into the spawning tank, where recovery from sedation will take place.

- Put few drops of filtered sea water on the biopsy sample and examine under the microscope and measure the diameter of the oocytes and record the measurements.

Induction of spawning

Spawning can be obtained either naturally or by inducing with hormones. Induced breeding is commonly practiced in most commercial hatcheries. The hormonal treatment is intended to trigger the last phases in egg maturation, i.e. a strong egg hydratation followed by their release. However, if eggs have not reached the late-vitellogenic (or post-vitellogenic) stage, the treatment does not work; hence ovarian biopsy is essential for assessing the ovarian development. The human chorionic gonadotropin (hCG) is used at a dosage of 500 IU per kg of body weight in cobia females and 250 IU per kg body weight for males, whereas, for pompano 350 IU per kg body weight is used for both male and female. This dosage can be administered as a single dose on the dorsal muscles. Use of hCG treatment sometimes gives serious setbacks like not all females respond to it, egg quality may be below acceptable standards with hatching rate lower than 80%, being a large molecule it may provoke immunization reaction , and as a result, fish treated with hCG may not respond when treated repeatedly with this hormone. However, hCG can be successfully replaced by an analogue of the luteinizing hormone-releasing hormone [LH-RHa des-Gly10 (D-Ala6) LH-RH ethylamide, acetate salt]. It is a small molecule with 10 peptides and acts on the pituitary gland to induce the release of gonadotropins which, in turn, act on the gonads. Almost 100% of injected fish spawn eggs whose quality usually matches that of natural spawning.

Hormonal administration to cobia

Spawning

The spawning unit should preferably be kept separated from the main hatchery building to avoid disturbance to the spawners and possible risk of disease contamination. However, for economic reasons, it is usual to keep the brooders inside the hatchery in a specific dedicated area. It is preferable to use circular tanks with at least 1.20 m depth. Shape and depth of tanks count for easy and free movement of brooders. Normally the spawning could be noted within 36 -48 hours after hormonal induction. The spawning in cobia and pompano takes place normally between late night and early morning hours. The number of eggs spawned by cobia ranges from 0.4 to 2.5 million, whereas, the pompano brooders spawn 0.5 to 1.5 lakh eggs.

Egg harvest

The fertilized eggs of cobia and pompano float and are scooped gently using 500 ìm net. To minimise the presence of poor-quality eggs, which usually float deeper in the water, it is advisable to collect only

the eggs which float at the water surface. Therefore, aeration can be switched off allowing the unfertilized / dead eggs to settle at the bottom of the tank. The floating layer of eggs thicker than one cm should be avoided. A thicker layer may reduce oxygen supply to the eggs, leading to possible anoxia after a short time. Then in the temporary container, eggs must be thoroughly examined to assess their quality, number and developmental stages. With a pipette eggs should be taken from the floating egg layer in the temporary container, and should be placed on a watch-glass or on a Petri dish for observation under microscope. Few dozens of eggs, which are placed under a microscope or a transmitted-light stereomicroscope have to be observed for the egg developmental stages.

As fertilised cobia/ pompano eggs float in the seawater, they can be collected using egg collectors. If well dimensioned and properly placed, these devices harvest only the floating eggs, while the dead or unfertilised ones sink to the bottom. The presence of eggs in the collectors should be checked rather frequently in the case of cobia, as its spawning releases a large amount of eggs in a very short time there is risk of clogging the collectors or of mechanical stress to the eggs.

Check for the following egg characteristics:

- Presence of opaque, whitish eggs which are unfertilised. Similarly, eggs in the sample with transparent, but without evidence of cell divisions
- Regular rounded shape and size (diameter 900-1000 mm in cobia; 800 -900 mm in pompano), regular cell division that can be observed only in the first blastomers; regular shape of yolk (it should occupy the egg volume entirely, without perivitelline space),
- Absence of parasites or associated micro-organisms on the chorion surface.

Incubation of eggs

It is done in incubation tanks of 3-5 tonne capacity. After hatching, only the hatched fish larvae have to be moved to the larval rearing tanks filled with filtered seawater. Prior to this, the aeration should be stopped briefly to enable the debris and exuviae to settle at the bottom which can be removed by siphoning. Aeration needs to be adjusted suitably, not too strong to avoid excessive physical collision among eggs, but not too weak either, to keep the eggs suspended in water column. The main purpose of aeration is to prevent clumping and settling down of eggs. Air bubbles should not be too small as seen while using air diffusers instead of stones, as it results in clumped eggs and damage of the eggs. It is suggested to limit as much the number of air stones as possible. Stocking density can be maintained at a moderate level of 200 to 500 eggs per litre. The development of embryo can be observed at frequent intervals under a stereo / compound bionocular microscope. The hatching of eggs takes place from 18 to 24 hours.

Hatchery Technology for Commercially Important Crustaceans

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Crustaceans contribute more than 20% (in value) to global aquaculture production, ranking first in unit price per kg. Farmed shrimp contributes about 60% by volume and 82% by value to India's total shrimp export. Fast growth, short food chain, efficient conversion of food, ready acceptance of compounded feeds, good table quality, disease resistance, ease of breeding in captivity, early maturation, high fecundity and tolerance to a wide range of environmental parameters render crustaceans as good candidates for aquaculture, and farming of crustaceans using seed collected from the wild has been a practice in vogue the world over. As aptly stated by Laubier and Laubier (1993), crustacean aquaculture is a high-risk activity with good prospects for profit, but also potential for heavy losses. Limitations

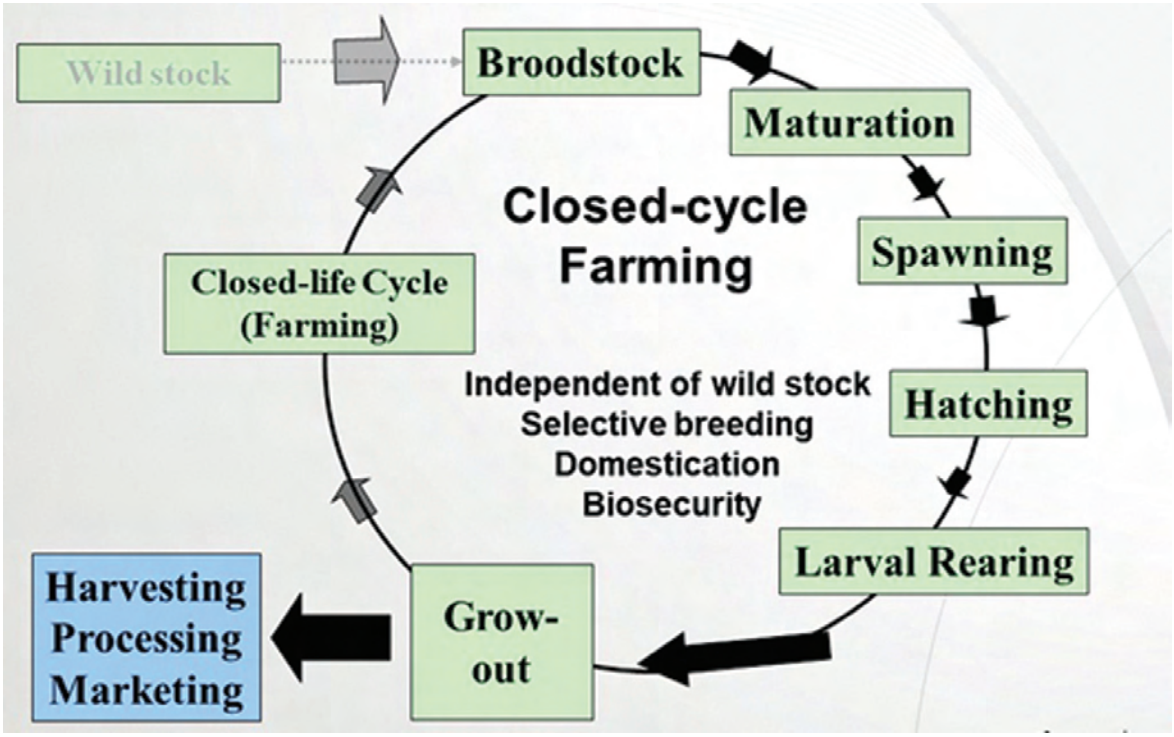

Fig. 1. Model of Aquaculture Propagation System: Closed Life Cycle
Source: Smith G., AIMS; personal communication

come mainly from supply of good quality seedstock and broodstock, which is strongly linked with nutrition requirements, disease and environmental issues. To be considered a true farming sector, the life cycle of the organism must be fully completed in captivity – from adult to egg to adult. With closed life cycle production, the productivity gains of selective breeding and specific production of strains can be fully attained without reliance on wild stocks and overfishing of natural populations and impacts on marine ecosystems.

In the second half of the 19th century, strides were made in understanding the life histories of several commercially exploited species such as the lobsters *Homarus americunus* and *H. gammarus* and several species of prawns and crabs (Laubier and Laubier, 1993), paving the way for focussed efforts in captive maturation and breeding of several species. While early impetus was on sea ranching of young seed to augment the natural stock, research efforts were eventually diverted to developing technologies for hatchery production of seed and subsequent farming of hatchery produced seed.

The decade 1935-1945 saw several important scientific contributions with the life cycle of penaeid prawns being analysed in detail - *Penaeus japonicus* by Hudinaga (1942) and three Mediterranean species *Penaeus trisulcatus, Parapenaeus longirostris* and *Sicyona carinata* by Heldt (1938); the morphology of larval (nauplii 1-5 or 6, zoea 1-3 and mysis 1-3) and post-larval stages was also described.

Prawns have always formed the mainstay of crustacean aquaculture. All farmed freshwater prawns belong to the genus *Macrobrachium*. Until 2000, the only species farmed was *M. rosenbergii*, also known as the Malaysian prawn Since then, China has begun farming *M. nipponense* in large quantities, and India farms a small amount of *M. malcolmsonii*. In 2003, these species accounted for all farmed freshwater prawns, about two thirds being contributed by *M. rosenbergii* and one third, *M. nipponense*. Commercial crustacean culture in India was mostly confined to scampi production and culture of the penaeid prawns *P. monodon* and *P.* indicus, until the introduction of *P. vannamei* during 2009-10.

Lobsters and crabs rank next to shrimps in flavour acceptability. Lobsters are the most valued of all seafood delicacies and lobster tails are always in great demand world-wide. Freshwater crayfishes, which are considered a delicacy in many parts of the world, is a favourite aquaculture candidate in North America, Europe and Australia. Lobster and crab culture in India are in their infancy stage C.M.F.R.I. has been spearheading research in the development of culture technologies for different species of lobsters and crabs.

Marine prawns

Marine prawns undergo a life cycle marked by three major larval stages (with substages, the number varying between species) and several post-larval stages before settling as an adult prawn, with the larval cycle lasting from 10 to 12 days. The adult prawns mature and breed in marine conditions whilst

the larval cycles get completed in coastal waters and hence 30-32 ppt salinity is optimally required for the hatchery operations. The externally fertilised eggs hatch out in 16-18 hours into the first larval stage called nauplius is a non-feeding, yolk-dependant stage. It has antennal appendages as locomotory organ fixed on the head, with a median eye. The nauplius advances through several moults, before transforming into a protozoea, which is the second larval stage. This is a critical stage of larval rearing. The larvae are slow and continuous feeders. The larvae at this stage start feeding on external food and feed on minute and easily digested microscopic algae such as *Skeletonema costatum*, *Chaetoceros* sp. and *Tetraselmis* sp. The shrimp larvae are also fed with either wet or dried processed crustacean tissue during protozoea stage. Since the time of metamorphosis is usually uncertain, feeding must start one day ahead of the expected time of metamorphosis. The use of marine invertebrates as food organisms which can be purchased at low prices and in large quantities since these are available locally is advantageous. The commonly used food organism is the paste shrimp (*Acetes* sp.). Microencapsulate diets (MEDs), liquid diets and frozen algae are the latest research products in alternative feeding strategies.

The protozoea advances through 3 stages before transforming into the mysis, which bears some resemblance to the adult prawn. The larvae at this stage will start feeding on rotifers (*Brachionus plicatilis*) or nauplii of the brine shrimp *Artemia* sp., the requirement depending on the density of shrimp larvae being reared. Each mysis larva consumes about 100–200 rotifers or about 20–50 *Artemia* nauplii per day or can be reared on artificial diets.

The mysis, after 3 stages, develops into the postlarva, which looks like a “mini-prawn”. The development time from spawning to postlarva is usually between 2-3 weeks. The larval stages are all free-swimming while the postlarva resorts to a bottom existence. Water temperature and salinity greatly influence the hatching success and conversion rates between larval stages.

A typical hatchery should have a diatom indoor culture facility, mass culture facility, LRT (small or big depending on the system design applied) and nursery tanks to rear the postlarvae to stocking sizes. The densities in these tanks and facilities vary according to the species and system adopted. A recent advancement in penaeid prawn hatcheries, particularly *P. vannamei*, in India is that nowadays nauplii are packed and shipped to different hatcheries from nauplii production centres as the breeders are confined to select centres with protocols and approval. The Japanese were the first to make a breakthrough in hatchery production of penaeid prawn, with the success achieved in *Penaeus japonicus*. Offspring were reared from wild females, through 12 larval stages (6 nauplii, 3 zoea and 3 mysis) and 21 post-larval stages (Hudinaga, 1942). An equally major achievement was the determination of the different food requirements of those stages, beginning with the unicellular algal food required by the zoea, with Hudinaga being the first to develop laboratory culture of the diatom *Skeletonema costatum*. The laboratory techniques were later transferred successfully to a larger scale of production (Hudinaga & Kittaka,

1967; Kittaka, 1971).

The major species of penaeid prawns commercially cultured in India are, *P. monodon, Penaeus indicus* and the recently introduced exotic *P. vannamei* all of which are euryhaline. Early strides were made by CMFRI in developing hatchery technology for seed production of *P. indicus* (Silas et al., 1985). CMFRI has also developed technology for hatchery production of seed of the marine prawn *Penaeus semisulcatus* (Maheswarudu et al., 1990; Maheswarudu et al. 2013). Larval rearing techniques have been evolved through different methods - Taiwanese (large tanks), Aquacop Clear water systems, Galveston sytems, Green water systems, to suit regional requirements.

Freshwater prawns

Fujirnura (1966, 1974), working in Hawaii on a few adults of *Macrobrachium rosenhergii* introduced from Penang, was able to develop large-scale hatchery techniques utilizing “green-water” technology for post-larval rearing. Unlike the marine prawns, there are no naupliar stages and the larval cycle of the freshwater prawn is completed through 11 zoeal stages, which transform into the postlarval stage in a span of 17-32 days. The hatchery operations are carried out in 12-14 ppt salinity medium and the post larvae after 5-10 days are acclimatised to rearing conditions and salinities. Recent innovations and interventions have shortened the larval cycle duration and have assisted in synchronising the PL settlements and improving survival rates. More of clear water systems are applied in the LRT with densities close to 100Z/l initially reduced to 25/l towards the end in 3-5 tonne tanks.

Recent trends in innovative business opportunities within the prawn culture segment has seen the establishment of different minor segments, which have increased livelihood and employment opportunities by several folds -

- Breeder collection and supply units
- Nauplii production and supply units
- Hatcheries
- Nursery units
- Farming systems
- Live feed supply units
- Artificial feed units & probiotics
- Hatchery/Farm implements

Table 1. Major cultivated species of prawns

Marine prawns	Countries/areas of occurrence
Family Penaeidae	
Penaeus setiferus	Western hemisphere (U.S.A., Puerto Rico, Mexico, El Salvador, Guatemala, Belize, Honduras, Costa Rica, Nicaragua, Panama, Cuba, Dominican Republic, Brazil, Columbia, Peru, Venezuela, Ecuador)
P. duorarum	
P. teraoi	
P. aztecus	
P. californiensis	
P. schmitti	
P. vanamei	
P. stylirostris	
P. brasiliensis	
P. chinensis	
P. monodon	
P. subtilis	
P. occidentalis	
P. japonicus	Eastern hemisphere (Japan, Korea, China, Thailand, Taiwan, India, Hong Kong, Philippines, Vietnam, Malaysia, Indonesia, Australia, Israel, Iran, Egypt, Saudi Arabia, Kuwait)
P. monodon	
P. indicus	
P. orientalis	
P. semisulcatus	
P. merguiensis	
P. latisulcatus	
P. penicillatus	
P. chinensis	
M. dobsoni	
M. ensis	
M. joyneri	
Freshwater prawns	
Family Palemonidae	
Macrobrachium rosenbergii	U.S.A., Hawaii, Australia, Polynesian Islands, Israel, India, South-east Asia, Solomon Islands, Antilles, French Guyana Russia, Belarus, Moldova, Australia, India
M. nipponense	
M. australiense	
M. malcolmsonii	

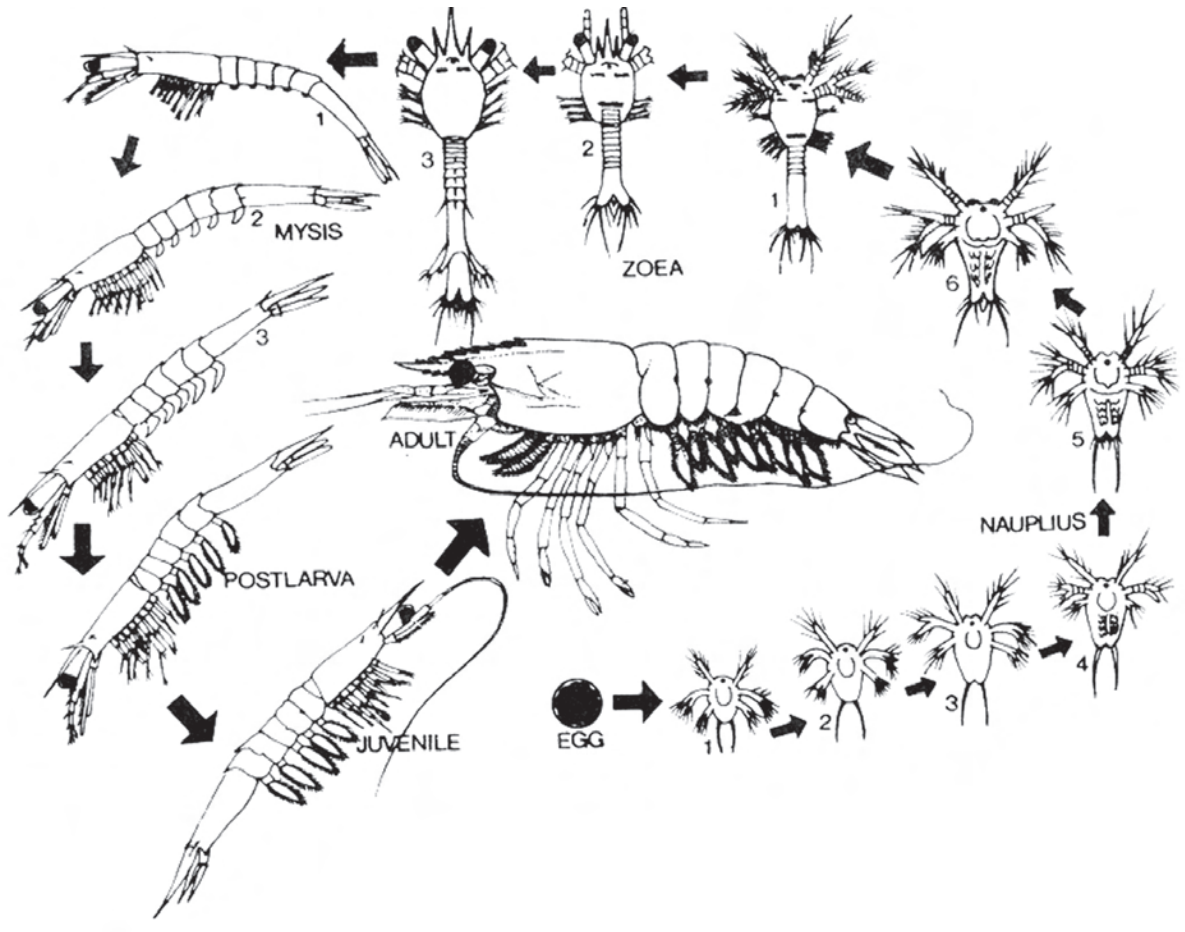

Fig. 2. Life cycle of a penaeid prawn

Crabs

Live mud crabs (*Scylla serrata*, *S. tranquebarica)* being a much sought-after export commodity, mud crab fattening was considered the best alternative. Mud crab/green crab/mangrove crab (Scylla serrata) commands sustainable domestic and international market. Owing to this fact, this species is widely exploited from all along the coastal belt ofIndia and also in many parts of the tropical/subtropical regions of the world where its natural distributionis ascertained (Ganesh et al., 2015).

In mangrove crab, *S. serrata*, there are three larval stages, viz., zoea (1–5), megalopa and crab instar (baby crab). Larval development is usually completed in a span of 27-30 days till formation of the crab instar. The main live feeds are rotifers and *Artemia* nauplii for the entire larval rearing period. In order to sustain the production of rotifers, initially microalgal species, viz., *Nannochloropsis salina, N. oculata, Chlorella marina,* etc., are cultured in large scale for feeding the marine rotifer, *Brachionus plicatilis*. Similarly, *Artemia* nauplii and *Artemia* biomass production is also to be maintained as these

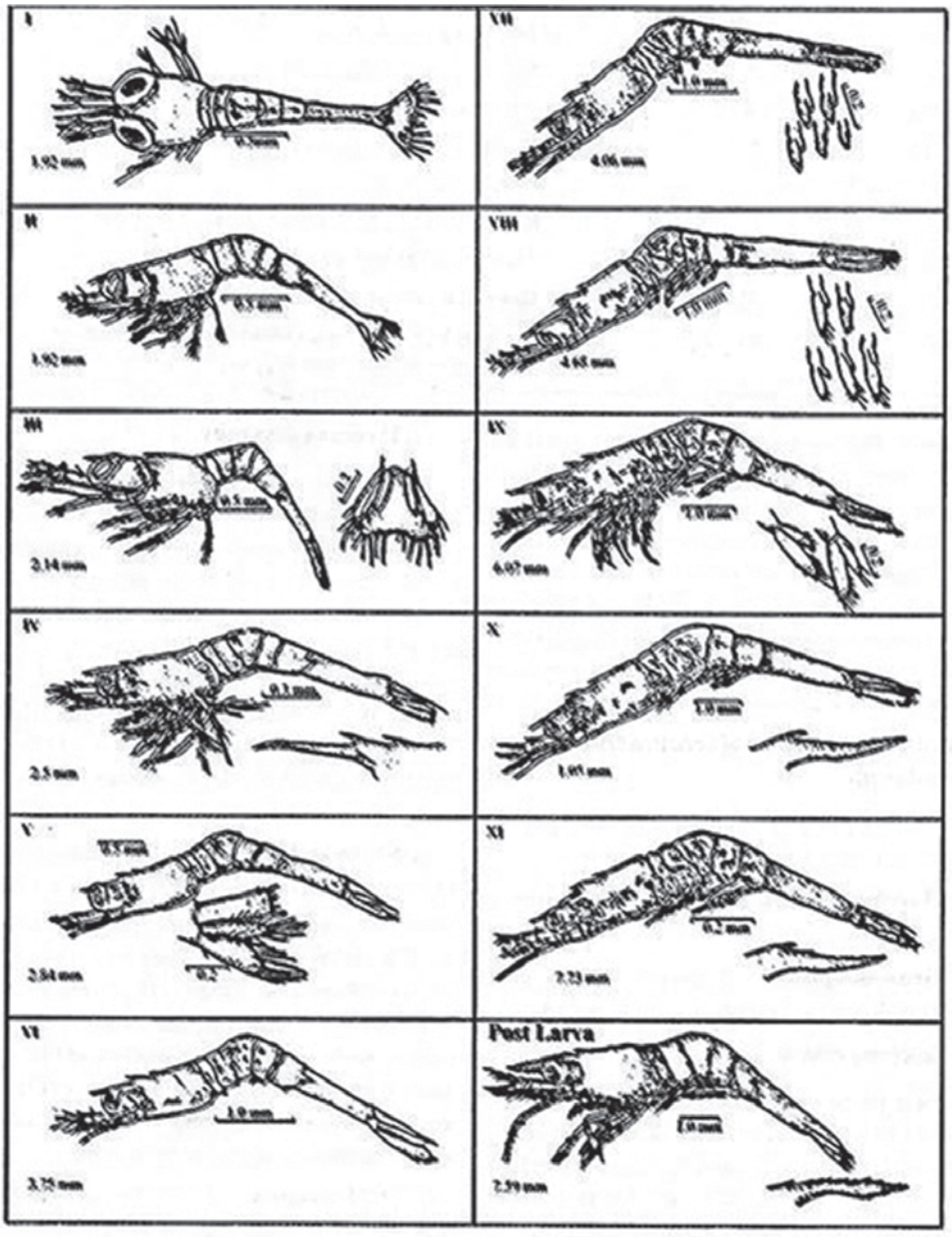

Fig. 3. Larval stages of the freshwater prawn Macrobrachium rosenbergii

are the exclusive feed for the later part of the larval stages (Ganesh et al., 2015). Artificial or supplementary diets have not been developed on a commercial scale for mangrove crab larval rearing (Shaji *et al.*, 2006).

Experiments on breeding and seed production of *S. tranquebarica* have given 20 percent survival rate from egg to first instar stage and attempts are on to improve the survival rate for an economically viable hatchery technology. One of the decisive factors for successful larval rearing and seed production

of mud crab is to scale up the survival rate from zoea1 to zoea2. Zoea1 is tiny, fragile and is the earliest hatched feeding larva with incomplete development of visual perception organs (sessile eyes) and digestive system (Maheswarudu et al., 2007).

Hatchery technology for breeding and seed production of the blue swimming crab, *Portunus pelagicus*, has also been developed by CMFRI. Larval development of *Portunus pelagicus* includes four zoeal stages and one megalopa. The megalopa moulted to the first crab instar. The zoeae and megalopa were very similar to those of other portunids. The duration of each of the first two zoeal stages was 3-4 days, the following two stages 2-3 days, and the megalopa 3-5 days, reaching the first crab stage in 15-17 days (Josileen and Menon, 2004).

The larval development of *C. feriatus* includes six zoeal stages and a megalopa stage, which metamorphoses into the crab stage. Each zoea has a long rostrum, a dorsal spine and a pair of short lateral spines on the carapace. Zoeae resemble the typical portunid larva in morphology and are very active and photopositive. The total duration of the zoeal phase varied between 19 and 26 days during different trials (Josileen, 2011)

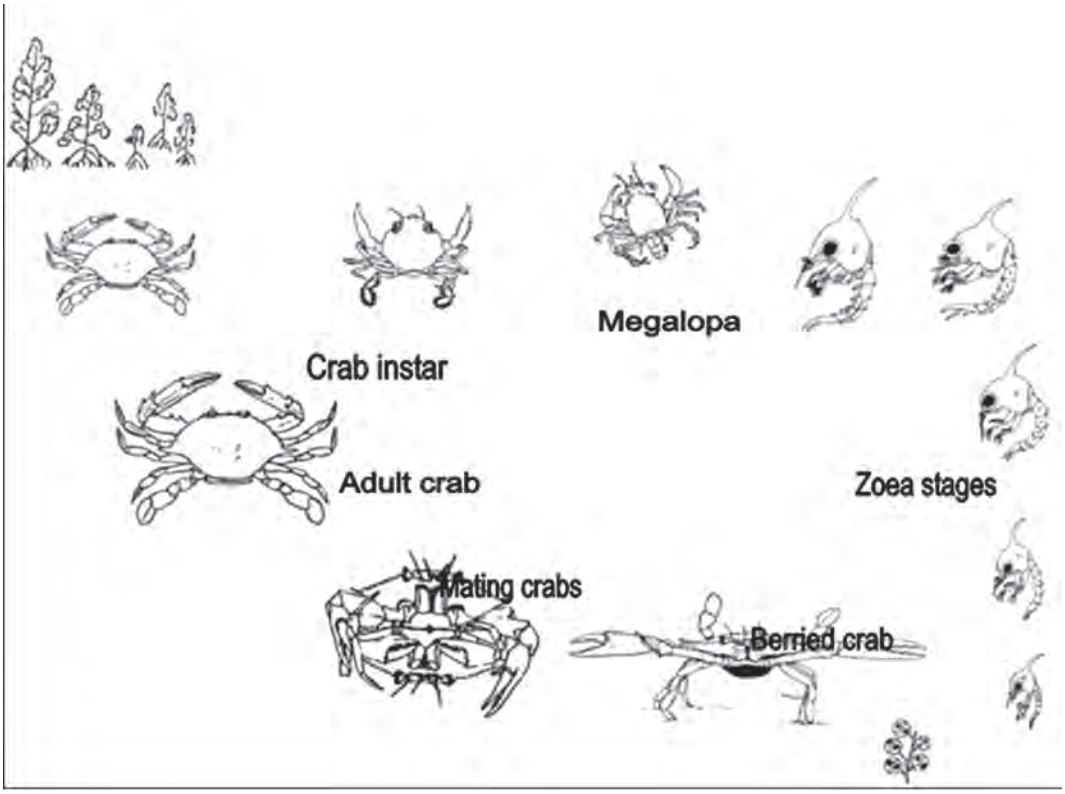

Fig. 4. Life cycle of mud crabs
(modified from Ganesh et al., 2015)

Table 2. Major cultivated species of crabs

Crabs	Countries/areas of occurrence
Family Portunidae	
Scylla serrata	Philippines, Australia, India
S. tranquebarica	Philippines
S. olivacea	Philippines
S. paramamosain	Vietnam, Indonesia, Thailand
Portunus pelagicus	Australia
P. trituberculatus	Japan, Korea, China
Charybdis feriatus	Indo-Pacific
Callinectes sapidus	U.S.A.

Lobsters and crayfishes

Crayfish and rock lobster aquaculture industry has already taken off in countries like the U.S.A. and Australia. Crayfish breed easily in captivity, grow faster, are detritovres/omnivores with minimal supplemental feed requirement, have 22-30% meat yield, have good flavour acceptability, can be grown in polyculture with fishes and freshwater prawn, and in density farming in stagnant pond systems. Crayfishes have 3 zoeal stages and 1 postlarval stage, with an incubation period of 2-20 weeks. The broodsize of crayfishes is 200-500 per brood.

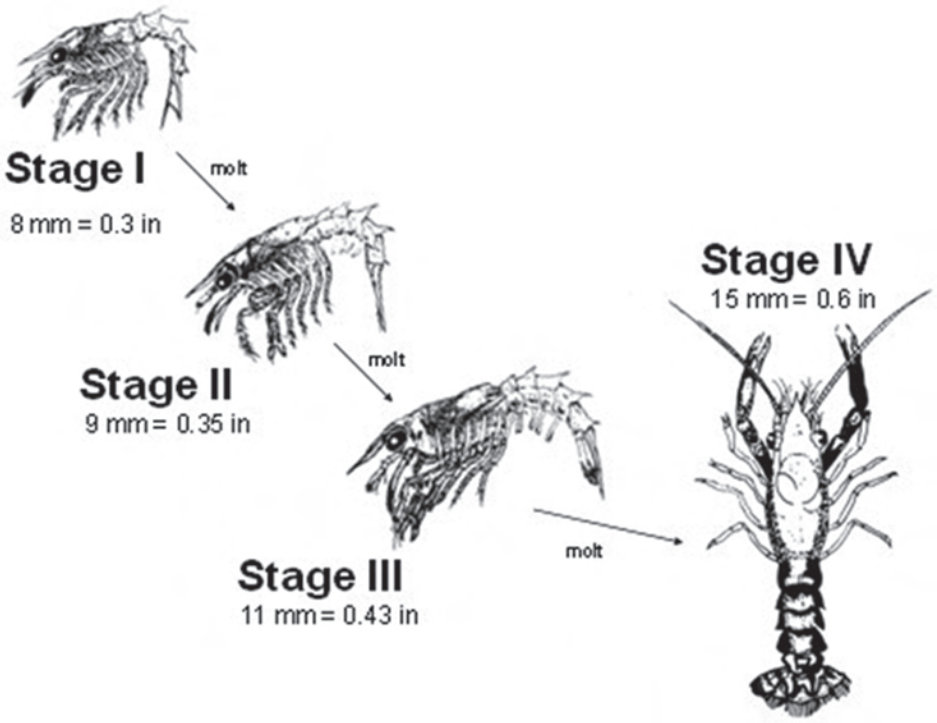

Fig. 5. Life stages of the American lobster Homarus homarus

Incubation period in the homarid lobsters may vary from 9-12 months, and larval stages, from 35-70 days, with 4 zoeal stages and 4 post larval instars. About 5000-8000 larvae are produced per brood. The rearing system consists of individual chambers for incubation of eggs and for individual rearing of baby lobsters.

Table 3. Major cultivated species of crayfishes & lobsters

FRESHWATER CRAYFISHES	**Countries/areas of occurrence**
Families : Astacidae & Cambaridae	
Astacus astacus	Europe
A. leptodactylus	Europe
A. pachypus	Europe
Austropotamobius pallipes	Europe
A. torrentium	Europe
Orconectes limosus	North America, introduced in Germany
Pacifastacus leniusculus	Europe
Procambarus clarkii	North America, South America
P. acutus acutus	North America
Cherax destructor	Australia
C. tenuimanus	Australia
C. quadricarinatus	Australia
Astacopsis gouldi	Australia
Euastacus armatus	Australia
A. franklini	Australia
MARINE LOBSTERS	**Countries/areas of occurrence**
Family Palinuridae	
Panulirus homarus homarus	Indo-west Pacific
Panulirus homarus megasculpta	Arabian Sea
P. penicillatus	Indo-Pacific
P. ornatus	Australia
P. japonicus	Japan, Taiwan
P. longipes	Western Australia
P. polyphagus	North Indian Ocean
P. versicolor	Indo-west Pacific
P. Cygnus	Western Australia
P. argus	Caribbean Islands
P. gracilis	Central America
P. interruptus	Central America
P. inflatus	Central America
P. marginatus	Hawaii
P. guttatus	Central Atlantic (Mexico, Bahamas, Surinam, Bernuda)
Palinurus elephas	Ireland, France
Jasus edwardsii	New Zealand
J. lallandi	South Africa

J. novaehollandiae	Australia
Sagmariasus verreauxi	New Zealand, New South Wales
Family Scyllaridae	
Ibacus ciliatus	Japan, Taiwan
I. novemdentatus	Japan, Taiwan, Western Indian Ocean
I. peronii	Western Australia
I. altecrenatus	Australia
Paribacus antarcticus	North America
Thenus orientalis	Western Central and Eastern Pacific, Indian Ocean
Thenus unimaculatus	India
Scyllarus bicuspidatus	Western and eastern Indian Ocean, Northwest and western central Pacific Ocean
Scyllarides latus	Mediterranean countries
Family Homaridae	
Homarus americanus	North America
H. gammarus	Europe
Family Nephropidae	
Nephrops norwegicus	Europe

The spiny lobster, *Panulirus homarus* has been the chief candidate for lobster aquaculture research in India. While complete larval rearing in captivity is yet to be achieved, other technologies like broodstock development, maturation and breeding in captivity and fattening of juveniles collected from the wild have been standardized. The sand lobster *Thenus unimaculatus* which contributes to 8% of the global lobster production and ranks next to spiny lobsters and tiger shrimp in export value, is one of the most promising candidates for lobster aquaculture in India. Increasing demand for live lobsters in the export market led the farmers and entrepreneurs to collect juvenile lobsters and crabs from the wild and grow to marketable size in ponds and tanks by feeding trash fishes and other discards. In some maritime states juvenile lobsters, pueruli of *Panulirus homarus, P. ornatus, P. polyphagus* and *T. unimaculatus* are grown in captivity. Eyestalk ablated lobsters have been found to attain sizes up to 180 – 200 g in 5 – 6 months period. This type of lobster fattening at a stocking density of 10 – 15 young ones per square meter yielded appreciable growth rates with a profit margin of INR.50, 000/- from a pond of 70 m^2. Complete larval development of *T. unimaculatus* was achieved for the first time in India at the Kovalam Field Laboratory of CMFRI (Kizhakudan et al., 2004). The larval cycle is completed in 26-30 days and juveniles attain a size of 150 g (the minimum legal size for export) in about 300 days. The relatively shorter duration of the larval phase is an advantage in captive rearing of the sand lobster as compared to the spiny lobsters.

As in any aquaculture system, broodstock development and hatchery management are the primary aspects to be tackled while establishing an aquaculture unit for lobsters. Sub-adult and adult lobsters are usually collected from the wild and acclimatized to captive holding. Different techniques for induced maturation and breeding in captivity involve physical handling and provision of favorable influential factors like artificial and natural diets, shelters and hiding places, pathogen-free rearing medium etc. The life history of lobsters shows a transition for a free-swimming planktonic larval phase to a benthic,

crawling adult phase. We need to understand the specific requirements of the species before designing the right type of broodstock and hatchery units. The design of an indoor lobster broodstock and hatchery unit is based on the inherent nature of the animals.

The larval phase in most lobsters is usually complicated, extended and highly dependent on external factors. Like other crustaceans, lobsters begin life as a developing embryo inside an egg which is carried by the female along with hundreds or thousands of other eggs, on the pleopods. These egg-bearing females are called “ovigerous”. Fertilized eggs are dark yellow or orange in color and turn dark brown at the time of hatching. Unfertilized eggs remain cream or pink in colour and are shed off in 3-5 days. After a rigorous incubation phase (early embryo development inside the eggs) when the eggs are fanned with the help of the pleopods, small, transparent, flattened larvae called “phyllosoma” hatch out. The incubation period varies from 26-30 days in tropical spiny lobsters to 30-37 days in sand lobsters. Hatching takes place in batches only during the early morning hours and is usually completed in 1-3 days. Water quality, tank bottom quality and handling stress, particularly during the incubation period, greatly influence the success rate of hatching.

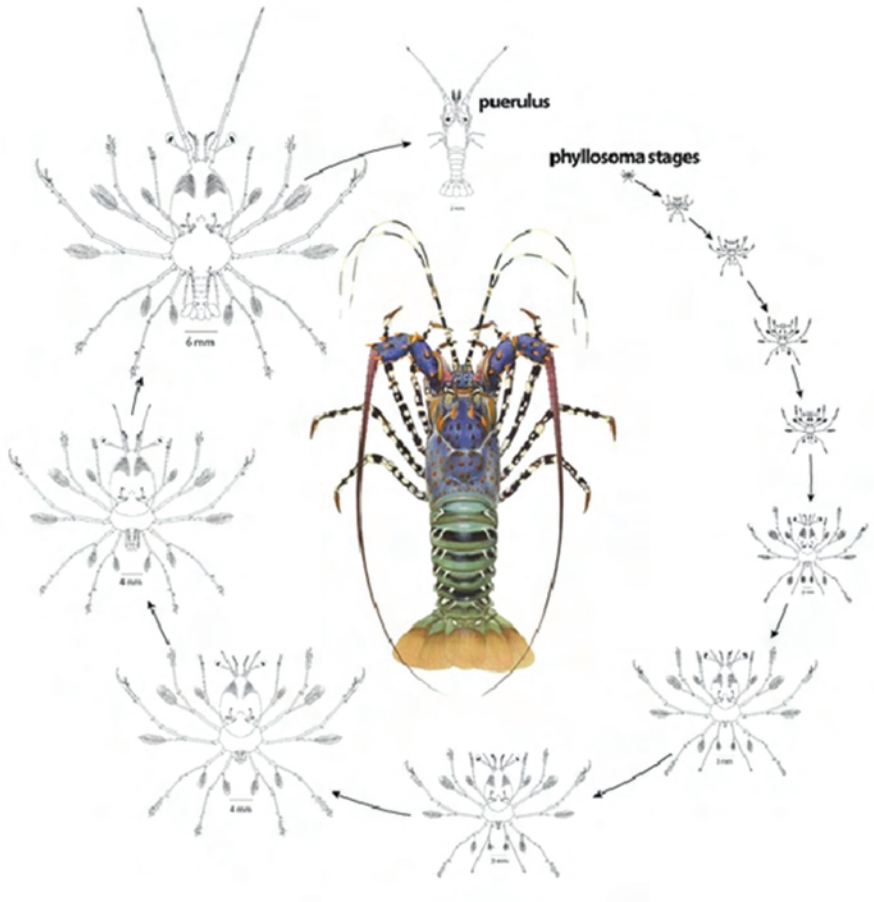

Fig. 6. Larval cycle of Panulirus ornatus
Source: Smith *et al.* (AIMS): pers.communication

Larvae are usually small when compared to the adult except in clawed lobsters. These larval stages (phyllososma) undergo progressive molts to complete metamorphosis before settling as the post larval stage, called “puerulus” in spiny lobsters and “nisto” in sand lobsters. The hatchery phase is often the crucial stage in lobster aquaculture, since handling of the delicate phyllosoma is very difficult, and renders the hatchery phase labour intensive. The number of larval stages varies greatly among species, ranging from about 12 stages in spiny lobsters to 4 stages in sand lobsters. Compared to the spiny lobsters, the hatchery phase is of shorter duration in sand lobsters. While larval metamorphoses can extend up to 300 days in spiny lobsters, it is usually completed in 25-30 days in sand lobsters.

The rearing system should accommodate only minimum numbers per litre, as most of the species are aggressive and cannibalistic; while 10 phyllosoma per litre in tropical spiny lobsters in the initial stages is fine, as stages progress beyond fourth the density has to be thinned further to 5 and 1-2 per litre towards the final stages. The equivalent stages of most species follow almost the same stocking density limits. Larval rearing tanks are usually of shallow depth with upwelling and flow through designs ensuring very less water agitation and reduced photoperiod intensity. Light source is used to pool the larvae to facilitate collection and shifting.

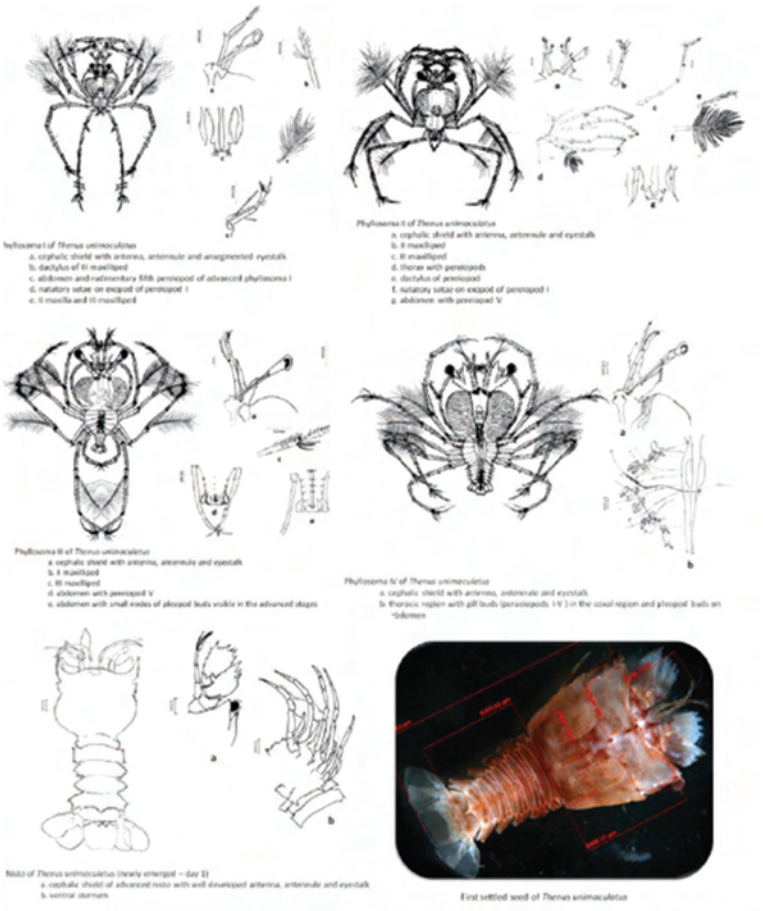

Fig. 7. Larval and post larval stages of Thenus unimaculatus

The phyllosoma are mostly phototactic and prefer specific zooplankters as live feed. Spiny lobster larvae ingest arrow worms and other live feeds in the early stages. Sand lobster larvae show a preference for ctenophores. Suitable artificial, preferably gel texture, supplementary diets are also essential in lobster hatchery feeding regimes. These diets should be floating and stable in water. Water quality in phyllosoma rearing is of utmost importance as delay in molting attracts too fouling microbes on the shell which render the larvae immobile and obstruct their feeding activity. Organic load and ammonia load should be minimal in the system and tank surfaces should be devoid of biofilm formation to reduce bacterial invasions. Proper feed and health management can improve larval survival and growth to a great extent.

Live feed culture

Several crustaceans like cladocerans, copepods, harpacticoids, branchiopods, mysids and euphasids are cultured for live feed and frozen feed sources to cater to commercial crustacean and finfish hatcheries and farming systems. Culture of the brine shrimp *Artemia* sp. is a thriving industry

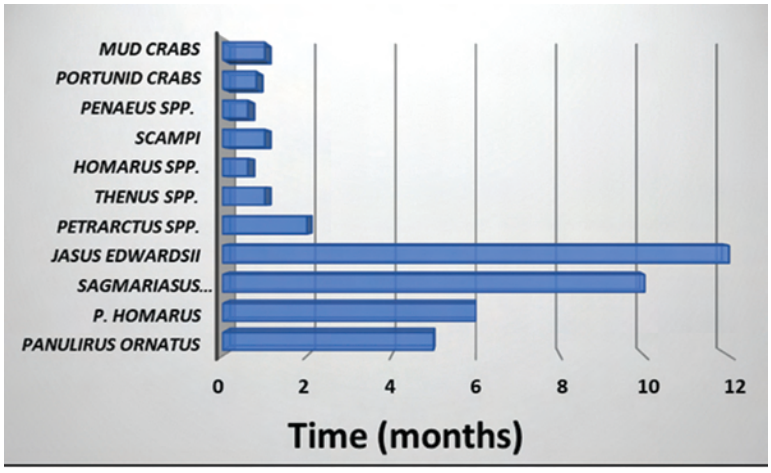

Fig. 8. Larval periods of some crustaceans

Conservation Mariculture

The populations of many marine species are constantly declining and are getting endangered. These include species of *Limmulus polyphemus, Tachypleus tridentatus, T gigas* and *Carcinoscorpius rotundicauda* and coconut shell crab, spider crabs. Stock replenishment through large scale seed production and sea ranching will be a positive step towards the conservation of these species, as is being done with homarid lobsters in the western hemisphere. CMFRI has successfully developed hatchery techniques for some of the species. However future research thrust in this sector is very much warranted.

Captive Seed Production Technology for Marine Ornamental Fishes in India

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Introduction

Aquarium keeping is the second popular hobby next to photography in the world with millions of enthusiasts. At present modern aquarium gadgets for fabrication and maintenance of miniature reef aquaria have been well established. As a result the trade of marine ornamental fishes has been expanding throughout the tropics, and has grown into a multimillion dollar industry. The global marine ornamental fish trade is estimated at US$ 200-330 million. Since this multi stakeholder industry involved fish collectors, culturists, wholesalers, exporters, retailers, hobbyists, researchers, government resource managers and conservators, series of issues are emerging which need to be addressed for developing and expanding a sustainable trade in the domestic and international market. The most important issue that emerged recently is the depletion of wild stock of reef communities. In recent years, it has been reported that nearly 1,500 species of marine ornamental fishes are traded globally and most of these are associated with coral reefs. Nearly 98% of the marine ornamental fishes marketed are wild collected from coral reefs of tropical countries such as Philippines, Indonesia, Solomon Islands, Sri Lanka, Australia, Fiji, Maldives and Palau. This has been threatening the long term sustainability of the trade due to indiscriminate exploitation of ornamental fish resources from coral reef areas. The three key elements in the development of marine ornamental fish trade are – collection, culture and conservation. The development of technologies for hatchery production of selected marine ornamental fishes is the only option for evolving a long term sustainable trade without damaging the coral reef ecosystem. Even at an international level, the technologies for hatchery production of ornamental fishes are limited to a few species. The main steps in captive production of ornamental fishes are broodstock development, breeding, live feed culture, larviculture protocols, grow-out culture methods, diseases monitoring and prevention, packing and transportation etc. The Central Marine Fisheries Research Institute (CMFRI), India has been focusing on these vital aspects for the past several years. CMFRI is successful in developing hatchery technology for 21 species of marine ornamental fishes. The marine ornamental fish trade is a low volume high value industry in rural and urban areas, and hence it is very lucrative to initiate a trade, exclusively rely on hatchery produced fishes.

Captive Breeding of Marine Ornamentals in India

Central Marine Fisheries Research Institute (CMFRI) has developed hatchery technology for 21 species of marine ornamental fishes. These comprises of clown fishes *Amphiprion percula* (True percula/ clown

anemone fish), *A. ocellaris* (Common Clown/False clown aenemone fish), *A. sandaracinos* (Yellow Skunk Clown), *A. frenatus* (Tomato clown), *A. clarkii* (Clark's anemone fish), *A. sebae* (Sebae clown) *A. Perideraríon* (Pink anemone fish) *A. ephippium* (Red saddle back anemone fish), *A.nigripes* (Lakhadweep clownfish), *Premnas biaculeatus* (Maroon clown/ Spine cheek anemone fish. The species of damsels for which technology developed under captivity includes *Dascyllus trimaculatus* (Three spot damsel), *D. Aruanus* (Striped damsel), *Pomacentrus caeruleus* (Blue damsel) *P. pavo* (Sapphire or Peacock Damsel)~ *Neopomacentrus nemurus* (Yellow tail damsel), *N. filamentosus* (Filamentous tail damsel), *Chrysiptera cyanae* (Sapphire devil), *C. unimaculata* (One spot damsel), and *Chormisviridis* (Green chromis) first time in India and also dotty back *Pseudochromis dilectus* (Redhead Dottyback), purple fire goby *Nemateleotris decora* for the first time in the world (Madhu and Rema-Madhu, 2002, 2006~ Madhu *et al.*, 2006a, b, c, Gopakumar *et al.*, 2007, Rema Madhu, *et al.*, 2007~ Madhu *et al.*, 2008, Madhu and Rema Madhu, 2014, Madhu *et al.*, 2016). The advantage of captive production of these reef communities is that, tank reared fishes have more survivability than wild caught fishes which will also be paramount importance for annulling the DOA (Death on Arrival) and long term sustainable trade. The economic viability of ornamental fish production under captive conditions is more lucrative when compared to other maricultured species, due to their high unit value. The complete package of practices developed for their production can be taken up as an alternative livelihood option for small and large scale fish farmers. The transfer of technology to the public and private sector entrepreneurs who have approached for the technology is being planned by imparting hands on training through different modes under the Consultancy Processing Cell (CPC) of the CMFRI, organized trainings, demonstrations, exhibitions and Kisan melas. In addition, the hatchery produced seeds are also being sold to the farmers and aquarium hobbyists and traders through Single Window System and seed counters are operation in marine hatcheries of CMFRI at Cochin, Mandapam and Vizhinjan under the ICAR Mega seed project. This has resulted in the emergence of several ornamental fish trade shops all over the country (India). Recently the National Fisheries Development Board (NFDB), India has also developed schemes to fund for ornamental fish culture in the unutilized hatcheries of the prawn farmers in India.

Captive Breeding

In order to conduct the breeding of ornamental fishes under captive condition, the following steps are to be followed

Transportation of fishes

The basic requirement for any captive fish breeding programme was the procurement of sufficient number of healthy broodstocks or breeding pairs. These can either be collected from the coral reef habitat or can be purchased from the pet shop depending upon the availability. In the wild, clown fishes generally show symbiotic mutualism with sea anemone. In a group, sexually active pair of adult fishes and one to three juveniles or sub adult fishes was normally seen. Female fish was somewhat larger than the male fishes and shows monogamous pair formation. These pairs were needed to be collected for the broodstock development and breeding programme. During transportation, the fishes and sea anemones should be kept in separate plastic bags to avoid fish mortality by toxin secretion of sea anemones.

Quarantine

Newly procured fish from wild as well as pet shops may have disease or may carry disease causing organisms. It may spread to the other healthy fishes in the hatchery. Due to these reasons, they should be kept separately in a tank or system, for 3-4 weeks for close observation. Medicines can be use for curing any existing diseases during quarantine period. Prior to marketing, fishes should be screened and quarantined to make sure that the fishes were healthy for trade.

Pair formation

In case, mated pairs are not available, five fishes having different size and gender need to be stocked along with a single host sea anemone in a 500 L FRP tank fitted with biological filter. These tanks need to be maintained in the hatchery where an incident light intensity of 2500 to 3000 lux should be deployed, as the sea anemones require sunlight for its better survival under laboratory condition. The fishes and anemones should be fed two times per day with wet feeds such as chopped meat of shrimp, mussel and clam at the rate of 15% of their body weight and live feeds like *Brachionus plicatilis,* artemia nauplii and adult artemia. Environmental parameters such as temperature 26 to 29° C, salinity 32 to 35 ppt, dissolved oxygen 4.6 to 6.2 mg/L and pH 8.1 to 8.3 were to be maintained in all the rearing tanks for proper growth and survival of the pair.

Sex reversal and pairing

As the clown fishes are protandrous (first mature to male) sequential and opportunistic hermaphrodites, a pecking order is established in which the female is dominant, the male is subordinate to the female, and all the other juveniles are subordinates to the adult male and female. Thus generally all clown fishes mature as males and later change into females when they reach larger sizes or loss of a male mate. The male and female form a monogamous pair bond that lasts until one of them dies. If the female dies first, the largest male rapidly changes into a female and the second largest or dominant juvenile becomes an active male and that pairs with the newly sex reversed female. By utilizing this adaptation, pairs of clown fishes can be developed under captive condition through creating social systems. After a period of 3 to 4 months of rearing, in each tank one pair of fishes grew faster than others and became the spawning pair. As the newly formed pairs would be very aggressive and spending time for fleeing the other fishes rather than breeding, it is very essential to stock each breeding pairs in separate brood stock tanks.

Broodstock development and maintenance

The pairs formed through pair formation should be transferred to separate glass aquaria for brood stock development. The brood stocks need to be fed with wet feeds such as meat of green mussel, shrimp, clam and fish egg. These can also be feed with formulated feeds enriched with vitamins, minerals and algal powder at the rate of 10% of their body weight at an interval of every 3 hrs during day time. Apart from these, the brood stocks should also be fed with enriched rotifer 800 to 1000 nos/ml and artemia nauplii (200-400 nos/ml) and adult artemia (3 to 5 nos/ml) daily. It is found that provision of enriched live feeds apparently improved the egg quality and hatchability than the brooders fed with

non-enriched live feeds. Depending upon the production capacity and seed demand, several pairs can be maintained for commercial hatcheries.

Water quality parameter management

The sea water need to be filtered through a series of sand filters before being taken to the rearing tanks and following range of environmental parameters has to be maintained.

Temperature	:	26 to 30°C
Dissolved oxygen	:	4.8 to 6.3 mg/L
pH	:	8.0 to 8.3
Salinity	:	32 to 35 ppt

The water needs to be re-circulated to ensure better water movement and provide good water quality with the aid of a specially devised filter system during the period of rearing. Once in a week 25% of the water should be exchanged to avoid stress like a rapid increase in plasma cortisol concentration which will leads to Cushing's syndrome, depression of gonadal steroidogenesis and subsequent gonadal atresia.

Substrate for egg deposition

It is essential to provide a suitable substratum, preferably tiles or earthen pots or shells of oyster or PVC pipes near to the host sea anemone. These objects act as a substratum for depositing eggs and it would make easy for the transfer of deposited eggs without any mechanical injury to the hatching tank.

Breeding and spawning

The gonad normally developed (IIIrd stage) within a period of 4 to 6 months of rearing in captivity under suitable rearing condition and proper feeding. Few days prior to spawning the fishes shows breeding behaviour, as the male select a suitable site near to sea anemone for laying the egg and clear algae and debris with its mouth. On spawning days, brooders spend considerable time for cleaning the egg deposition site which indicates that spawning may occur within few hours. Under laboratory condition, the spawning can be obtained at day time (0500 hrs to 1530 hrs).The spawning lasted for one hr to one and a half hour. Each female lays 300 to 1000 capsule shaped eggs at every 12 to 15 days interval depending upon the species of clown fish, size of fish and previous experience. Generally the egg size of clown fishes ranges between 1.5 mm to 3.0 mm in length with a width of 0.8 to 1.84 mm. The eggs were adhered to the substratum with a stalk. An average of two spawning per lunar month per pair resulting in an estimated annual fecundity of 7200 to 24000 eggs/ breeding pair/year can be obtained under laboratory condition.

Parental care

The parents were allowed to remain in the spawning tank till the eggs get hatch out. During these period, both male and female carefully looked after the eggs during day time *viz*. fanning by fluttering the pectoral fins and mouthing to remove the dead or weakened eggs and dust particles. Male took all responsibility for caring the eggs and spent a higher percentage of time at the nest than the females,

which increased up to 70% of time at final hatching period. When incubated at a water temperature range of 27 to 29° C, the hatchling emerged on 7th day of incubation (168 hrs) and peak hatching took place shortly after sunset.

Colour variation of eggs:

0-2nd day	:	white to bright orange
3-5th day	:	black
6th day	:	Slight Silvery
7th day	:	Fully Silvery

On the final day of hatching, the glowing eyes of the developing larvae inside the egg capsule were clearly visible.

Hatching

The eggs of clown fishes usually hatch from 6 to 8 days depending on the water temperature (26 to 33°C). On the expected day of hatching, two hours before sunset, the eggs along with substratum were transferred from the spawning tank to the hatching tank (1000L). Complete darkness in the tank normally accelerates the hatching process. The larvae broke the egg capsule and the hatchling emerged from the egg as tail come out first. Normally the hatching occurred soon after sunset and the peak hatching took place between 1900 to 2030 hrs in darkness.

Methods for larval rearing

The newly hatched larvae measured 3 to 4mm in length, transparent body, large eyes, visible mouth, and a small yolk sac and observed to be remaining at the bottom of the tank for a few seconds before free swimming. The larval rearing can be carried out under green water system and feeding with super small rotifer *B. rotundiformis* and newly hatched artemia nauplii. The larval period of clown fishes generally last for maximum of 20 days and after 20th day of hatching most of the fry resembles juvenile fish. They began to shift from partially pelagic to epibenthic and started eating minced shrimp, fish flesh, mussel meat, clam meat and formulated diets. The larval rearing of clown fishes can also be carried out in three ways (i) Same tank or parental (spawning tank) method (ii)Transferring of eggs to hatching tank and subsequent larval rearing, (iii) Transferring of larvae to the larval rearing tank.

Larval feeding

Many of the larvae had only little quantity of yolk material and it starts exogenous feeding within few hours after hatching. As the mouth gape of clown fish larvae is between 80- 123 µ, the larvae need to be fed with live feeds measuring less than 100µ to ensure sufficient feed intake. The successful feeding strike is low at first feeding but rises rapidly during early developmental stages of fishes. At this stage provision of suitable size and nutritionally adequate enriched feed in high density is one of the important factor for their survival as the larvae could be able to accept only small sized organism due to the small mouth gape, and if they do not encounter and successfully capture food before depleting their energy reserves, the larvae may starve and it may eventually lead to mortality. All the rearing

tanks need to be provided 24 hrs light up to 20 days of post hatch (DPH). During this time the larval tank must be kept very clean by siphoning the bottom detritus, dead larvae, faeces etc. twice a day. Water exchange also needs to be carried out at a rate of at least 25% per day.

Feeding schedule of larvae of clown fishes

Stage 1: Enriched the rotifer with algae from Day 1st to 8th day.

Stage 2: The hatched enriched artemia and rotifer algae/ enrichment media from 9th to 20th days.

In order to gets successful prey capture of larvae, 50-100 numbers ml^{-1} super small rotifer (*B. plicatilis*) having size 60 to 100 µ need to be provided after enrichment with vitamins and fatty acids.

Rearing conditions

The maintenance of high water quality is possibly the critical factor when larval rearing of clown fishes or any marine fishes is done under controlled condition. As a measure for this, the sea water needs to be filtered through a series of sand filter tanks before being taken to the larval rearing tank. However during larval rearing it was found that the period from 3rd to 8th day of post hatching (dph) was very critical due to the alteration or change in feeding (exogenous) whereas once the larvae of clown fishes completed 8 days after hatching, no further mortality was observed.

During the larval rearing period, in all tanks, the environmental parameters were maintained as follows:

pH	:	8.0 to 8.3
Temperature	:	26 - 30° C,
Dissolved oxygen	:	5.5-7.8 (mg/L)
Salinity	:	32-35 ppt.
NH_{4+}/NH_3 and NO_2	:	0 mg per L
NO_3	:	Below 0.2 mg /L.

Light intensity

Low intensity light needs to be provided by hanging 2 nos. of 60 watt bulb or night lamp at a height of 15-20 cm from the surface of water level in rearing tank for 24 hours from 0 day to 20th day which enabled the larvae to detect and capture its feed and it also helped them to swim towards the surface at night rather than sinking to the bottom which otherwise show high mortality in night time.

The tanks were cleaned with cotton and magnetic tank cleaner to remove the dust and slimy coat forming inside the tank once in 2 days, and 25 % water is replaced with same amount of filtered sea water along with enriched rotifer and artemia and micro algae.

Juvenile rearing and feeding

On 19-20 dph, the larvae became juvenile of clown fishes and shift from pelagic to epibenthic stages, and look like a miniature of adult fishes. The rate at which the young fish grows depends on the

size of the rearing tank, stocking density, quality and quantity of food given and the water temperature. As the clownfish exhibit social hierarchy, dominant clownfish will grow faster and will suppress the growth of the fish below its hierarchical order. However this can largely overcome by growing all juveniles together in a large tank with sufficient host anemones or culling the juveniles to several groups in different juvenile rearing tanks of size 250 to 1000 L capacity fitted with biological filters. At this stage, the stocking density need to be reduced to 90 -100 numbers of juveniles (size range between 8-10 mm) with single host sea anemone in glass or perspex tank of 100 L capacity for initial 1 to 2 months rearing. During juvenile stages, the fishes show different banding pattern and growth rate, and on attaining a size of 24 to 35 mm in total length (TL), the stocking density need to be reduced to 30 to 50 number with single sea anemone in 100 L tank with 80 L bio filtered sea water until marketing. In the case of each 500 L FRP tanks, 130 to150 juveniles can be reared with 1 to 3 sea anemones.

In the juvenile rearing, a survivability of 100% was obtained through feeding with different wet feeds: mussel meat, prawn muscle, fish eggs and minced flesh of trash fish at the rate 15 to 20 % of body weight. Apart from these, artemia nauplii or brackishwater cladocera *Diaphanosoma celebensis* (10-15 numbers/ml) and rotifer (*B. plicatilis*) 50 - 55 nos/ml were given after enrichment with brown algae (10^4 cells/ml) and green algae (10^6 cells/ml) with cod liver and fat soluble Vitamin A, D, E, K twice daily which helped to retain the colour of fishes.

Packing and Transportation

Fishes are starved for about 1 day before being exported or transported. A small quantity of tranquilizer (depending upon the size and species) dissolved in fresh water can be added to the packing sea water to for longer journeys. Packing starts just prior to the transportation. Fishes are packed with oxygen and a little water either singly or multiple in double polythene bags to ensure that fish are not stranded without water. Polythene bags are packed in cardboard boxes for short journeys and for long journeys they are packed in Styrofoam boxes with some ice packs to keep the temperature down. Layers of paper may be inserted between plastic bags in the box to avoid catching sight of aggressive species. Packaging methods have improved considerably over the years mainly due to feedback from the customers and many exporters now guarantee almost 100% survival for most destinations.

Difficulties

1. Head-butting syndrome is one of the critical problem encountered during the larval rearing due to the immature development of the retina and subsequent hitting of larval head to the sides of the tank. In order to reduce this, all the 4 sides of the tanks were covered with black cloth or painted black to avoid reflection of the light.
2. Anorexia
3. Growth hierarchy
4. Gonadal atresia
5. Bleaching of anemones

Coastal Aquaculture in India

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Aquaculture is the culture of aquatic organisms in captivity for human uses. It can be defined as the high-density production of fish, shellfish and plant forms in a controlled environment. The modern fish culturists employ both open and close systems to raise fish. Open systems, such as, the cage culture and raceways are characterized by rapid turnover of water. Closed systems are common place in pond culture of carps, catfishes, tilapia, sea bass, prawn and shrimp among others. Closed aquaculture systems do not have rapid turnover of water, or a high surface to volume ratio facilitating exchange of gases, nutrients, energy etc. with the surroundings.

As the second largest country in aquaculture production, the share of inland fisheries and aquaculture has gone up from 46 percent in the 1980s to over 85 percent in recent years in total fish production. Freshwater aquaculture showed an overwhelming ten-fold growth from 0.37 mt in 1980 to 4.03 mt in 2010; with a mean annual growth rate of over 6%. India's aquaculture production basically can be classified into freshwater, brackish water and mariculture production. The coastal aquaculture comprise of brackishwater and mariculture in the inshore waters.

Brackishwater aquaculture

Brackish water aquaculture in India is concentrated around the giant tiger prawn (*P.monodon*) as the single most important species. Mainly the shrimp farming utilizing semi-intensive culture practices mainly with giant tiger prawn at stocking densities of 0.1 – 0.3 million/ha. With the provision of a high protein diet, water exchange, aeration and improved health management, production levels of 4–6 t/ha have been obtained with 4–5 months. Recently, the culture of exotic, whiteleg shrimp, *Penaeus vannamei*, has attracted the farmers because of its fast growth, low incidence of native diseases, availability of Specific Pathogen Free (SPF) strains and culture feasibility in wide salinity ranges. With the production levels of 10–12 t/ha/crop of 3-4 months the production has reached to a level of 10,470,516 t during 2012–13.

Mariculture

Mariculture in India, although limited to the farming of mussels and edible oysters undertaken in some coastal regions of Kerala over the years, has successfully produced sea cage farming in recent years, initially with seabass and most recently with cobia,pompano, groupers and carangids. Since the last decade, considerable changes have taken place in the diversification and production of mariculture in India.

As far as marine fish farming is concerned, culture of *Lethrinus* sp, *Epinephelus* sp, *Mugil cephalus*, *Chanos chanos*, and *Etroplus suratensis* has been tried, either in monoculture or in the integrated systems. Pen and cage culture of finfishes has been tried, and leading to commercial semi-intensive farming in the country. Success has been achieved in the broodstock development and seed production of Cobia, Silver Pompano, grouper, *Epinephelus tauvina, Lates calcarifer* and Indian pompano.

Different types of culture practices

The level of management practices can make a fish farm to be extensive or intensive system. Depending on the level of management inputs, especially in feeding, fertilization and liming, pond culture systems can be classified as extensive, semi-intensive or intensive.

Extensive: When food base in a pond is exclusively naturally occurring without supplementation, either by feeds or fertilizer, the culture system is an extensive one. This practice is popular with small-scale producers.

Semi-intensive: In this system, there is occasional supplementary feeds addition and natural productivity is augmented with manures.

Intensive: This demands a higher level of management input. Feeds and fertilizers are intensively applied following appropriate recommended rates. Suitable liming materials like agricultural lime are also applied to stimulate productivity and disinfect the pond from parasite and diseases. Fish grow very fast when intensively managed and grow least in extensive management. Most commercial farms adopt this approach.

Hyper-Intensive: This system demands the highest level of management inputs. The culture environment is completely under control. Feeding is totally with highly formulated pellets. Mechanical and automated feeders are used. The main features are intensive re-circulatory with bio-filtration tanks. Highest fish yield obtained in this system.

When species combinations are taken into consideration, culture systems can be either monoculture or polyculture systems.

Fish farming in cages

Cage culture involves growing fishes in existing water resources while being enclosed in a net cage which allows free flow of water through it. It is an aquaculture production system made of a floating frame, net materials and mooring system (with rope, buoy, anchor etc.) as a round or square shape floating net pen to hold and culture large number of fishes and can be installed in reservoir, river, lake or sea. Economically speaking, cage culture is a low impact farming practice with high economic returns and with least carbon emission activity. In view of the high production attainable in cage culture system, it can play a significant role in increasing fish production. Cage culture is presently undergoing great innovations in response to globalization and the growing demand for aquatic products. The design of the cage and its accessories can be tailor-made in accordance to the individual farmer's requirements. HDPE frames installed in open unprotected waters like sea can withstand severe wave conditions.

Round cage (volume depends on diameter) with floatation system made of butt-welded HDPE pipes, designed for the culture of fishes such as milkfish, mullet, cobia or pompano, sea bass, lobsters etc. are experimented and used in many countries including India.

Asian sea bass is a potential candidate species in India for rearing in floating cages because of its high demand and rapid growth, ability to adapt to varying environmental conditions and its demand in domestic as well as export markets. The best method of sea bass culture is the cage culture due to its nature of competitive feeding and corresponding fast and uniform growth in high densities in cages in which other energy inputs are very less than any other culture systems urge the farmers to do cage culture of sea bass in the open water systems. The important factors determining the success in sea bass culture in cages are the availability of quality seeds, commercial feed availability and easy culture technology and all these are available sea bass has been cultured successfully in cages in India since 2008. Presently cage culture of finfishes are greatly accepted and adopted by many marginal farmers and entrepreneurs in the country especially in the state of Kerala where it is growing in an unpredictable manner.

Site selection

Selection of a suitable site is most important factor in the case of any culture especially in the open sea cage culture because it determines investment, running cost and mainly the ultimate success. A calm bay or inbound sea with good water flow and with sandy or rocky bottoms should be selected as an ideal culture site. In the case of cage culture, most cage sites have been placed in relatively sheltered waters but there are a finite number of such suitable sites. But most of the times such an ideal area may not be available in most of the places. However, the future is in the open sea cage culture is likely to be further offshore, as the coastal waters limitations when the same develop as an industry and scarcity of water bodies. For site selection, a pilot survey has to be conducted prior to the commencement of cage farming. The water and sediment quality parameters of the proposed sites should be determined prior to the culture to meet the standard requirements. So we can take the factors one by one and find out the most suitable area in our locality.

- The **depth** should be sufficient to keep the nets clear of the sediment and allow water exchange beneath the nets. Otherwise we have to adjust the length of the nets according to the depth of the water column.
- Good **water exchange** is important in cage culture to replenish oxygen and flush away wastes.
- **Tidal amplitude** is found to have great role in making daily water currents and pulling effects on the cages will be very high especially during the full and new moons. The ideal is 1 – 1.5 m or less than that.
- Knowledge of the **wave action** at a potential site will help for the selection of a proper cage and mooring technology for the site.
- The **wind velocity** of the site must be less than 30 km h^{-1} during culture period.

- **Water quality factors** such as temperature, salinity, pH, suspended solids and the presence of algal blooms can potentially influence the growth and survival of the cultured fish.
- **Bottom characteristics** also have some role in the site selection as sandy and rocky bottom is good than muddy.
- Sources of **pollution** which can negatively impact on water quality.
- **Weather** is also another important factor in determining the suitable site for cage culture as they can impact on both the cage structure and enclosed fish.

Cage fabrication/HDPE Item specifications

a) Outer ring of cage frame made of 8 m dia high density poly ethylene (HDPE) pipe with 140mm /10kg/ cm^2 Polyethylene 100 grade material

b) Inner ring of the frame made of 6m dia HDPE pipe with 140mm/10kg/ cm^2 PE 100 grade material

c) Middle ring (cat walk) of the frame made of HDPE pipe with 90 mm/10 kg/ cm^2 PE 100 grade material

d) Base supports are 250 mm diameter with perfect fixing with running pipes

e) Vertical supports are 90 mm, 0.8 m height, and top-railing complete circle with 90 mm HDPE pipe, with suitable T- joints. T- Joints are fixed with fusion welding and provided with 2", SS hooks, fixed with hand railing to fix the bird net.

f) Diagonal supports 8 in No. are 90 mm dia, connecting with middle ring (cat walk) and top-railing, besides the vertical joint, fixed with fusion welding as well as with SS bolts and nuts

g) Two Solar Blinkers are provided for night visibility of the structure. They are water proof, shock-resistant and with red colour blinking lights.

h) Flag Posts 2 m high of HDPE are provided, with alternate vertical support, fully bolted to vertical support.

i) Buoys used in sea are 350 mm diameter, 10 kg pressure, filled with PUF, with 16 mm iron rod bending ends into 2-4 rings (3 inches).

j) Mooring clamps: 14 mm, 4 inch mooring clamps, completely fixing with 140 mm outer ring, flexible to open and close, with suitable bolt and nuts, are with provision for linking the 12 mm long link chain.

Fabrication of the frame, welding, jointing, erection and floating of the cages can be done at site.

Nets

1. **Outer Net or predator net for protection from competitors and predators in open waters:** Braided HDPE net 3 mm/80 mm mesh size

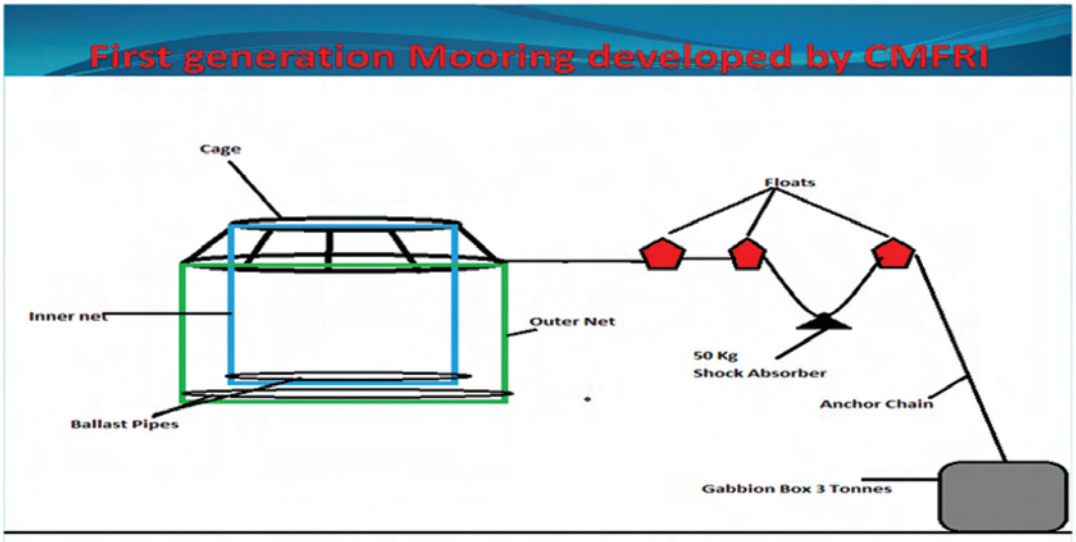
2. **Inner net for holding the fish:** Nylon / Sapphire/ HDPE with 15 -40 mm mesh
3. **Bird net**: With 1.25 mm/80 mm twisted HDPE/ nylon (Birds should be particularly prevented from cages because they prey on fish and are in many cases are carriers of disease agents and parasites)

For fish fry/ fingerlings are stocked for short periods in small meshed (6-10 mm mesh size) nets, nylon/ HDPE hapa nets can be used and its sizes varies from 2 mx 2 mx 2m (L x B x D) to 4m x 2 mx 2m.

Mooring

A system of moorings with a single fixed point in the seabed was used. This type of mooring system is relatively cost effective and easy to install. Instead of expensive anchors, the cost effective gabion box (3x1x1m polypropylene, Garware Wall Ropes, India) with 15 cm mesh filled with about 2.5 t of raw granite stones, was used instead of anchor weight. A 10 mm MS mooring chain of 30 m was connected to the cage frame using D-shackles. The swivel connected to the chain rotates the entire cage by mooring only at a single point. Tension on mooring cable was maintained by cylindrical HDPE floats (100 m^3 pressure) connected with a shock absorber of 100-150 kg, which in turn resists any pressure on the cage structure.

Single point mooring system: It is used in sea; here the cage can rotate 360° and mooring is done either by anchor or gabion box with granite pieces:



Present Single point Mooring Diagram of the Sea Cage

Pipes: Round GI pipes of 1 ¼ – 1 ½ inch diameter are usually using for cage fabrication; the required number of pipes (13 nos for 4 x 4, 18 nos for 6 x 6 and 22 nos for 9 x 4) has to be procured from the market cut according to the measurements as marked in the fig.

Cage frame/ GI: GI frames can be of any measurement like 4 x 4, 6 x 6 or 9 x 4 according to the area or nature of the water body or our requirement; it can be square, rectangular or round (if it is for sea). The frames are be welded as a single unit or as dismantling types fitted with nuts and bolts and can be joined at the culture sites. The whole structure has to be painted with marine epoxy primer and paint and allow dry properly before mooring.

Drums for flotation: Minimum 8 numbers of 200 l plastic drums are required for a single cage for floatation; and it has to be tied to the frame as shown in the picture.

Nets: Two nets are required at a time for a cage to hold the fishes while doing grow out culture.

Fixed mooring system: It is used in lakes, rivers or back waters where two directional water flows prevails. It uses poles in shallow areas; whereas anchors in deeper waters. Mooring will be on both the sides; so that cages will be protected and keep in place if water flow in both the directions happens consequently mainly due to tidal influx.

Candidate species

Fast growing and high value species are the best suited species for marine cage culture. A number of species are already grown commercially in cage culture overseas and notable examples are rainbow trout, brown trout and Atlantic salmon. Cobia *Rachycentron canadum*, groupers and Asian sea bass *Lates calcarifer* and juvenile lobsters are the potential fish species for India due to its high market demand, better growth rate and seed availability. Hatchery technology is available for sea bass; in the case of lobsters the juvenile fishery is prevalent in the Indian coast as it fetches high price. The prospect of developing commercial interest in lobster farming in India seems bright due to the substantial increase in price consequent upon heavy demand from export market. To support and sustain this situation, research on conservation, seed production and sustainable capture based lobster farming in India needs to be further strengthened. Fattening of lobster juveniles in the sea cages is very advantageous as the juveniles will get a chance to grow, mature and spawn in the cages. As it grows well in short duration with high feeding the entrepreneur also gets more income. As its fishery is in live condition a better co-ordination can increase the production and it helps in the conservation of the species at the same time. A variety of ornamental fishes, shrimps and mollusks can also form candidate species for cage aquaculture.

Stocking of fishes in cage

The minimum recommended stocking density for common carp, tilapia, and catfish is 80 fish /m^3. A recommended maximum stock density for beginning farmers is the number of fish that will collectively weigh 150 kg/m^3 when the fish reach a predetermined harvest size (Schmittou, 1991). The smallest recommended fingerling size for stocking is 15 g. A 15-g fish will be retained by a 13-mm bar mesh net. Survival rates in well-placed and well-managed cages are typically 98 to 100 %. An example of how to calculate the number of fish to stock per cage follows: Assume that a farmer wants harvest fish weighing 500 g from a 1-m^3 cage.

Total fish weight at harvest = 150 kg/m^3

Number to stock = 300 fish (300 x0.5kg)

Desired average fish weight = 0.5 kg at harvest

Production = 150 kg/m^3

For a harvest of fish averaging 200 g, the number of fish to stock would be:

Number to stock = 750 fish/m^3

0.2 kg x 750 = 300 kg/m^3

The carrying capacity of a body of water limits the weight of fish that can be cultured. Stocking so many fish that the carrying capacity is exceeded will result in increased stress, disease, and mortality, and reduced feed conversion efficiency, growth rate, and profit.

Grow out of the sea bass culture starts as it transfers to the cages from the nurseries. Juveniles of sea bass reared in the nurseries of size 10 - 15 cm in length (25 – 50 g in wt) can be transferred to the cage for the grow-out. The stocking density in the cages varies from 20 – 25 kg/m^3 in the final harvest time. So with a final weight of expectation of 1 kg fishes in harvest time after a period of 6 – 8 months; from the cages the stocking density varies from 25 – 30 fishes / m^3 for the sea bass. Care must be taken to avoid handling stress and other physiological stresses as maximum as possible while transport and stocking.

Fishes farming in ponds

Commonly raised species in freshwater ponds are the carps, tilapia, catfish, snakehead, eel, trout, goldfish, gouramy, trout, pike, tench, salmonids, palaemonids, and the giant freshwater prawn *Macrobrachium*. In brackishwater ponds, common species include Pearl spot (*Etroplus surratensis*), mullet (*Mugil* sp.), milkfish (*Chanos chanos*) and the different penaeid shrimps (*Penaeus monodon, P. orientalis, P. merguiensis, P. penicillatus, P. semisulcatus, P. japonicus,* and *M. ensis*). The more popular species for culture in marine cages and/or ponds are the Sea bass, Cobia, Pompano, Grouper, Red sea bream, Rabbitfish and marine shrimps.

Traditional culture of grey mullets *Mugil cephalus* & milk fish *Chanos chanos*

In India two major cultivable fin fishes, namely, mullets and milk fish have been used in the traditional culture practices and also in the scientific culture of fin fishes in ponds and pens. Among mullets, the striped mullet *Mugil cephalus* is a fast growing species and is commonly available on the east and west coasts of India. It is also an important table fish and has a good market in the markets of our country.

Suitability of the species for cage farming:

- Ability to live in varying genre of water resources.
- Ability to adapt in crowded conditions and in mixed culture.

- Good growth rate.
- High survival rate of young ones.
- Delicious and good flavor.
- Ability to feed from natural sources as well as formulated feeds
- High market demand

Seeds

Most of the flathead grey mullet fry used in commercial aquaculture are collected from the wild. During the late summer months adults migrate to the sea in large aggregations to spawn. Fecundity is estimated as 0.5–2.0 million eggs per female, depending upon the adult size. Hatching occurs about 48 hours after fertilization, releasing larvae approximately 2.4 mm long. When the larvae are 16–20 mm, they migrate to inshore waters and estuaries, where they can be collected for aquaculture purposes during late June to early September. Shoals of fry are collected by fine seine nets, transported in seawater to hapas or shore. They are then transported by trucks to separate nursery units, or nursery facilities in grow-out farms.

Pond preparation

Prior to culture ponds are to be prepared by drying, ploughing and manuring with 2.5 – 5.0 t/ha of cow dung.Ponds are then filled to a depth of 25 – 30 cm and kept for 7 -10 days – for natural feed build up. Increase water level to 1 -1.5 m and finger lings are stocked. Productivity has to be maintained at the required level – Chicken manure / chemical fertilizers.

Nursery rearing

The nursery pond comprises about 1-10 % of the total area. The most suitable place is where it can be easily supplied with fresh unpolluted water at all times and at elevation where it can be readily drained even during ordinary low tides. Water depth should be 15 to 25 cm. A manageable area ranges from 0.01 to 0.25 ha.

Feeding areas, corners and side ditches in the pond has to be properly tiled and dried to avoid the formation of black soil. The average water pH of 7.5-8.5 would be ideal for pompano farming. The level of lime application during pond preparation depends on the pH of the soil. Hence, the dosage has to be calculated accordingly. Water filling has to be initiated by covering the inlet pipe by using 2 layers of fine nets (100 micron) to avoid introducing other fishes and predators. A week before stocking, the pond must be fertilized with either organic or inorganic fertilizers to stimulate the plankton bloom.

Grow-out techniques

Culture of flathead grey mullet are usually done in polyculture in semi-intensive ponds and netted enclosures in shallow coastal waters. Mullet can be polycultured successfully with many other fish, including common carp, grass carp, silver carp, Nile tilapia and milkfish, and can be reared in freshwater,

brackish water and marine water. Prior to stocking, aquaculture ponds are prepared by drying, ploughing and manuring with 2.5–5.0 t/ha of cow dung. Ponds are then filled to a depth of 25–30 cm and kept at that level for 7–10 days to build up a suitable level of natural feed. The water level is then increased to 1.5–1.75 m and fingerlings are stocked. Productivity is kept at the required level by adding chicken manure and/or chemical fertilizers. Optimal dissolved oxygen is maintained by the use of various types of aerators, especially after sunset. Extruded feed is supplied to semi-intensive ponds to cover the feeding requirements of both carps and tilapia grown in the same ponds.

The growing season is normally about 7–8 months. If mullet are monocultured, manuring may be sufficient to reach the required feed level. Growth is checked by sampling, and if growth rates are not as expected, rice and/or wheat bran is added daily in amounts of 0.5–1 percent of biomass to supplement the natural feed in ponds. When mullet are reared in polyculture, they are usually stocked with tilapia, common carp and silver carp. In this case, feeding and fertilization programmes are usually targeting the other cultured species and the mullet feed on the natural feed, detritus and feed leftovers. Acclimatized to the appropriate salinity, and stocked as 10–15 g individuals at 6 200 –7 500/ha, a harvest of 4.3–5.6/tonnes/ha/crop can be obtained. In semi-intensive polyculture with tilapia and carp, mullet fingerlings are stocked at 2 500–3 750/ha together with 1 850–2 500/ha of 100 g common carp juveniles and 61 750–74 000/ha 10–15 g Nile tilapia fingerlings. Total harvests are typically 20–30 tonnes/ha/crop, of which 2–3 tonnes are mullet. After an on-growing season of 7– 8 months in either culture systems in the subtropical region, flathead grey mullet reach 0.75–1 kg; if kept for two on-growing seasons, they reach 1.5–1.75 kg each. Rearing for a second year depends on the market requirements; in some countries mullets are marketed at a size of 1.5 kg and larger. The two seasons are continuous until they reach that size. As usual, the choice of rearing technique depends on market demand and economics. In monoculture, mullet feeds on natural food and on the by-products of grain mills and rice polishing plants. In polyculture, manufactured extruded pellets are produced either in feed mills specialized in the production of fish feed or, in many cases, in chicken feed mills that have a line for fish feed production. Feed is formulated according to the dietary requirements of the major cultured species (i.e. tilapia and common carp).

Milk fish Chanos chanos

Attributes for aquaculture

- Omnivorous species and feeds on cyanophyta, diatoms and other similar food items.
- Can be grown in monoculture or in polyculture with other finfishes and crustaceans.
- Wild fry occurs in the tropical and sub-tropical seas.
- Technology for nursery and grow-out in ponds, pens and cages in fresh, brackish and marine environment is developed.
- Artificial feeds for intensive farming have been developed.
- No known occurrence of disease outbreak in aquaculture.

Seed: Under natural conditions, larvae and fry migrate inland, seeking tidal pools. They settle in

them for 1 month until they become juveniles, then migrate into lagoons, lakes and shallow waters. Larvae for aquaculture can be collected from brackish waters such as shallow areas, mouths of rivers, and lagoons. Intensive milkfish farming depends heavily on hatchery bred fry.

Nursery: Nursery ponds are prepared by sun drying, liming and application of organic and inorganic fertilizer to enhance growth of benthic algae (lab-lab). Supplemental feeding with rice bran and other feedstuff is often done. Fry are stocked in 1–5 hectare nursery ponds, at the rate of 30–40 fry /m^2, for 30–45 days. Densities are reduced as the fish grow. Some are directly stocked in grow-out ponds and the rest go to transition or stunting ponds at 15 fingerlings /m^2 for 6 months to about a year.

Grow-out: A grow-out can be square or rectangular in shape constructed in series design with independent water supply / drain gate / canal system. Sluice gates can be made up wood or concrete. The pond bottom must be leveled flat but inclined towards the gate for convenient water management and easy harvesting stocks. Comparatively, lab-lab excels over other food types in milk fish culture. When it comes to raising milkfish Lab-lab is local term benthic algal communities which consist of yellowish – greenish minute plants and animals that form a mat on the pond bottom. They are sometimes detached and float in clumps or patches. There are different types of grow out systems are practicing in different parts of the world.

***Shallow water culture*:** In the traditional culture method, milkfish are cultured in shallow (40–60 cm) brackish water ponds of 2–50 hectares. Water exchange is tidal. The growth of benthic algae is encouraged through photosynthesis and fertilization. Other natural foods like filamentous algae (lab-lab) may be resorted to, but yield is less compared with lab-lab. Stockingdensity; varies from 2,000-3,000 fingerlings (5–10 g)/ ha; 1–2 crop/year; and yield 1 - 1.5t/ha/yr.

Deep water culture: Milkfish are cultured in ponds, with a depth 80–110 cm and area 1–10 ha; usually stocking; 3,000–4,000 (5–10 g)/ha. Production: 1–2 t/ha/yr. Water exchange is tidal.

The modular system: Allows 6–8 crops/yr. with yield of 2–4 t/ha/yr. The growing fish are moved through three adjoining ponds of increasing sizes, at the ratio of 1:2:4 or 1:3:9. Ponds are prepared by the lab-lab method of growing natural food. Water exchange is tidal. The program involves pond preparation, stocking, transfer & harvest in regular intervals. To sustain year-round production, an inventory of fingerlings, organic and inorganic fertilizers, and organic pesticides needs to be maintained. Increased productivity can be gained through culture in deep ponds (0.1–1.5 m) using paddle wheel aerators, feeding machine and water pump to increase primary productivity. At the minimum stocking density of 8,000–12,000 fingerlings/ha, production of 4–6 t/ha/yr can be attained. At the highest density of 30,000 fingerlings per hectare, yield is 12–15 t/ha.

Pond Preparation: Drain the pond completely and allow it to dry for about 1-2 weeks until the soil cracks. Do not over dry because prolong drying is not advisable as it makes the soil hard and powdery. Eradicate unwanted species using organic pesticides such as combination of ammonium sulfate fertilizer and agricultural lime. Prepare a mixture of hydrated lime and ammonium sulfate fertilizer (21-0-0) at a ratio of 3:1 at a rate of 100-grams/1000 m^2 and broadcast it in wet waters of pond bottom during sunny

days. The mixture releases heat and ammonia, which effectively kills unwanted species in the pond. Fertilize the pond by applying chicken manure at 2 tons per hectare. Fill the water to depth barely covering the pond bottom and broadcast urea (45-0-0) at 15 kg/ha, 2-3 days later to speed up the breakdown of chicken manure. Increase the water depth gradually over a period of half – one month at 3-5 cm from time to time until the stocking depth of 0.8-1.0 meter. An abrupt increase in water depth will cause the lab-lab to detach and float. Install fine-mesh screens at the water gates to prevent re-entry of unwanted species and the possible escape of cultured species. Initial size of stocking is being done with average weight of 80-100 grams from reliable source.

Stocking and management: Fingerlings are normally held in hapa a few hours before stocking. Stocking should be done during the cooler part of the day. Slowly release the fingerlings to the pond at the density of 50,000 fingerlings/ha per crop.When lab-lab starts to get overgrazed, apply inorganic fertilizer (16-20-0) at 50 kg/ha every 1-2 weeks. Provide formulated diets 5% of the body weight/day. In designated area, broadcast or use feeding tray to condition the fish to eat pellets for a week. Water management can be either tidal or with the aid of water pump. Maintain the optimum water condition for both the fish and natural food. When using lab-lab food base, apply fertilizer (16-20-0) at the rate of 50 kg /ha, divide into small doses and apply every 12-15 days. As much as possible coincide the fertilization during the spring tide cycles. Replenish about one-third of the pond water before any fertilizer application. During hot months, increase the frequency application. During rainy months, drain the uppermost freshwater layer in the column to prevent the occurrence of salinity fluctuations. In the middle of the culture period, lab-lab may be prematurely depleted because of overgrazing, poor water conditions. Provide supplemental feeds at a rate of about 5% of the average body weight of the fish per day using commercial feeds. This phenomenon is characterized by the presence of fish at the water surface gasping or swimming in circles. These are indications of stress associated with sufficient dissolve oxygen (DO) concentration. Replenish water at the first opportunity stress associated behavior of the fish. The water may be splashed to increase oxygen concentration in the pond. To attain the highest possible profit, culture period should be about 60 days. Yield is up to 2.0-2.5 tons/ha./crop which is equivalent to 6.0-7.5 tons/ha/ year for 3 cropping. Milkfish are normally harvested at sizes of 20-40 cm (about 250-500 g).

Asian seabass *Lates calcarifer*

Extensive culture of sea bass as a traditional activity is followed in the Indo-pacific region. In low lying coastal ponds, juveniles of assorted sizes collected from estuarine areas are introduced and fed with the forage fishes like tilapia, shrimps and prawns available in these ponds. These ponds receive water from adjoining brackish water. Harvesting is done after 6-8 months of culture. Since sea bass exhibit differential growth, the size of the harvested fishes varies from 0.5 to 5.0 kg. Production up to 2 ton/ha/7-8 months has been obtained.

The two-week nursery reared fingerlings are suitable for pond culture. Seabass culture in ponds can be carried out either by poly-culture method or by feeding with low cost fishes like tilapia/oil sardines or with extruded floating pellets. The pond is at first dried, tilled, leveled and manured with raw cow

dung @ 1000 kg/ha. If required, lime is added @ 50-200 kg/ha to maintain soil pH above 7. Urea @ 100 kg/ha and super phosphate @ 50 kg/ha can also be added to enhance the algal bloom. Sea water/fresh water is then filled to a depth of 60 – 70 cm in the pond. When the pond water becomes light green in colour indicating sufficient development of algae in the pond, forage fishes are introduced. In pond culture, stocking with seed of uniform size (5-10 g), @ 3000-5000/ha is desirable. Feeding of fish is carried out following two methods. In the first method, the fish are fed exclusively with chopped trash fish @ 10% of biomass twice daily (08.00 & 17.00 hrs) and reduced to 5% subsequently. In the other, the food is made available in the pond in the form of forage fish like Tilapia. Pelletized feed can also be given. In a well-prepared pond, manured/fertilized with raw cow dung @ 1000-1500 kg/ha and urea @ 100-150 kg/ha, Tilapia adults (male and female in 1:3 ratio) are reared for 1-2 months prior to stocking with seabass. To maintain natural food production for the forage fish, periodic manuring at fortnightly interval is done @ half the initial dose. 20% of pond water is exchanged on alternate days. Harvesting is done by draining the ponds or by using seine nets. Grow-out pond culture of seabass can yield a production of 2-3 tons/ha within a rearing period of 7-8 months.

Pompano culture

The culture of pompano has been successfully established in many Asia-Pacific countries like Taiwan and Indonesia. The farming can be successfully carried out in ponds, tanks and floating sea cages. The species is pelagic, very active and is able to acclimatize and grow well even at a lower salinity of about 10 ppt and hence is suitable for farming in the vast low saline waters of our country besides its potential for sea cage farming. The shape, colouration and meat quality of this fish is comparable with silver pomfret. In the international market, the dockside price of Florida pompano averaged to $ 8 /kg and in India, the current price of silver pompano is about Rs. 200/kg at the fish landing centers and around Rs. 250/kg in the retail markets.

Pond preparation: The pond has to be dried properly until the cracks appear on the surface. The top layer of the soil containing waste accumulated through previous crop of fish or shrimp has to be removed. Ploughing has to be done to tilt the soil below 30 cm. Feeding areas, corners and side ditches in the pond has to be properly tiled and dried to avoid formation of black soil. The average water pH of 7.5-8.5 would be ideal for pompano farming. The level of lime application during pond preparation depends on the pH of the soil. Hence, the dosage has to be calculated accordingly. Water filling has to be initiated by covering the inlet pipe by using 2 layers of fine nets (100 micron) to avoid introducing other fishes and predators. A week before stocking, the pond must be fertilized with either organic or inorganic fertilizers to stimulate the plankton bloom.

Nursery Rearing and Seed Stocking: Hatchery produced pompano fingerlings of 1 inch size can be stocked in hapas/ pens of 2 m length, 2.0 m width and 1.5 m depth. In each hapa about 200 fingerlings can be stocked. While stocking care should be taken to avoid agitation of the pond bottom and too many persons getting into the pond may increase the suspended solid load in the water, which may cause gill chocking of the fish fingerlings leading to mortality. Initially the fishes have to be reared in hapas for 60 days or until they attain 10 – 15 grams size and thereafter it can be released into the pond. The mesh

size of the hapa could be initially at 4 mm size and it can be changed with 8mm mesh size hapas after 30 days. The stocking density in happa could be maintained as 200 nos/happa. After attaining 30 grams size ideally 5,000 Nos. can be stocked in a one acre pond.

Pompano is a fast moving marine fish and it requires highly nutritive feed to meet the energy requirements. During nursery rearing Pompano can be weaned to any type of feeds viz., extruded floating pellet, sinking pellet feed and chopped trash fishes. Ideally pompano can be weaned to extruded floating pellet feed to avoid feed wastage and spoilage of pond bottom. The CMFRI has conducted pompano farming demonstration by using the extruded floating pellet feed manufactured by M/s. Rudhra Techno Feeds, Bhimavaram, Andhra Pradesh. During the happa rearing phase, feeding has to be done 4 times a day and in pond culture phase it could be 3 times a day. The feed size should be lesser than the mouth size of the fish and hence, suitable sized feed has to be selected for feeding the fishes.

Water Quality Management: Plankton bloom is essential for early stages of pompano (until 100 grams) culture. If the colour of the pond water is clear a mixture of organic (10-30 kg/ha.) and inorganic fertilizers (1-3 kg/ha) has be applied to obtain algal bloom. Sufficient water level must be maintained in the ponds. The water depth in the shallowest part of the pond should be at least 100 cm. Water quality can be maintained by exchanging 10% of the water once in a week; 20% per week after 3 months and 30% per week after 6 months. If water colour is too dark, the quantum of water exchange can be proportionately increased. To maintain water pH within an optimum range of 7.5 - 8.5, agri-lime has to be applied regularly. Dissolved oxygen (D.O) level should be maintained above 5 ppm at all times. During the entire culture period the growth pattern of pompano was monitored through regular sampling of fishes at fortnightly intervals.

Harvestingis normally carried out using drag net. To maintain the freshness and quality of harvested fish, washing in clean water and chill killing can be done. Harvested fishes can be stocked in plastic crates by adding layers of ice in equal quantities at the bottom and top of the fish. It is suggested that harvesting of fish can be carried out during the off season period of April to June to get a better price. It is well recognized that for sustainable production in aquaculture, diversification of species is a vital requirement and from the lessons learnt from the shrimp farming scenario in India, it is very much needed to diversify the marine and brackish water aquaculture with high value fin fish species. Generally, high value marine fishes are in good demand in the Indian market and often there is a scarcity of the same. In the domestic market, silver pompano has demand starting from 250 grams size onwards. Hence, it is felt that pompano aquaculture can prove to be much lucrative and emerge as a major aquaculture enterprise in the coming years.

Live feeds in mariculture

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Introduction

Marine finfish and crustacean aquaculture mostly depend on the hatchery production of fry and fingerlings. In nature, these larva basically feed small live organisms (live feed) around them. For hatchery production of fish or crustacean larvae, live feeds are essential. This can only be compared with mother's milk for a new born baby. Generally, larvae will survive only if it gets the right live feed at right time. Fish and crustacean larvae are evolutionary adapted for feeding live food organisms. In wild, breeding of many fishes synchronise with the higher availability of live food organisms. Successful larval rearing in hatchery primarily depends on the live feed. Most of the larvae are pelagic in nature and plankton form the most important component in the live feed culture. Size of the live feed is an important barrier when compared to the mouth size of larvae. Poor vision, improper digestive system and weaker movements make it difficult for the larvae to get proper nourishment. Some fish larvae (precautionary type) are with good yolk reserve and they start feeding comparatively developed stage while some others (atresial type) which start feeding at a smaller and lesser developed stage. Salmon, cobia and clown fish larvae are comparatively larger than grouper and damsel larvae. Larval feed should be smaller, easily digestible, rich in nutrients and allow autolysis. Formulated feed may not meet all these requirements and in most of the cases this will reduce the larval survival rate than live food. Moreover, the fish larvae have poor vision and less developed olfactory and digestive organs. Continuous movement of live feed in in the water will help the weaker larvae to prey upon these tiny organisms. Copepods, cladocerans, decapod larvae, rotifers and ciliates are the important live food organisms which form the food of fish larvae in the wild. Most popular zooplankton used as feed for fish larvae in fish hatchery are rotifers, artemia and copepods (Lavens and Sorgeloos, 1996).

The principle behind the famous saying- "no food can replace mothers milk" is true in case of live food also. No artificial feed can give right nutrition required for the fish larvae. Generally live feed like copepods are nutritionally higher and easily digestible even for weak fish larvae. Generally, live feeds are rich in proteins, essential fatty acids and amino acids, vitamins and minerals in the appropriate ratio and composition meeting all the requirements of fish larvae. But most of the cases, it become very difficult to identify and culture the required live feed for each species of fish. In general, artemia and rotifers are the popular live food organisms used for feeding most of the fish larvae. Mostly these may not meet the nutritional requirements of the larvae and additional enrichment is essential before feeding them. Green water technique is traditionally used for larval rearing of fishes and crustaceans.

Microalgae form the base of and base medium for most of the live feeds. The current status of live microalgae as feed is reviewed by Brown and Blackburn (2013). Microalgae are traditionally used to make green water for larval rearing of fishes and crustaceans. These are generally free living nanoplankton with a size range of 2-20µ. Stock and mass culture of microalgae using combination of fertilizers/ nutrients and culture media is already developed and popularly used in hatcheries throughout the world. Details of culture of microalgae are included as a separate session.

Rotifers

Rotifers (means: wheel bearers) are the most famous and commonly used live feed in marine fish hatcheries. These are omnivorous, microscopic aquatic organisms of the phylum Rotifera having an average size of 150ìm. Small size and potential to reach high densities in short time, make them an important live feed in hatchery rearing of marine fish larvae (Gopakumar and Jayaprakas, 2004). These are organisms with a complete digestive system and specialised organ systems. Rotifers can tolerate a wide range of environmental conditions. Rotifers are planktonic filter feeders; they feed on small organic particles directed to their mouth using a specialised ciliated apparatus (corona). Corona is the wheel shaped ciliated organ on the head region for feeding and locomotion.

Stable and reliable supply of rotifers is a vital factor in the marine fish larval rearing. Among many species, *Brachionus plicatilis* and *Brachionus rotundiformis* are the two major species of rotifers used in marine larviculture (Anitha and Rani Mary George, 2006). Previously both were considered as *B. plicatilis* "S type" and "L type". Further studies differentiated the "L type" as a new species and named *B. rotundiformis*. Strain selection for the mass culture is of great importance in the successful rotifer culture. However, the nutritional quality of the life feed primarily depends on the feed it consumes. For the survival and increased growth rate of fish larvae, poly unsaturated fatty acids including EPA, DHA and arachdonic acid are essential. Therefore, the feed source of rotifers also should contain these essential fatty acids. Rotifers are usually cultured in hatcheries using algae or and baker's yeast. The wide range of feed choices makes the rotifer culture easy and approximately 1g of yeast is sufficient to feed a million rotifers for a day. Excess feed always make contaminations and ammonia formation.

Culture conditions affect the density of the rotifer culture. Among the external factors, pH and temperature plays an important role in rotifer culture. The optimum pH for rotifer culture is about 7.5 – 8.5. Rotifers can be easily collected from stagnant water bodies including brackish water using 50 - 100µm mesh. Pure culture can be initiated from the microscopically isolated individuals using water with the same salinity and temperature of the source. Stock cultures can be maintained in considerably smaller quantities and can be used for long periods (Dhert, 1996). Stock culture is prepared using sterile sea water with 4 – 6 rotifers per ml of sea water, the culture is replenished with algal feed every two days and the whole culture is renewed in 7 – 10 days. The culture can be reconstituted when they reach 200-300 individuals per ml, the entire culture can be sieved through 200µm and 50µm mesh serially to avoid algal or other debris. The collected rotifers in 50 µm mesh can be redistributed in fresh containers to start new culture. Dissolved oxygen levels of rotifer culture media should be maintained above 4ppm and in cultures with pure oxygen supply instead of normal aeration, the number of rotifers will increase

considerably. Six parameters including egg ratio, swimming velocity, ingestion rate, viscosity, enzyme activity and diseases are the factors deciding the health status of rotifer culture. The nutritional quality of the rotifers is not enough to meet the nutritional requirements of fish larvae. So it is necessary to enrich the rotifers before feeding to fish larvae.

Rotifers can reproduce sexually and asexually and for most of the species parthenogenesis is more common. The quality and quantity of available feed, temperature, salinity and density of the culture affect the formation of male individuals. In the absence of male the amictic phase (parthanogenesis) occurs and on other hand in the presence of male initiates the mictic phase results in the formation of males and resting eggs. Resting eggs are diploid and possess thick sculptured walls to withstand adverse environmental conditions and is disseminated to wider areas through wind and water. Microalgae are the best preferred diet for rotifers.

Both *B. plicatilis*and *B. rotundiformis* have three strains developed for hatchery purpose. L type with lorica ranging from 100-340µ; S type with a size range of 100-210µ and SS type with less than 100µ size.

Ideal water quality parameters for maintaining a successful mass production of *B. plicatilis* are - salinity below 35ppt, temperature 20- 28ºC, dissolved oxygen level above 4mg/l, pH above 7.5 and ammonia below 1mg/l. Major contaminants in the culture are ciliates and bacteria. Bacterial load especially of *Vibrio* sp. should be below 10^7 CFU/ml. The culture should be free from ciliates like *Uronema* sp. and *Euplotes* sp. In case of severe contamination, washing through a flow through system with 50µ mesh plankton net can regain the pure culture.

Intensive indoor culture is mainly by batch culture using microalgae as feed. Algal feed is ideal for stock culture. Small closed vials are used for maintaining pure stock culture (Dhert, 1996).

Mass culture of rotifers always carry some risks of sudden mortality. Hence it is always ideal to maintain stock culture separately in clean aseptic conditions. Rotifers for initial culture can be collected from the wild and isolated through a series of antibiotic treatments and purified culture without any contamination can be prepared. It is always easy to start culture by taking a small sample from a well maintained stock culture of a hatchery or from a laboratory. All the culture tubes and filters should be properly sterilised before going for stock culture. The stock should be maintained at 28ºC with proper illumination of approximately 3000 lux using *Chlorella* as feed. It is ideal to add fresh algal culture on daily basis to these tubes. It is better if all the culture tubes are placed on a gentle shaker or a rotating shaft for providing enough oxygen evenly. Ideally this should be maintained at a density of 2 rotifers/ml upto 200 nos/ml. The stock culture should be periodically re-cultured and disinfected using mild antibiotic as and when it requires.

Once the density reaches around 200 nos/ml, this can be transferred to Erlenmeyer's flasks of 500ml capacity, with algal concentration of $1.6x10^6$ cells/ml. Approximately 50ml of the algae should be added daily. No aeration is required during this short rearing period. The concentration will reach 200-300 cells/ml within 3 days period and now the culture is ready for inoculation to 15l bottles. The culture

should be passed through first strainer of 200 µ mesh and then strained using 50µ mesh and the filtrate can be transferred to 15l bottles with 2l water and a density of approximately 50nos/ml for producing starter culture. This stage onwards we should go for aeration. Fresh algae of concentration of $1.6x10^6$ cells/ml should be supplied on daily basis ration. Within 7 days the 15l bottle will be completely full and the culture is now ready for mass culture.

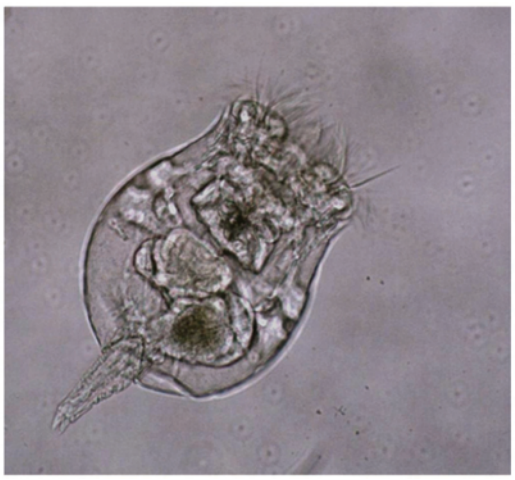
The culture can be maintained using fresh algal culture or commercial algal pastes or with baker's yeast culture and also in formulated diets. Formulated ideal diets for rotifers are now available in market and several companies including Selco is producing rotifer feeds.

For mass production of rotifers the hatchery should have facility for atleast any one of the above feed. Mass culture is generally maintained in large indoor tanks. Continuous harvest can be possible if the rotifer reaches density of 300-500 nos/ml. Daily the rotifers will double its population. Different types of sieves/strainers can be prepared using 50µ mesh nets for filtering the mass culture to harvest rotifers. Algal culture should be pumped in the culture tank on daily basis and enough aeration should be given to maintain the production.

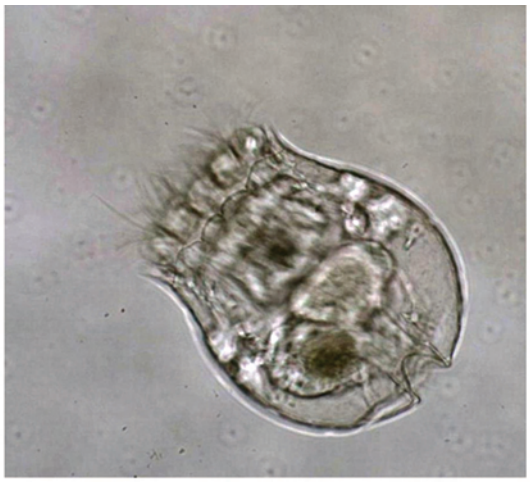
Nutritional value of rotifers mainly depend on the type of feed used. Rotifer cultured using a mixture of *Tetraselmis*, *Nannochloropsis* or *Isochrysis* or a mixture of these will be higher in DHA and PUFA content than that cultured using *Chlorella*. Several commercial products are also available for enrichment of rotifers. Use of enriched rotifer for feeding the larvae is essential for getting good larval survival. Harvested rotifers can be reared separately in water containing enrichment media. The enrichment time require the type of media. Simple enrichment can be done by using *Tetraselmis*, *Nannochloropsis* or *Isochrysis* or a mixture of these fed finally for one day to enrich the rotifers naturally. But commercially available enrichment media is also very effective. The media can be added to the harvested rotifers kept in higher concentrations with minimum water and allow these to remain there for few hours. The enrichment status can be observed by the colour change of the rotifers used. The enriched rotifers can be directly fed to fish larvae.

In general practice batch culture is the most common method to cultivate rotifers. In this method, a constant volume of culture will be maintained until it reaches maximum density and restart the entire process after the whole culture harvested for larval feeding. In intensive cultures, 200- 500L tanks are used. In semi continuous method, a constant number of organisms will be maintained in the system by regular partial harvesting. Extensive culture can be done in larger tanks with chlorinated and dechlorinated seawater with sufficient density of algal cells. Baker's yeast also is an acceptable diet for rotifers but the resulting organism will be nutritionally poor and should be enriched before use. The harvested rotifers are incubated in enrichment media in considerably higher densities for 8 – 20 hours. Enrichment components are commercial products containing highly unsaturated fatty acids which are inevitable for the growth and survival of marine fish larvae. Rotifers are enriched for improving their nutritional quality and also to encapsulate them with probiotics or antibiotics (Markridis*et al.*, 2000). Bioencapsulated rotifers should be used within 6 to 8 hours of encapsulation.

The major drawbacks in the rotifer culture are that they should be maintained only in live condition. Investigations are going on to develop standard protocols for the storage and resting egg productions of rotifers. Freezing rotifers, results the deterioration of nutrient contents. However, *B. plicatilis*can be stored in comparatively higher densities at 4°C up to one month. At 10 ^{0}C rotifers can be stored for about two weeks without any feed and water exchange. When comparing with *B. plicatilis*, *B. rotundiformis* are less tolerant to cold storage (Lubzens *et al.,* 1990, 1995) Asexually produced eggs can be cryopreserved using liquid nitrogen and can be used for longer period. In this method, the genomic characters also can be preserved (Hadani *et al.,* 1992). The future research of rotifers in larviculture is the development of storage technologies and economically viable production of resting eggs.



Brachionus plicatilis (live)



Lorica of B. plicatilis

Artemia

Artemia or the brine shrimp which has the ability to make dormant eggs (cysts) is the world's most popular and widely used live feed. The artemia cysts can be stored in dry condition for a longer period and over 200 tonnes of artemia cyst is marketed annually. Artemia is typically a primitive crustacean belonging to the class Branchiopoda. Total length is about 07-1.2mm and sexes are separate. Artemia generally produced in hyper saline ponds and can tolerate wide range of salinity and temperature but the optimum salinity required is 35-38ppt. Artemia can reproduce parthenogenetically but in the adverse conditions, it produce dormant eggs (chorion coated brown eggs) which can be stored in dry condition without losing its viability for more than two years (Stappen, 1996).

In dormant condition artemia cyst is round but concave in one or two sides. On hydration this will become spherical and in less than 24 hrs hydration and aeration, this hatches out into naupliar stage. Freshly hatched out stage is nauplius I with length of 400-500µ. This stage is popularly used for feeding the larvae. Within 7-8 hrs this will change to nauplius II and start feeding minute algae. The larvae again undergo 13more moults to become adult. Artemia is basically a filter feeder mainly feeding on microalgae.

Each gram of artemia cyst contain 200000 to 300000 eggs and almost 50% will hatch within 20-24hrs on proper hydration. The artemia cysts must be properly weighed and kept for hydration in normal sea

water of salinity less than 35ppt. The density can be 2g/l approximately and the pH should be above 8 and the temperature should be around 28°C. Strong aeration and illumination (above 2000 lux which can be achieved using fluorescent tubes) are essential for ensuring maximum hatching. Depending on the volume of larval rearing tank and the species under culture, requirement of artemia nauplii should be calculated. Daily measures the artemia nauplii left over in the tank by examining water in the larval rearing tank and back calculate the requirement of nauplii/l and requirement of cysts in g for producing that amount of nauplii.

Artemia nauplii if requires in large quantities, it is essential to disinfect the cysts before hydration to reduce the bacterial load to increase the quality and quantity of hatching. Soak the cyst in 200ppm sodium hypochlorite solution for 30 minutes and wash the cyst thoroughly several times with tap water using 125µ sieve. Cylindroconical tanks are ideal for hatching and aeration should be from the conical tip of the tank. Hydrate the cysts prior to hatching using tap water for one hour and use filtered sea water for hatching. Remove the aeration prior to harvesting of nauplii and the nauplii are phototaxic and are easily aggregated using light.

Artemia cysts can be decapsulated and directly used for feeding the fish larvae or this can be stored at 4°C for 1-2 weeks without losing its viability. Decapsulation process is simple but need constant observation. Sodium hypochlorite solution (0.5g/l) or liquid bleach (5ml/l) are commonly used for decapsulation. Decapsulation process should be monitored properly. Keeping longer duration in bleaching agents will affect the survival seriously. The entire container should be immersed in the ice cold water so that the temperature inside the container should be below 20°C. The time required for decapsulation process will vary from 5 to 15 minutes. The cysts will turn grey with powder bleach and orange colour with liquid bleach. Few samples should be observed using a stereo microscope and if the cyst wall is dissolved, the cysts should be rinsed using 125µ sieve several times in water till there is no trace of chlorine. In order to ensure the removal of chlorine, wash the cysts in 0.1N HCl or 0.1% Sodium thiosulphate solution ($Na_2S_2O_3$) for one minute. Finally wash through clean filtered seawater and check the water using chlorine test kits and chlorine free cysts can be directly fed to the fish larvae or can be kept for hatching or this can be sieved and stored in refrigerators at 4°C.

Artemia nauplii are nutritionally por when compared to copepod nauplii and this can be enriched PUFA and DHA using the same method of enrichment as in the case of rotifers. Lot of enrichment media are commercially available now.

Artemia biomass can be regularly produced using microalgae in tanks with natural sea water. This can be fed by algal paste or fresh algae. All stages of artemia can be cultivated in large scale and can be harvested regularly using normal sea water in the tropical climatic conditions without much effort.

Copepods

One of the major problems in the larval rearing of marine fish is the non-availability of a complete larval feed. Only copepods can cater the need of complete live feed fish larva. Copepods have almost all desirable characters for an ideal live feed such as small sized naupliar stages, high nutritional value,

desirable movement pattern, easy digestible composition and exogenous enzymes. Fatty acids especially the EPA and DHA ratio is available in the most appropriate combination in copepods. Copepods are tiny planktonic crustaceans with more than 20000 species living in a variety of ecological niches. They are a good source of proteins, amino acids, lipids, fatty acids, pigments, antioxidants, vitamins and minerals (Watanabe *et al.,* 1983). Copepod nauplii are successfully used as first feed for fish larvae in cases where rotifers are inadequate to meet size and nutritional requirements. In comparison to rotifer, *Brachionus plicatilis* (Kuhlmann*et al.*, 1981; Watanabe and Kiran 1994) or artemia (Kuhlmann*et al.*, 1981), using copepod as live feed lead to increased growth, survival and development in marine fish larvae. Most of the early fish larvae are evolutionarily adapted for feeding on copepods than on other animals.

Sexes are separate and clear Copepods of aquaculture importance mainly belong to the orders Calanoida, Cyclopoida and Harpacticoida. Calanoids can be easily distinguished by their long (20-27 segments) antennules. These are mostly pelagic and filter feeding. Rarely these can be carnivores or predatory. Cyclopoids have shorter antennules than calanoids with six to 17 segments. They have a variety of feeding habit from filter feeding to parasitic. Antennules are much reduced in parasitic forms. These are distributed in all depths and more abundant in freshwaters. Harpacticoids are more numerous in species and occupy more than 50% of the total species of copepods. They have a short antennule having less than 10 segments. Generally harpacticoids are benthic with a wide variety of food habits from filter feeding to detritus feeding. There are many predatory and parasitic forms also in this group (Huys and Boxshall, 1991; Dussart and Defaye, 2001).

Sexual dimorphism is there in most of the cases. In general, males are smaller and less numerous in any population. In most of the species, male antennule is modified for holding female during courtship. Eggs can either be broadcasted or kept in egg sacs and released after the development. Egg production rate is dependent on species, climate or season, feed, health status and age of the female. It can vary from 1-230 or more eggs per day (Stottrup, 2003). Eggs are mostly benthic and may hatch within 1-24 hrs. Resting eggs or diapause eggs are also common to withstand unfavourable conditions. Those species directly release their simple eggs generally has more fecundity. It can be more than 50-60 numbers of eggs/female/day. Paracalanid copepods belong to this category and these are more important in live feed culture.

All species of copepods are not ideal for culture. Preferred species should have desirable qualities like filer feeding (non-predatory or non-cannibalistic), prolific, hardy and pelagic with pelagic naupliar stages of size less than 100µ. Copepods preferably having nauplii 1 (N1) less than 60µ are ideal for culture. Copepods and larval stages measurements are important for choosing appropriate size of live feed in relation to the mouth size of larvae.

More than 60 species of copepods have been raised in laboratories. For promoting mass culture of copepods in cost-effective way, the development of appropriate culture technique is essential for each species. Copepods can be cultured extensively, intensively and semi-intensively. The extensive cultures are mainly in tanks, outdoor ponds, lagoons or enclosed fjords. By using plankton nets or sieves of

appropriate mesh sizes, these cultured copepods can be made available to fish larvae. In extensive systems, culture is done normally by producing microalgal blooms using ordinary agricultural fertilizers. Agriculture fertilizers, both organic and inorganic, were used with or without combination of fishmeal, rice bran, wheat bran and fish feeds as inputs for nutrients. But here the main disadvantage is the unpredictable nature of production. Rotifers if present may easily dominate in the culture. Semi intensive culture is generally carried out in indoor tanks with regular supply of microalgae in combination with baker's yeast or other feeds. Here regular harvest is possible and yields a mixed culture of different species of copepods. Here also the culture may not be stable for longer periods. Intensive culture is developed generally by maintaining selected isolated pure culture of copepod species with desired qualities. Basically there are small stock culture units, large mass culture units and modified culture tanks fitted with structures for harvesting naupliar stages on regular basis. Specialised nauplii collection units can be attached to mass culture units also. All important water quality parameters were regularly monitored and adjusted.

Though intensive culture may not be economical, most of the hatcheries prefer this because of the assured production of copepods and nauplii of desired size and species. This will help larvae to thrive well during critical periods of larval rearing. Once the critical period is crossed, the larvae can be fed with enriched rotifer and *Artemia* nauplii.

Feeding with wild copepod is always risky because these carry some unwanted predatory organisms, pathogens and intermediate stages of parasites. Moreover, in wild, the availability of desirable nauplii is always uncertain. Intensive hatchery production of copepod is always better as we completely avoid introduction of unwanted species and parasites. It is stable and production can be easily synchronised with larval production. It is easy to filter sea water and rear few copepods for few days. But pure and continuous culture and mass production is difficult and needs some specialised management techniques.

Rotifers can be cultured to a very high density. But in case of most of the copepod species, the density rarely exceeds 2-5 nos/ml for adults and 10 nos/ml for nauplii. Studies conducted on copepod cultivation reveal that, calanoids are comparatively difficult for culture than harpacticoids. Harpacticoid copepods can be cultured at higher density but, they will be relatively unavailable for fish larvae due to their epibenthic nature.

Calanoids are the most abundant zooplankton which forms a connecting link between phytoplankton and the fish in marine ecosystem. Most of the copepod species are less than 1.5 mm in total length, some being as small as 0.4 mm or some as large as 10.0 mm. Few species of calanoid copepods especially the temperate forms have been already cultured and utilised in several hatcheries. *Acartia clause, A. tonsa*, *Centropages hamatus*, *C. typicus, Parvocalanus crassirostris*, *Gladioferens imparipes*, *Tisbe* spp., *Oithona simplex*, *Bestiolina similis*, *Apocyclops* spp. and *Temora stylifera* are already used in fish seed production in many hatcheries. From India, though there are a few reports on production of copepods on experimental basis, pure and isolated culture and mass production technologies are not available for fish seed production. CMFRI is the pioneer in developing techniques for large scale production of copepods. We have used hatchery produced copepods for seed production of ornamental fishes and food fishes

including groupers and snappers. At present CMFRI have pure stock and large scale culture of eight species of copepods suitable for larval rearing of almost all types of fish larvae. Now CMFRI is in a position to distribute stock culture and also to impart knowledge on culture techniques to farmers and entrepreneurs.

All three groups can be cultured for larval rearing of marine fishes, but only few species have the potential to reproduce in large scale under hatchery conditions. Calanoids and cyclopoids can multiply (upto 5000-6000nos/L) in containers of 5-10 tons capacity within a short period but live microalgae are essential as feed. Harpacticoids can reach more than 10000 nos/ml within a short period in small containers and are generally ideal for small scale production units like ornamental fish culture units. Some harpacticoids can be cultured using artificial food for short periods. If artificial food is used for longer periods, it may lead to development of contaminants like protozoans and helminths.

Regular close monitoring of subsamples under microscope is essential for understanding growth, composition of life stages, contaminants and health status of the culture. It takes close monitoring of several generations of culture to acclimatize a particular species completely to laboratory/ hatchery conditions. Initially, the cultures are subjected to some seasonal changes or sudden fluctuations in population. But continuous culture in the hatchery can change the seasonal cycles and increase the stability of the culture.

Many reports are already there stating the suitability of culture of a number of species of copepods. Still, commercial production of copepods and utilization of the same has been achieved only in a few hatcheries of the world. More simple and effective technologies are needed for the wide spread acceptance and utilization of copepods as a live feed for feeding marine food fishes.

Collection and isolation

Collection can be done using plankton net during early hours of the day. The marine copepod can be isolated using fine dropper under stereozoom microscope and culture separately in small containers and serially to large containers. The water temperature and salinity are the basic factors considered during this period. The basic algal combination of *Isochrysis galbana* and *Nanochloropsis oculata* or *N. salina* can be used for feeding. Sieves of different sizes ranging from 60 to 440µm needs to be prepared using bolting silks and PVC couplings or pipes.

Culture

Culture starts in 500ml beakers can be transferred to 1 litre beakers. If sufficient numbers of copepods exist, this can be shifted to plastic buckets of 10 litre capacity and then later to larger tanks. Mass cultures of copepods were done in tanks of 500 litres to 5 tonnes capacity. Tanks were filled using chlorine treated and de-chlorinated sea water from existing outdoor tanks filtered through a 5 micron filter bag. The water should be contamination-free and the resident population of copepod culture can be introduced into it. The tanks should be placed in 60% shade. Using a refractometer, the salinity of the resident water should measure always and be maintained at 30 ppt(+/-2 ppt). The optimum temperature should be maintained at 27^{o}C - 30^{o}C. Routinely each tanks should be fed with algal culture mainly a

mixture of *Isochrysis galbana* and *Nanochlorella oculata*. Based on the assessment of the cloudiness of the medium, overfeeding was avoided. Ideal range of density should be 20,000-30,000 cells/ml. This helps prevent contamination of the culture system by ciliates uptoan certain extent. Mild aeration is also required in culture tanks. Siphoning off of the sediment in alternate days from the tanks is essential to prevent the ciliate growth. From the bottom samples, nauplii and copepods can be filtered out after sedimentation and can be washed and re-introduced into the culture. For harvesting, 30-40% of the culture can be regularly filtered by passing through a series of filtering sieves of 20µ, 110µ and 330µ. Copepods of different stages, naupliar stages and adults were sorted out and brought for further culture or feeding larvae.

Cleaning

The major threat occurring to the copepod population is the ciliate infection. Total removal of ciliates is an impossible task. By means of proper cleaning, ciliates can be avoided to a large extent. The regular removal of accumulated fecal debris, wastes and untaken food materials can be done using separate siphoning tubes. The siphoned water has to be collected in separate buckets. The buckets should be contamination free. Later the supernatant portion of the filtrate can be filtered through a 100 micron filter to recover adults if any. The bottom filtrate can be stored in buckets with mild aeration for 3-4 days. Every day the developed copepod nauplii in the buckets can be filtered using a 150µ and 20 µ mesh, washed thoroughly in sea water. The adults if any collected in 150µ filter can be deposited into the main tank itself. The young nauplii collected through 20µ filter can be washed thoroughly with sea water and put in another fresh bucket for further growth or it can be used for feeding.

Renewal of resident sea water should be done in every 2 weeks and a replacement of tank to be done in every 4 weeks for preventing ciliate development. Although, the volume to be removed is not critical, the exchange of 10% of water is most effective at the time of removing debris from the bottom.

Certain naupliar harvester designs are already available. Most of the hatcheries are using these harvesters. Adult copepods are introduced into the harvester which has a bottom fitted with a micron mesh of about 150µ size. There will be a continuous recirculation of water from bottom to top of the tank using a pipe and air stones. The water flowing back into the tank should pass through a sieve of 30-40µ. The system should run continuously and all the eggs or nauplii produced will pass through the bottom filter and airlifted to the top and collected in the sieve. The nauplii collected can be used for feeding the fish larvae. Adults in the tanks can be replaced after every 10-15 days from mass culture tanks.

Unconventional live feeds

Few other groups other than rotifer, *Artemia* and copepods also form important resources as live feed. But these are not fully explored and their potential is still not known properly. Future investigations on economic production of larvae may pave the way for utilization of these resources.

Crustaceans other than *Artemia* and copepods

Nauplii of the barnacle *Balanus* sp. which are smaller than *Artemia* nauplii and have been used to feed larval *Clupeaha rengus*, *Pleuronecte splatessa, Elennitispholis Centronotus gunnellus* and *Myliomacrocephalus*. Barnacle nauplii production is seasonal and nauplii are highly transparent and need more light to be visible in the medium to get caught by the fish larvae. This forms its major disadvantage of this group (May, 1970).

Ciliates

Ciliates forms one of the abundant components in the microzooplankton community which got potential for utilization as live feed. Few hypotrichand tintinnid ciliates are already been utilized as live feed for rearing marine fish larvae. Ciliates can be an important alternate live food source for first-feeding fish larvae due to their abundance, smaller size when compared to other live feeds (Kamiyama, 1994; Taniguchi, 1978; Sanders, 1987). Rhodes and Phelps. (2006) reported that *Fabrea salina*, an ovoid ciliate can be effectively used as feed along with the copepods in larval rearing but the mass culture techniques need to be standardized. Among tintinnids genera,*Tintinnopsis*, *Favella* and *Helicostornella* have been isolated and maintained in the laboratory. Fatty acid composition of tintinnids is comparable to that of copepods and has good potential to be utilised as live feed (Claustre *et al.*, 1988).

Nagano *et al.*, (2000 a & b) reported larval rearing of *Epinephelus septemfascialus* (Serranidae) (Thunberg) and *Paracanthurus hepatus* using loricate and non-loricate ciliates. They used *Euplotes* sp., *Favellatara ikaensis*, *Amphorellopsis acuta* etc. They suggested that both tintinnid and naked ciliates play important role as alternate food sources to copepod nauplii especially for feeding larvae with a smaller mouth size. The higher ciliate densities enhanced larval survival.

Cladocerans

Cladocerans are mainly freshwater zooplanktons with an exception *Diaphanosoma celebensis* which can tolerate salinities upto 42 ppt. There is a popular acceptance for this species in Asia. Size range of *D. celebensis*is between 400 to 800µ. Production of biomasses can be up to 1 kg/cubic meter of water in every 3 days. This species need to be enriched with a source of DHA before feeding. It can reach mean densities of 72 to 100 individuals per ml and could be maintained on *Tetraselmis chui* after reaching maximum density. In 1998, researchers at SEAFDEC in the Philippines successfully used *Diaphanosoma*as substitute for *Artemia*for rearing larvae of Barramundi (*Lates calcarifer*). Other cladocerans considered as promising species are *Evandneter gestina, Penilia avirostris* and *Podon polyphemoides*. The cladoceran *Moinamacrocopa* has been used in Southeast Asia as feed for sea bass fry immediately after weaning from *Artemia* and prior to feeding minced fish flesh. A related cladocera, *Moina salina*, is also being used in finfish culture (Treece, 2000).

Molluscan larvae

Many molluscan larvae form attractive food sources due to their steady availability and small size. These are being used successfully at many places, especially to feed very young fish larvae. Trochophore

and veliger larvae of bivalve molluscs are more popularly used. Bivalve larvae proved as an excellent food for early larvae of flatfish, *Liopsettaobscura* and red sea bream, *Pagrus major* (Kurata, 1959; Okamoto, 1969; Hirano and Oshima, 1963; Loosanoff and Davis, 1963). Hirano, (1969) used oyster larvae to for rearing *Myliomacrocephalus* larvae. Veliger stage of gastropod larvae also was used as live feed less frequently than bivalve larvae. Lasker *et al.,* (1970) used gastropod larvae to feed advanced stages of fry of anchovies.

Larvae of Polychaetes

Kurata (1959) successfully used the sabellidpolychaete*Choneteres* to feed the larvae of *Clupeapallasii*instead of *Artemia* nauplii. Due to short spawning season it cannot be used as a steady live feed. Only limited success was obtained for the use of *Nereis* eggs to rear larval plaice **(**Cunningham 1893-95).

Conclusion

Hatchery production of marine fish and crustacean larvae depends on the production of suitable, nutrient rich and economically viable live feed components. Identification and culture of more species will be helping in seed production of more finfishes for mariculture. For development of mariculture it is essential to have commercial seed production of more species.

Health Management in Mariculture

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Diseases in mariculture

Mariculture, especially cage farming of finfishes and shellfishes in marine and brackishwater is highly economically viable culture system in the world due to its high production and value. But, high density production in a confined volume will always cause disease outbreaks which further leads to economic loss in a short span of time. Occurrence of diseases in cage culture varies between the species and environment and is mainly due to the lack of management practices. In recent years, prevalence and spread of diseases and has been increasing enormously in marine fish farming which are caused by a wide range of infections including bacteria, viruses, fungi, protozoan and metazoan parasites; nutritional and environmental problems etc. Many of the marine finfish and shellfish are encountered with many viral, bacterial and parasitic infections during the culture period due to several environmental stress conditions and also through horizontal transmission. Hence, a thorough knowledge on diseases, parasite and pathogens profiling, surveillance and monitoring programmes and also development and implementation of preventive protocols as better management practices of cage farming is the need of the hour. Major Diseases encountered in cage cultured fish and their management practices are mainly discussed in this chapter.

Viral Diseases

Viral Nervous Necrosis (VNN)

VNN is the most common disease that encounter in almost all the stages of Asian Seabass both at hatchery as well as cages. This disease is found to be very acute in early stages of larvae and cause 100% mortality. The infected larvae with hyper inflated swim bladder exhibits whirling movements. The infected fishes from cages (juveniles and adults) shows no gross clinical signs on the surface of the body or gills but exhibits erratic swimming behaviour such as spiral, whirling, belly-up floating with inflation of swim bladder or laying down at rest. Infected fishes congregate as clusters on the surface with external symptoms of Anorexia, darkened body colouration and loss of reflexes. Mortality ranges between 60 to 90% due to this infection.

Histopathology and nested PCR are the best tools for confirmation of this outbreak in fish. Histopathology (H & E stain) with light microscopy reveals vacuolation and necrosis in the brain, spinal cord and eye. VNN belongs to Genus Betanodavirus and Family Nodaviridae and contains 2 single-stranded, positive-sense, nonpolyadenylated RNAs, RNAl and RNA2. The viral particle is 25 to 32 nm in diameter, non enveloped and spherical.

This disease can be transmitted by either vertical or horizontal i.e., through brood stock, eggs and larvae and also through water. In some cases, the transmission will be through wild fish in cage farm. The disease is significantly influenced by water temperature and the disease was preliminary identified as Summer Disease. This disease is encountered in Asian Sea bass, *Lates calcarifer* Cobia, *Rachycentron canadum* in marine farm.

Disease Management: Control of viral infection in open waters is difficult once the disease outbreak happens. Prevention of this disease by taking precautions like usage of virus free water in hatcheries and also screening of the virus in the fish stock before stocking into the system. Washing of eggs in ozone treated water followed with chorination is an effective control measure of the disease in hatcheries. To avoid the vertical transmission it is always suggestible to disinfect the broodstock tanks, use of biological filters, avoid the usage of wet feed and screening of each brood stock fish for the presence of VNN by RT PCR which can be carried out through gonaldal biopsy and discard the positive specimens. It is always suggested that the stocking of Asian Seabass can be performed during autumn months to avoid the disease outbreaks in summer months as the VNN is found more virulent during summer months.

Iridovirus

Iridovirus is one of the most serious disease problem especially and recorded in tropical maine fish viz. Asian Seabass, grouper, pompano and seabream. This disease mainly occurs in the initial stages of growout system (10-50 g size fish) and the mortality is of 80-90%. External symptoms of the infected fish exhibits lethargy with pale clouration of gills, red colouration of eyes and also the enlargement of cells in kidney, heart and intestine of fish. The disease can be confirmed by histopathological and molecular tools. Histopathological sections indicate that abundant blast-like inflammatory cells are clearly visible throughout the circulatory system. The enlarged cells usually have intensively basophilic and Feulgen positive cytoplasm, and an expanded nucleus with a prominent nucleolus. Inclusion bodies containing compactly packed iridoviral virions can be seen through Electron microscopy. The size of viral particles ranged between 175-196 nm. Necrotic cells in the spleen and haematopoietic tissue exhibited diffuse multiplication of iridoviral virions in the cytoplasm. A simple and rapid PCR test can be done to detect irodovirus in diseased fishes. The pathogen is a DNA virus of icosahedral symmetry with a diameter of 200–240 nm.

Disease Management: There are no control measures of this disease once it is attacked fish and hence, it is always better to prevent the occurrence of this virus through water exchange and screening of the fish and water regularly for the presence of the virus in order to eliminate the positive samples. Avoidance of exposure to the pathogen, environmental manipulation, development of disease resistant-strains, health maintenance, and chemotherapy. Activation of non-specific defense and specific immunization based on general health maintenance seem to be the most promising prophylactic methods for the control of iridovirus. It is also recommended to apply the formalin killed commercially available vaccine as a preventive measure.

Bacterial diseases

Many bacterial diseases of cage cultured fish are reported worldwide most of which are found to be opportunistic in nature. Vibriosis is a common disease outbreak in both hatchery and cage cultured fish.

Although a number of bacteria are reported to be associated with diseases in fish, only a few are responsible for large-scale mortalities. Bacteria such as *Vibrio anguillarum, V. alginolyticus, V. vulnificus, V. damsela, V. harveyi*, *Photobacterium damselae* are the major pathogens recorded in marine finfishes. Among the *Vibrio*s *V.harveyi* and *V.alginolyticus* are the most pathogenic bacteria of cage cultured fish especially Asian Seabass and Cobia which cause haemorrhagic septicaemia. Infected fish exhibits sluggish swimming and frequent surfacing, septicaemia, anorexia, exophthalmia and haemorrhages. Darkening of the skin, lethary, inappetance, exophthalmia, swollen abdomen, pale gill color, erosion and hemorrhage in the fins and lesions in skin. Gills and liver are pale with profuse mucous secretions pale kidney and liver, ascites in the body cavity, yellowish-bloody fluid in the intestine, enlarged spleen and empty stomach.

The disease can be identified by classical microbiological taxonomy, histopathology and molecular diagnosis. Histopathological studies indicate hepatic lesions included congestion, haemorrhages and swollen hepatocytes vacuolation severe depletion of haemopoietic cells, deposition of haemosiderin in the spleen and peritubular vacuolar degeneration or liquefactive necrosis in the renal tubules and haemprrhages and vacuolar degeneration in the liver of infected fish with Vibriosis. Classical microbiological studies by conducting various biochemical tests and molecular taxonomy through 16 s r RNA sequence gives the specie identification as rapid diagnostic tools. Major Vibrio species recorded in Asian Seabass which cause mortalities are *V. harveyi, V. alginolyticus, V. anguillarum* and *Photobacterium damselae sub.sp.damselae* recorded from diseased Cobia from cages.

Disease Management: Vibriosis can be controlled by chaemotherapy and application of antibiotics. Oxytetracycline is the most common antibiotic used in hatchery and culture systems. But continuous usage of antibiotics is not suggestible in culture systems which may cause resistance against those drugs and also to avoid quality control issues. Hence its is always suggested that the bacterial infections can be controlled by usage of probiotics in hatchery and cage systems in addition to the water quality management of environment. Chlorination is the best preventive measure at hatcheries to prevent the attack of any disease. In addition to this, usage of commercially available water and feed probiotics in hatchery tanks as well the feed probiotics along with feed in cage culture are the best preventive measure for occurrence of any bacterial infections.

Parasitic infections

Among the parasitic infections, ectoparasites which feed on mucous, tissues and other body fluids cause the most serious disease outbreaks in larval and juvenile stages of Asian seabass, cobia and pompano. Most predominant ecoparasitic infection in cage cultured fish are *Caligus* sp., *Diplectanum* sp., *Myxosporidia* sp., *Ichthyobodo* sp., *Epistylis* sp. *Amyloodinium spp).* They cause damage to the epithelial layer resulting haemorrhagic lesions on the skin. Many of these parasites act as vectors of bacteria and viruses which may lead to the outbreak of multiple infections in fish.

Disease management: Most of the parasitic infections can be controlled by the application of formalin treatment with specific dosages as per the prevalence of parasitic occurrence. It is also suggested the application of vaccines of respective parasites and pathogens always give the best management practice in cage culture systems.

Water quality Management

Water quality is the most important determinant for maintaining sustainable marine cage farming. The most important physico-chemical and biological parameters to be considered in cage aquaculture include water temperature, turbidity, salinity, pH, dissolved oxygen, ammonia, nitrates, nitrites, phosphates and algal blooms. It is also understood that the effects of marine finfish cage aquaculture on water quality are of great concern to the development of an ecologically viable mariculture industry. To achieve a sustainable culture of these species, management of good water quality in the cage farm is of prime importance. Most important parameters to be monitored and maintained in closed and open systems are discussed in this chapter.

Temperature

Water temperature has the maximum effect on fish and can be considered as a primary factor affecting the economic feasibility of a commercial aquaculture venture. Extreme temperatures can induce stress in the animal, and the metabolic activities of fish are affected, which ultimately affects the growth and health of fish. In cage culture, optimum water temperature depends on the type of cultivable species i.e., 26–32^{o}C for most tropical species and 20–28^{o}C for most temperate species. Some of the fish species can survive even at varied temperatures but the growth of the fish may be affected due to temperature fluctuations. The sudden change in water temperature will affect fish metabolism, oxygen consumption, ammonia and carbon dioxide production, feeding rate, food conversion as well as fish growth. The best solution is to select fast growing species and avoid the culture period during the months with unsuitable temperature.

Salinity

Salinity is the most important factor which can influence the ionic balance in the fish and extreme changes in salinity values further affect the growth of fish. In general, the optimum salinity required for cage culture of finfishes ranges between 10-30 ppt. However, the optimum salinity varies with the type of species cultured. Asian seabass can tolerate salinity ranging between 0-33 ppt, whereas, the salinity tolerance of cobia, pompano, snappers and groupers range between 15-35 ppt, 5-35 ppt, 15-33 ppt and 10-33 ppt respectively. Optimum salinity required for culture of Asian seabass, cobia, pompano, snappers and groupers, which are the potential candidate species for cage farming in India, are 15, 25, 15, 25 and 15 ppt respectively. It is suggested to have the culture of these species during the suitable season required for these fishes and also the area suitable and kind of water bodies. It is also suggested to culture Asian seabass in marine as well as brackishwater bodies, as the species can tolerate extreme salinity conditions. The culture of Asian seabass can be practised as in brackishwater areas and in controlled pond conditions as coastal farming. Cobia farming can be done preferably in marine water bodies as the growth rate of cobia is high under high saline conditions in marine water bodies. Pompano, *Trachinotus blochi*, can be cultured both in marine and brackishwater areas in cages and also in ponds as it tolerates all the salinities and the growth rate is more in brackishwater bodies.

pH

The suitable pH for most marine species is from 7.0 to 8.5. The pH values vary directly or indirectly with other water parameters like salinity and temperature, which also influences the dissolved oxygen and ammonia levels. Extreme values of pH can directly damage gill surfaces, leading to death of fish.

Dissolved oxygen

Dissolved oxygen is one of the prime factor that influences the fish health and growth in marine farms. DO is found to be a very essential element for the maintenance of osmotic activity and also digestion and assimilation of food. DO levels are mainly influenced by other environmental factors, such as temperature and salinity, and the levels decrease with increase in temperature and salinity. Ideal dissolved oxygen levels required for cage culture of marine fish range between 6-9 ppm. However, the oxygen consumption of fish varies, with species, the pelagic fish like snapper and seabass requiring more than demersal species such as grouper. In general, dissolved oxygen should preferably be around 6 ppm or more and never less than 4 ppm for pelagic fish or 3 ppm for demersal species. In the case of cage culture, benthic organisms and sediment wastes may also reduce the oxygen level. Depletion of DO always occurs during night time at neap tide in summer. It is a known factor that the algal community forms a net oxygen consumer and the occurrence of algal blooms more in the areas where nutrient flux is more, and this can lead to the oxygen depletion in water columns. Hence, it is always suggestible to culture the fish in the open waters with sufficient currents that can remove the settled particulate matter and wastes at the bottom.

Nutrients

The ammonia-nitrogen levels in the water should be less than 0.1 mg l^{-1}. Ammonia nitrogen levels in water increase by the decomposition of uneaten food and debris at the bottom, and can affect the fish. Normally in the coastal areas, sewage discharge and industrial pollution are the main sources of higher level of ammonia in seawater. The total inorganic nitrogen of water should be < 0.1 mg l^{-1} for a better fish culture operations. The excessive amount of nitrite in water leads to the oxidation of iron in fish haemoglobin, which causes hypoxia in fish. Total inorganic phosphorous plays an important role in growth of algae and other aquatic plants and it should always be <0.015 mg l^{-1}. Excess of phosphorous levels lead to algal blooms.

Algal blooms

A number of marine algae groups form blooms, including diatoms, Cyanobacteria, prymnesiophytes and dinoflagellates, which interfere with fish gill function. Excessive algal blooms can happen whenever the suitable conditions, such as higher light intensity, higher nutrient level, warm water temperature, stagnant hydrological conditions, prevail. Algal blooms can affect fish by damaging fish gills by clogging and they also compete with fish for dissolved oxygen during night time. Red tides commonly occur in warm water, especially during summer months. Cage site should be selected in those areas where there is no occurrence of blooms and also where the waters are stagnant.

Maintaining good water quality of the marine cage culture operations is important to maintain the ecological balance and also for the health of the cage cultured fish. For maintenance of good water quality, it is essential to monitor all the parameters, which influence the growth and health of the fish, at regular intervals throughout the culture period. It is important to develop standard protocols for water quality management for the cultivation of different species. A standard policy should be clearly developed for the water quality criteria to be considered while selecting a site for cage culture operations.

Recommendations for better water quality management practice in cage culture

1. Selection of a suitable site with sufficient depth (6-10 m) is recommended to have better water exchange and to avoid the deposition of suspended wastes at the bottom. It also helps to avoid the contact of cage bottom to the sea floor which eliminates the bacterial interactions and benthic foulers.
2. Cages should be installed at a place where there is a continuous water current for good exchange of bottom fish wastes and suspended materials. The water current velocity should be between 0.05 m S-1 to 1 m S-1 with a tidal amplitude of <1 m
3. To avoid the fluctuations in salinity and dissolved oxygen levels, culture of marine finfish in cages should be carried out after monsoon period and also to avoid the current velocity, which further influences deposition of suspended solids at the bottom of the cage.
4. Development of nutrient and water quality threshold values
5. Development of feeding strategies to improve the FCR and reduce the nutrient influx into the waters
6. Regular Monitoring of water quality parameters, at weekly intervals, is essential to understand the health status of the cage environment.
7. Regular net exchange, at monthly intervals, also improves the water exchange in the cages and improves the environmental health. The nets which are with biofoulers are to be brought to the shore and should be thoroughly cleaned and can be reused.
8. Measures should be taken while using the farm vessel, and properly operated with minimum spill and leaks, which may cause pollution in the farm site, that may further lead to fish mortalities.
9. Rotation of cages should be implemented to decrease the waste deposition
10. Fish wasters, dead organisms. debris and other suspended materials must be transported to the shore and properly disposed.
11. Usage of antifouling agents must be avoided and mechanical cleaning of nets and frames is highly suggestible.
12. Integrated Multi Trophic Aquaculture (IMTA) must be practised in combination with other species like mussels and seaweeds, which filter the waste particulates and absorb dissolved nutrients.

General Protocols for Fish Health Management of Mariculture: Disease and

Health management of cage cultured and hatchery reared marine finfish is always a challenging aspect due to its dynamic nature in open waters and also dealing with broodstock management practices. Hence, the following protocols should always be followed as a part of better health management practices in cage as well as hatchery systems

- Development of rapid and sensitive disease diagnostic kits for application in field will be more helpful for disease diagnosis in early stages which helps in taking further steps for control and management practices.
- Biosecurity measures with effective quarantine methods should be implemented at all the marine hatcheries so as to eliminate pathogens in the larval development process.
- All the broodstock must be screened before initiating the breeding programmes for larval development and also eggs, fry and fingerlings must be checked before going for further rearing in nurseries.
- Nursery reared fish fingerlings and wild collected fish seed must be screened for the occurrence of parasites and pathogens in order to avoid the vertical transmission of pathogens.
- It is always suggestible to undertake regular monitoring of the fish health and environmental health in the marine cage farm to understand the health condition in relation with water and sediment quality.
- Maintenance of optimum stocking density is always suggestible in order to avoid stress due to over stocking in cages which may lead to develop opportunistic secondary infections due to stress factors
- It is suggested to avoid use of trash fish which may be one of the reason for transmission of parasites and pathogens
- Avoid the usage of chemicals and antibiotics in the hatchery as well as in cage farm which creates a problem of development of residues and drug resistant strains in the open systems
- Application of tested and approved protiotics, immunostimulants and vaccines always gives a better management practice to produce sustainable, pathogen free and disease resistant fish in cage culture systems.

Integrated Multi-Trophic Aquaculture (IMTA)

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Introduction

Capture fisheries production is showing a stagnating trend for the past few years coupled with declining catch per unit effort. On a global level, a reduction in fishing effort is recommended by many governments so as to ensure a sustainable marine capture fishery. However, the demand for fish is increasing year after year, as it is an important source of protein and it provides essential nutrients to the poorer sections of the society. Hence in future years additional sea fish requirement has to be met only by farming in seas namely, mariculture. The Mandapam Regional Centre of Central Marine Fisheries Research Institute (CMFRI) had been developing technologies for the seed production of high value marine finfish and farming techniques such as sea cage farming. This centre was able to standardize seed production and farming technologies of cobia and silver pompano, was also successfully demonstrated. One of the anticipated issues while expanding the sea cage farming is the environmental degradation and consequent disease problems. In this context, the idea of bio-mitigation along with increased biomass production can be achieved by integrating different groups of commercially important aquatic species which are having varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA) which is gaining importance at global level.

What is IMTA?

Integrated Multi Trophic Aquaculture (IMTA) is the practice which combines in appropriate proportions the cultivation of fed aquaculture species (E.g. fin fish/shrimp) with organic extractive aquaculture species (e.g. shell/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental stability (bio-mitigation), economic stability (product diversification and risk reduction) and social acceptability (better management practices).

Successful demonstration of CMFRI technology - Integrated Multi-Trophic Aquaculture (IMTA)

ICAR-CMFRI has successfully conducted the demonstration of Integrated Multi Trophic Aquaculture (IMTA) under participatory mode with a fishermen group at Munaikadu (Palk Bay), Tamil Nadu by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*).

A total of 16 bamboo rafts (12× 12 feet) with 75 kg of seaweed per raft were integrated for a span of 4 cycles along with one of the cobia cages. A GI cage of 6 m diameter and 3.5 m depth with 750 cobia fingerlings was integrated with the above seaweed raft system. One complete cycle of seaweed extends

for an average of 45 days duration and four such cycles were performed in a row. As a control, a separate set of rafts of the same number were grown in a distant location without any integration with the cages.

Seaweed rafts (16 Nos.) integrated with cobia cage

Cobia cage without integration of seaweed rafts

Seaweed rafts - without integration

Economic benefit through increased seaweed production under IMTA

An integrated seaweed raft yielded 260 kg in 45 days, while the same yielded 150 kg only when not integrated. An additional production of 110 kgs of seaweed/ raft was achieved due to the integration with cobia cage farming. The total dried seaweed production of the integrated rafts after 4 cycles was 1280 kg, while that of non-integrated rafts was only 576 kg. So, an additional yield of 704 kg of dried seaweed was achieved due to the integration with cobia cage farming. Moreover there was an increased number (average 90-100 nos.) of newly emerged apical portion/tips in a bunch of harvested seaweed from the rafts integrated with the cobia cages, whereas the same was less (average 30- 40 nos) from the rafts which were not integrated. The bunches having more numbers of newly emerged apical portion/ tips, when used for replanting, will be ready for harvest within 40 days, whereas the seaweed with less

numbers of newly emerged apical portion/tips, if used as seed, will be ready for harvest only after 54 days. Revenue generation/ net profit of Rs. 32,000 were realized through integration of seaweed rafts with cobia cages.

Comparison of seaweed rafts -both integrated (with cobia cage) and non-integrated

Comparison of a bunch of seaweed taken from integrated and non-integrated raft

More numbers of newly emerged apical portion/tips from integrated rafts

Environmental benefits under IMTA

It was found that the organic waste mitigation of integrated system of *Kappaphycus* farming is more efficient than the non-integrated system of farming. Biochemical analysis of water and sediments from the experimental rafts and cages indicated a mutual beneficial effect of seaweeds and cobia in the integrated aquaculture system. The analyses for organic matter load and water quality parameters indicated that the organic wastes from the feed waste and excreta of fish were sequestered by the integrated seaweed. While the sequestration of the organic waste by seaweed acts as a fertilizer for itself, decreased the organic pollution and helps the fish to save and minimize its energy expenditure towards warding off environmental stress, thus helping it to have better growth rate over its counterpart cultured in non-integrated manner.

Experimental studies were conducted at Munaikadu, Ramanathapuram district, Tamil Nadu on assessment of carbon sequestration potential of seaweed (*Kappaphycus alvarezii*) and it was found that the specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed was estimated as 0.0187 gday^{1} (CMFRI Annual Report, 2015-16). Hence seaweed farming is considered as one of the mitigating measures for climate change.The total amount of CO_2 sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 223 kg and 100 kg respectively. Hence there is an addition of 113 kg carbon credit due to integration of 16 seaweed rafts (4 cycles) with one cobia cage (one crop).

Seaweeds provide shelter to a variety of organisms and enhance biodiversity and they absorb CO_2 and reduce global warming. They are also efficient in controlling organic pollution including heavy metals in the inshore waters and thereby ensuring ecological balances. Thus, integration of seaweed with cage farming is an eco friendly option with sustainable income to the coastal fishers. However, new technological solutions associated to IMTA (Integrated multi-trophic aquaculture) should be sought to provide required nutrients, level of nutrient release from the cage farming, assessment of absorption of nutrients by the seaweeds, nutrient conversation efficiency of seaweeds and simulated models for the analysis of these aspects need to be developed. Assessment of mutual benefit on growth rate of finfish & seaweed, carbon sequestration potential, waste mitigation in integrated cages and benthos analysis is also need to be developed.

Recirculating Aquaculture Systems

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Closed-system aquaculture presents a new and expanding commercial opportunity. Recirculating aquaculture systems (RAS) are tank-based systems in which fish can be grown at high density under controlled environmental conditions. They are closed-loop facilities that retain and treat the water within the system. In a RAS, water flows from a fish tank through a treatment process and is then returned to the tank, hence the term recirculating aquaculture systems. RAS can be designed to be very environmentally sustainable, using 90-99 percent less water than other aquaculture systems. RAS can reduce the discharge of waste, the need for antibiotics or chemicals used to combat disease, and fish and parasite escapes. RAS have been under development for over 30 years, refining techniques and methods to increase production, profit and environmental sustainability. There is a large cost involved in setting up and running a recirculation system and we need to consider a number of factors in designing the system that will fit our needs. This type of aquaculture production system is more commonly used in freshwater environments and can also be used in marine environments. Since failure of any component can cause catastrophic losses within a short period of time, the system must be reliable and constantly monitored. An important component of RAS is the control system which must measure and control all the critical system parameters. Recent developments in control technology and microcomputers may revolutionize the operation and control of RAS. A properly-controlled RAS will also be energy efficient since production can be optimized with respect to the various inputs. In addition, water levels, disruption of electric power, fire, smoke and intrusion of vandals should also be monitored.

Biosecurity

Hatcheries with RAS facility are often fully closed and entirely controlled, making them mostly biosecure - diseases and parasites cannot often get in. Biosecurity means RAS can continusously operate without any chemicals, drugs or antibiotics. Water supply is a regular route of pathogen entry, so RAS water is often first disinfected or the water is obtained from a source that does not contain fish or invertebrates that could be pathogen carriers.

Water Quality and Waste Management

The most important parameters to be monitored and controlled in an aquaculture system are related to water quality, since they directly affect animal health, feed utilization, growth rates and carrying capacities. The critical water quality parameters that are taken care in RAS are dissolved oxygen, temperature, pH, alkalinity, suspended solids, ammonia, nitrite and carbon dioxide (CO_2). These parameters are interrelated in a complex series of physical, biological and chemical reactions. Monitoring

and making adjustments in the system to keep the levels of these parameters within acceptable ranges is very important to maintain the viability of the total system. The components that address these parameters can vary from system to system. A successful water reuse system should consist of tanks, filters, pumps and instrumentation.

Fish Tanks

The round/ octagonal or square design with smooth corners and the arrangement of inlets and outlets of water treatment units support the circular water flow. Additional circular water flow and aeration can be enhanced by aqua jets. The circular flow promotes the behavior of fish. Circular tanks are good culture vessels because they provide virtually complete mixing and a uniform culture environment. When properly designed, circular tanks are essentially self-cleaning. This minimizes the labor costs associated with tank cleaning. Typically, water is introduced into a circular tank at the side and is directed tangential to the tank wall. The incoming water imparts its momentum to the mass of water in the tank, generating a circular flow pattern. The water in the tank spins around the center drain, following an inward spiral to the center of the tank. Centrifugal forces and the inward, spiraling flow patterns transport solid wastes to the center drain area where they are removed easily. Once the mass of water in the tank is set into motion, very little energy is required to maintain its velocity. The momentum of the water circling the center drain helps sustain the circular flow. The primary disadvantage of circular tanks is that they do not use space efficiently. A circular tank of a given diameter will have about 21% less bottom culture area than a square tank whose sides are the same length as the diameter of the circular tank. This means that if circular tanks are used there will be 21% loss of potential production in a given amount of space.

Aeration Systems

The most efficient aeration devices move water into contact with the air. The commonly used air stones produce larger air bubbles which rise quickly to the surface and hence the dissolution of oxygen is low. So,the usage of air diffusers are preferred in RAS. These diffusers produce small air bubbles within the tank that rise through the water column. The smaller the bubbles and the deeper the tank, more oxygen is transferred.

Carbon Dioxide (CO2) Control and Removal

CO_2 is produced through the respiration of fish and microorganisms and will accumulate within recirculating systems if not removed at a rate equal to its production. Elevated CO_2concentrations are not greatly toxic to fish when dissolved oxygen is at saturated levels. For most aquacultured fish, free carbon dioxide concentrations should be maintained at less than 20 mg/L in the tank for good fish growth. CO_2 is usually removed through some form of gas exchange process either by exposing the water to air in a “waterfall” type of environment, or mixing air into the water to remove excess CO2.

Stocking Number and Density

In evaluating RAS production capabilities, the unit most often used is maximum tank or system stocking density (kg/m^3 or lbs./gallon). However, in terms of production potential, this unit of measure

is meaningless. Fish can be held at very high stocking densities while feeding only enough to maintain their basic needs. Underfed fish consume less oxygen and produce less waste. Therefore, the stocking rate of a system (fish/m^3) and ultimate maximum fish density (kg/m^3) achieved within a tank should be defined by the maximum feed rate (kg feed/hr or day) that the system can accommodate without wasting feed and still maintain good water quality. This maximum feed rate capacity will be a function of the water treatment system's design, type of fish being grown and type of feed.

Solid removal in recirculation systems

One of the key problems in RAS is related to the load of suspended solids and in particular to very fine particles. The presence and accumulation of particulate wastes in RAS (faeces, uneaten feed, and bacterial flocs) will negatively impact the water quality by affecting the performance efficiency of the water treatment units. High suspended solids load has many disadvantages:

- Particulate matter consumes oxygen during biological degradation which will decrease the availability of oxygen for fish in culture
- The breakdown of organic wastes will increase the Total Ammonia Nitrogen (TAN) concentration in the water affecting nitrification. Small quantities of unionized ammonia can be toxic for epithelial tissues and disturb the elimination of protein metabolites across gills.
- Solids support the growth of heterotrophic bacteria which can outgrow and compete with nitrifyers. The nitrification process is strongly inhibited by heterotrophic processes when high amounts of organic carbon are present.
- Particles can potentially clog biofilters and reduce their efficiency
- Excessive solid loads can cause plugging within aeration columns, screens, and spray nozzles orifices, which could ultimately result in system failure.
- Suspended solids offer an ideal temporary substrate for facultative pathogens while they try to find a final host. It is also suspected that suspended solids may be involved in bacterial gill disease (BGD) outbreak.

Some type of filters used for the solid wastes are drum filters, bead filters, screen filters and rapid sand filters.

Biofiltration:

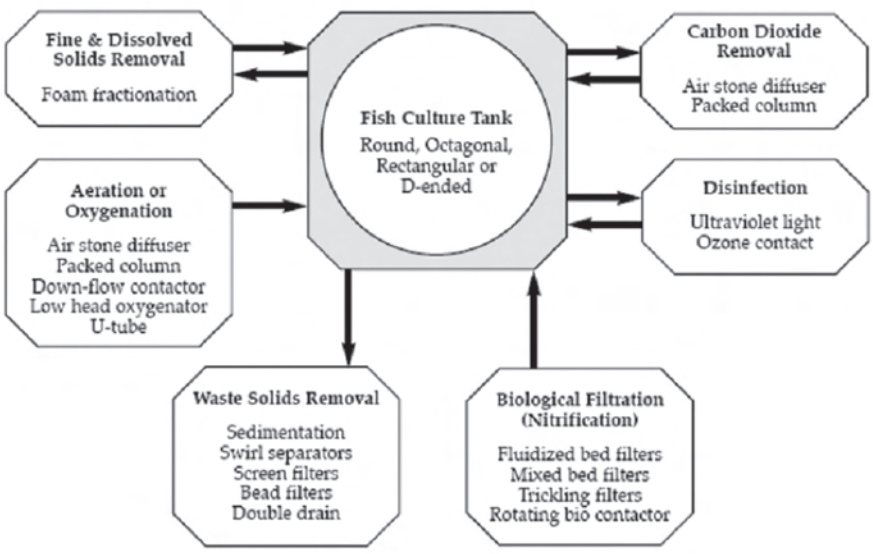
In closed aquaculture systems the accumulation of nitrogen compounds, as ammonia and nitrite, has a deleterious impact on water quality and fish growth. The biological filtration (BOD removal and nitrification) is a fundamental water treatment process in every recycling method for the cultivation of aquatic animals. It mainly digest dissolved organic material (heterotrophic bacteria) and oxidizes ammonium-ions via nitrite to nitrate (two-step nitrification) by bacteria like *Nitrosomonas sp.,* and *Nitrobacter sp*. A solid medium is used as substrate for the attachment of the micro flora. Conventional biofilters employ sand or coral gravel as filter media. Modern filters make use of various plastic structures

as grids, corrugated sheets, balls, honeycomb-shaped or wide-open blocks. The main goal is to provide a big active surface area for the micro flora settlement. During the last few years moving bed biofilters have received growing attention. These allow to have more specific surface area at the same volume, they need low maintenance due to self-cleaning (no back wash needed). Moving bed reactors are interesting cross between upflow plastic bead filters and fluidized bed reactors. These filters use a plastic media kept in a continous state of movement. The beads are usually buoyant or slightly heavier than water. The specific surface/volume ratio is about 800-1000 m^2/m^3. The plastic beads are mixed by hydraulic means driven by air.

Even if nitrate is usually mentioned as the least toxic form in comparison to ammonia and nitrite, high concentrations can reduce immune response and influence osmoregulation in fish. Optimal bacterial growth is the crucial step, otherwise toxic compounds like nitrite, nitrogen or hydrogen sulfide can be formed. The quantity required for denitrification can be calculated on basis of the influent nitrate, nitrite and dissolved oxygen concentrations. The oxidation-reduction potential (ORP) is measured to monitor the denitrification. Sequential removal and reduction of oxygen, nitrate and nitrite result in sequential decrease of ORP in the media.

Foam Fractionation:

Many of the fine suspended solids and dissolved organic solids that build up within intensive recirculation systems cannot be removed with traditional mechanisms. Foam fractionation is used to remove and control the build-up of these solids. This process, in which air introduced into the bottom of closed column of water creates foam at the surface of the column, removes dissolved organic compounds by physically adsorbing on the rising bubbles. Fine particulate solids are trapped within the

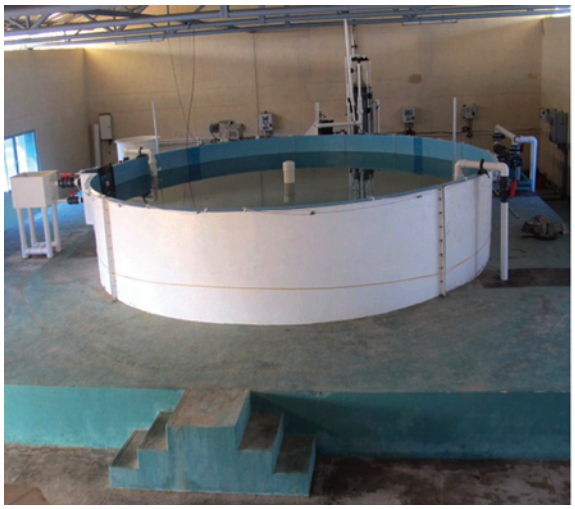


Source: Losordo, *et al.*, 1998

foam at the top of the column, which can be collected and removed. The main factors affected by the operational design of the foam fractionator are bubble size and contact time between the air bubbles and dissolved organic compounds. Foam fractionation is a suitable process in sea water as well as fresh water and the efficiency is increasing with increasing salinities. That is related to the increasing surface tension allowing smaller air bubbles in sea water and there with a higher filter area. Foam fractionation is working very efficiently from salinity of 12 ppm and more.

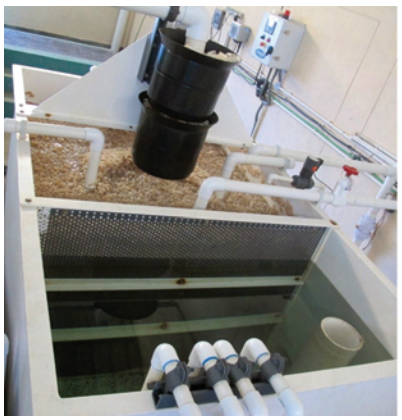
Disinfection of culture water:

Installation of suitable UV sterilizers or ozonisers in the water flow would remove unwanted bacteria, algae and pathogens. The capacity and the flow rate of the UV sterilizer/ ozoniser should be calculated based the on quantity of water to be treated and effectiveness of treatment.



Recirculating Aquaculture System at CMFRI

Drum Filter



Fluidized bed bioreactor

Protein Skimmer

UV Sterilizer

Programmable Logic Controller of the RAS

Status of seaweed farming in India

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Potential of seaweed

Worldwide around 9,200 species of seaweed have been recorded. The worldwide seaweed production (farming + wild collection) has substantially increased from 4 million tonnes (MT) in 1980 to 20 MT in 2010. Worldwide red seaweed production contributed to 9 MT during 2010 (47 % of worldwide seaweed production). Among the red seaweeds, *Kappaphycus* and *Eucheuma* contributed to 63 % of the total production i.e. 5.6 MT during 2010 (FAO, 2013). In India, about 434 species of red seaweed, 194 species of brown seaweed & 216 species of green seaweed have been recorded. Among these species, important seaweeds were *Gelidiella acerosa, Gracilaria* sp, *Hypnea* sp, *Acanthophora* sp, *Sargassum* sp, *Turbinaria* sp, *Ulva* sp, *Enteromorpha* sp, *Kappaphycus alvarezii*. Seaweeds are used as Phycocolloids (Agar, Alginate & Carrageenan), Food, Fodder & Bio-fertilizer.

Seaweeds provide shelter to a variety of organisms and enhance biodiversity. They absorb carbon-di-oxide (CO_2) and reduce global warming (Israel *et al.,* 2010). They are also efficient in controlling organic pollution including heavy metals in the inshore waters and thereby ensuring ecological balances. Thus, seaweed cultivation is an eco friendly option with sustainable income to the coastal fishers. Experimental studies were conducted at Munaikadu, Ramanathapuram district, Tamil Nadu on assessment of carbon sequestration potential of seaweed (*Kappaphycus alvarezii*) and it was found that the specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed was estimated as 0.0187 $gday^{1}$ (CMFRI Annual Report, 2015-16). Hence seaweed farming is considered as one of the significant mitigating measures for the adverse impact of climate change.

CMFRI role in seaweed farming

The Central Marine Fisheries Research Institute (ICAR-CMFRI) has been pioneering in seaweed research since early 1980s. The ICAR-CMFRI, Mandapam has developed the technology for large scale cultivation of *Gracilaria edulis*, an agar yielding red algae, using coir rope nets. In this method one kg of seed material would yield an average of 3 kg/m^2 of wet weight after 60 days. This technology was transferred to interested fishermen in the coastal villages of Ramanathapuram district, Tamil Nadu under Land to Land Programme of Indian Council of Agricultural Research. The ICAR-CMFRI, Mandapam developed a cottage industry method for the manufacture of agar from *Gracilaria spp*. during September 1999 and demonstrated the agar production to many farmers and entrepreneurs. These demonstrations paved a way for development of many small scale agar industries at Madurai, Tamil Nadu. The ICAR-CMFRI along

with other research organizations involved in seaweed resource survey in deep waters, estuaries and backwaters of Tamil Nadu. The seaweed collections for agarophytes (*G. acerosa, G. edulis, G. crassa, G. foliifera* and *G. verrucosa*) and alginophytes (species of *Sargassum* and *Turbinaria*) during 1978–79 to 2002–03 was reported by Kaliaperumal *et al.,* during 1997 & 2004. Although there is no seaweed exploitation data during 2005-2014, it was observed that there was a high fluctuation in availability of agarophytes resources. But, from 2015 onwards, ICAR-CMFRI is publishing annual seaweed landing data in marine fish landings report.

The ICAR-CMFRI is also pioneering in marine finfishes and shellfishes research. The idea of bio-mitigation along with increased biomass production can be achieved by integrating different groups of commercially important aquatic species, which are having varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA) which is gaining importance at global level. In this context, the CMFRI has successfully conducted the demonstration of IMTA under participatory mode with a fishermen group at Munaikadu (Palk Bay), Tamil Nadu by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*) during 2014-16.

Status of seaweed farming

Kappaphycus alvarezii is one of the very economically important red algae, which yields carageenan, a commercially important polysaccharide. Carrageenans are used in a variety of commercial applications in food, pharmaceutical, cosmetics and mining industry (Hayashi and Chow, 2007). Commercial cultivation of *K. alvarezii* originated in Philippines in the year 1960 (Doty & Alvarez, 1975). Since then, countries like Japan, Indonesia, Tanzania, Fiji, Kiripati, Hawaii and South Africa have been cultivating this species on a large scale (Subbarao *et al.,* 2008). In India, cultivation of *K. alvarezii* seaweed was initially started at Mandapam on the southeast coast of India, during 1995–1997 (Eswaran *et al.*,2002). The cultivation was popularized by PepsiCo during 2002 and later PepsiCo was taken over by AquAgri Processing Private Limited in 2008 (Krishnan and Narayanakumar, 2010). Many SHG's of women has been formed by the Corporate houses Pepsi, followed by Aquagri (Narayanakumar and Krishnan, 2011). Commercial cultivation of *K. alvarezii* was started in 2005 along the Tamil Nadu coast. At present, *K. alvarezii* production is carried out in five coastal districts (38 villages) of Tamil Nadu namely Ramanathapuram, Pudukottai, Thoothukudi, Thanjavur and Kanyakumari.

Apart from farming, seaweed (*Gelidiella acerosa, Sargassum* spp. and *Turbinaria* spp.) collection in the Gulf of Mannar and Palk Bay region, especially in the Ramanathapuram district of Tamil Nadu is being carried out mostly by women for their livelihoods.

The seaweed farming has proved to be an economically viable alternate livelihood option in Gulf of Mannar and Palk bay region of Tamil Nadu. The production has substantially increased from 21 tonnes (dry weight) in 2001 to 1500 tonnes (dry weight) in 2013 with reasonable increase in the purchase value from less than Rs. 4.50 to Rs. 37.00 – 40.00 kg^{-1} (dry weight) in 2016. However, there is a steep decline in the farming of *Kappaphycus alvarezii* since August 2013 due to "Heat Stroke" *i.e.* increase in sea surface temperature above 32°C in the coastal belt from Vedalai to Verkodu areas where *Kappaphycus* was farmed intensively. Hence, there was a reduction in number of farmers adopting the seaweed

farming during the year 2014. Though the farming was recovering from the year 2015, the productivity has significantly reduced. The seaweed farmers and industries expressed that there is a scarcity in availability of quality seed material for *Kappaphycus* cultivation in coastal areas of Tamil Nadu. Moreover seaweed farming in India revolves around only *Kappaphycus*. Farming of native seaweed species like *Gracilaria, Gelidiella* etc., is yet to be popularized due to shortage of seaweed materials and crop duration is longer.

Seaweed Farming Techniques

Kappaphycus farming is being widely adopted by floating bamboo raft method in Tamil Nadu coast. In few places tube net and monoline culture technique is also being practiced for seaweed cultivation. Floating raft is made of bamboo with 12' × 12' for mainframe and 4' x 4' for diagonals. In each raft, 20 polypropylene-twisted ropes are used for plantation. Around 150 – 200 grams of seaweed fragments are tied at a spacing of 15 cm along the length of the rope. A total of 20 seaweed fragments can be tied in single rope. The total seed requirement per raft is 60 – 80 kg. Fish net of 4m x 4m size is tied at the bottom of the raft to avoid grazing. In normal season, a cluster of 10 rafts are positioned in the near shore area of 1.0 to 1.5 m depth using a 15 kg anchor. Whereas during rough season the same cluster has to be installed using two or three anchors. Most of the seaweed farmers are using 25 to 45 rafts for their cultivation. Due to lack of space for the farming, in most of the villages a farmer is restricted to use maximum of 45 rafts only (Johnson *et al.*, 2017).

Self Help Group model in *K. alvarezii* cultivation

In *K. alvarezii* cultivation, self-help group model promoted by District Rural Development Agency (DRDA), Department of Bio-Technology (DBT), Tamil Nadu State Fisheries Department with the assistance of Non-Governmental Organizations (NGOs) is found to be more effective. A group of five members including men and women is formed, which is called as Joint Liability Group (JLG). Some of the eligibility conditions, which a group has to fulfill, were each member in the group has to undergo three days training programme on seaweed cultivation and should have interest and willingness to take up the *K. alvarezii* farming. The family should fall in Below Poverty Line (BPL) category. Preferably, they should have place near the seashore and should not be a defaulter with any financial institution / government.

The group that fulfills the above conditions is eligible to avail Rs.2.25 lakhs as loan for 225 rafts (45 rafts per member). Out of this 50 per cent is given as subsidy through the concerned promoting agency. Remaining 50 per cent is availed by the members through bank loan at nominal interest, which has to be repaid within three years. During 2005-2008, majority of seaweed farmers benefitted through this scheme. Later from 2012-13, National Fisheries Development Board (NFDB) is also promoting seaweed farming by providing 50 percent subsidy assistance on unit cost of bamboo raft method (Rs.1,000/-) to women SHG's and entrepreneurs. Apart from this, AquAgri Private Limited, Delhi provided infrastructure for farming to a seaweed farmer and take back the expenditure for infrastructure from his harvest at the rate of Rs.2 per kg on dry weight basis.

To promote seaweed cultivation as a livelihood support for the fisherwomen, five groups has been formed at Punnakayal, Tuticorin district with 20 members each in a group. Out of the expenditure of

Rs. 4,27, 500/- for a group, 50 percent subsidy was provided by Tamil Nadu Government during September 2016 and the bank provided the rest of the amount.

Economics of seaweed farming

The total cost of production for making one bamboo raft for *K. alvarezii* farming worked out to be around Rs.1,440/- (Table 1). As the investment is comparatively less and farmers were also supported through subsidy scheme the spread of the technology was rapid.

Table 1 Economic Feasibility Analysis of Seaweed Farming from 45 rafts (2014-16)

(A person in a group can maintain 45 rafts) (Total 4 cycles in a year; each cycle is 45 days)

S.No	Particulars/Description	2014		2015		2016	
		Quantity Required	Cost per Raft (Rs)	Quantity Required	Cost per Raft (Rs)	Quantity Cost per	Required Raft (Rs)
1.	3-4" dia hallow bamboos of 12'x 12' for main frame + 4' x 4' for diagonals (without any natural holes, crakes etc.,) @ Rs.5.50 per ft of bamboo	64'	352.00				
2.	Five-toothed iron anchor of 15 kg each (@ Rs.50 per kg) – one anchor can hold a cluster of 10 rafts	1.5 kg	75.00				
3.	3 mm PP twisted rope for plantation – 20bits of 4.5m each (@ Rs.230 per kg)	420 gm	97.00				
4.	Cost of HDPE braider pieces (20 pcs x 20 ropes = 400 pcs of 25 cm each) (@ Rs.330 per kg)	165 gm	55.00				
5.	Raft framing rope 6m x 12 ties per raft i.e., 36mts of 4mm rope (@Rs.230 per kg)	650 gm	150.00				
6.	Used HDPE fishing net to protect the raft bottom (4m x 4m size) (@ 70 Rs/ kg)	1 kg	70.00				
7.	2mm rope to tie the HDPE net (28 mts) (@ Rs.230 per kg)	100 gm	23.00				
8.	Anchoring rope of 10 mm thickness (17m per cluster of 10 rafts) (@ Rs.220 per kg)	100 gm	22.00				
9.	Raft linking ropes per cluster 10 rafts – 6mm thick – 2 ties x 3m x 9 pairs = 54m length (@ Rs.230 per kg)	100 gm	23.00				
10.	Raft laying charges	-	33.00				
	Fixed Costs in Rs. (Total initial investment per Raft)		**900.00**				

	Variable Expenditure					
1.	Seed material (150 gm x 400 ties @ Rs. 5.00 per Kg)	60 kg	300.00	60 kg	300.00	60 kg	300.00
2.	Braider twining charges		180.00		180.00		180.00
3.	Transportation		150.00		150.00		150.00
4.	Raft maintenance		450.00		450.00		450.00
5.	Miscellaneous expenses		27.00		30.00		30.00
	Recurring Cost (in Rs.)		**1,107.00**		**1,110.00**		**1,110.00**
6.	Interest on fixed cost (7%)		63.00		90.00		90.00
7.	Depreciation		270.00		90.00		90.00
	Total Operating Costs (in Rs.)		**1,440.00**		**1,470.00**		**1,470.00**
	Revenue						
1.	Annual seaweed production (190 kg/raft)* *(Retaining 60 kg for next crop, total seaweed production from 45 rafts; 4 cycles)*		23,400 kg		23,400 kg		23,400 kg
2.	35 % of total seaweed production is sold in fresh form		8,190 kg		8,190 kg		8,190 kg
3.	Price of fresh seaweed (Rs. per kg)		5		5		5
4.	**Revenue in Rs. (A)**		**40,950**		**40,950**		**40,950**
5.	Remaining 65% of total seaweed production is sold in dried form (15,210 kg will give 1,521 kg of dried seaweed)		1,521 kg		1,521 kg		1,521 kg
6.	Price of dried seaweed (Rs. per kg)		35		35		37.50
	Revenue in Rs.(B)		**53,235**		**53,235**		**57,037.50**
	Gross Revenue in Rs. (A+B)		**94,185**		**94,185**		**97,987.50**
	Total cost of production (Rs.) (Rs.1,440 × 45 rafts)		**64,800**		**64,800**		**64,800**
	Net income (Rs.) (Gross revenue - Total cost of production)		**29,385**		**29,385**		**33,187.50**
	Operating Ratio		**0.69**		**0.69**		**0.66**

In comparison to 2012-13, from the year 2014 onwards there is 25-30% reduction in per raft yield

The crop duration is for 45 days. In a year, four to six crops/cycle (6 to 9 months) can be harvested depending on the climatic condition. Planting of 150 g grows up to 500 to 1000 g in 45 days. In one raft of 12 x 12 ft size an average yield of 200-260 kg was obtained before the year 2012-13, whereas after the year 2013 it is 160-190 kg. After retaining 60 kg as seed material for the next crop, remaining 100-130 kg is sold either in fresh or dry weight basis. The average dry weight percentage of the harvested seaweed is 10 per cent. Now farmers receive Rs. 4.00 and Rs. 37.50 per kg for fresh and dried seaweed respectively. Most of seaweed farmers earn around Rs. 50,000/- to Rs.1,00,000/- annually. This finding

indicates that the *Kappaphycus* farming provides a substantial return, which in turn improves the livelihood of coastal fisherfolk.

Constraints in K. alvarezii farming

The constraint faced by the farmers was heavy loss of crop due to high temperature/disease. The other constraints were reduction in seaweed yield due to grazing and damage of bamboo rafts during cyclone.Seaweed farming is a low cost simple technology, provides substantial returns and had better adoption among the coastal fisherfolk. A fisherman family earns around Rs.50,000/- to Rs.1,00,000/- annually through seaweed cultivation. This trend shows that any economically viable livelihood options like seaweed farming, which can supplement the capture fisheries is readily accepted and adopted by the marine fisherfolk. At present the availability of agar yielding algae *Gracilaria* and *Gelidiella* is in declining trend. In order to meet the requirement of the agar industry, cultivation of *Gracilaria* and *Gelidiella* has to be promoted. The major constraints reported by farmers in seaweed cultivation were heavy loss of crop due to high temperature/disease, reduction in seaweed yield due to grazing and damage of bamboo rafts during cyclone. To overcome the problem of high temperature in the farming of *Kappaphycus alvarezii,* slightly deeper waters where the temperature is ideal for good growth of kappa seaweed can be identified for farming. It is essential to bring seaweed cultivation under insurance coverage to compensate the crop loss during natural calamities.

Aquaculture nutrition and feed technology in India

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Indian aquaculture production is mainly from freshwater fish known as Indian major carps (IMC) followed byshrimp (brackishwater), catfish, freshwater prawn and some bivalves. Total aquaculture production of India in 2017 is estimated as 5.77 million metric tonnes (mmt), out of which 3.4 mmt is IMCs. Out of the remaining 2.3 mmt, shrimp production is 550000 tonnes and catfish is 280000 tonnes. The remaining 1.47 million tonnes is contributed by all other species put together including production form mariculture and secondary aquaculture.

The total aqua feed production currently (2017 industry estimates[1]) is 572000 tonnes of fish feed and 684000 tonnes of shrimp feed. Roughly, 960000 tonnes of feed is sold in Andhra Pradesh and 96000 tonnes is sold in all other states of India which is approximately one million tonnes of feed per year.When we look at the capacity of aqua feed production, with about 13 extruded fish feed mills the installed capacity is 2.8 million tonnes with less than 50% capacity utilization. There are about 25 shrimp feed mills with an installed capacity of 1.3 million tonnes. However as the growth of shrimp culture is faster than fish culture the capacity utilization is more than 60% currently.

Freshwater fish nutrition

Aquaculture nutrition in India was dominated by feeding a mash of ground nut/ cotton seed oil cake and wheat/ rice bran mainly to freshwater fish. This technology was improvised by the ingenuity of the fish farmers. Perforated gunny bags filled with this mixture was suspended into the ponds using bamboo poles which bend due to the weight of the feed material in it. Fishes feed through the perorations and as the weight of the bag decrease it emerges up from the water column. A rope tied across the pond is also another way of hanging of feed filled bags dipping into the pond water. This technology minimised waste and ensured effective utilization of the feed resource by the fish.

From this scenario traditionally, in 2007 floating fish feeds were applied and demonstrated in fresh water fish farms along with the cost: benefit ratios mainly be American Soybean Association. Satiation feeding technique based on the tenet, the fish will tell us how much it can eat, approximately a saving of Rs. 5/- per Kg fish produced was demonstrated.

There are two products available commercially for fresh water aquaculture. Carp feed which is fully floating with fish meal and fish oil and catfish feed which is also a floating feed devoid of fish meal and fish oil. Both are produced using single screw extruders. The cost of extruders varies from 50 million to 100 million Indian Rupees (INR), depending upon their capacity.

Brackishwater shrimp and fish nutrition

In this segment shrimp feed is the major input which is a sinking pellet manufactured using steam pelleting technology. Tiger shrimp (*Penaeus monodon*) and white leg shrimp (*Penaeus vannamei*) are the species cultured. The feeds contain 34 – 41% protein and 6% fat. Tiger shrimp feeds require approximately 30% marine protein whereas white leg shrimp feeds contain 30% soy. As the pellet is a sinking one it can be produced on farm also which is resorted to by several farmers to make feeding cost-effective. Shrimp feed pellet mill machinery costs 10 million INR. Backishwater fish cultured in India are the Asian seabass, grey mullet and pearl spot or green chromide. Their gross nutritional and energy requirements are given in the Table below.

Nutrient	*L. calcarifer*	*Mugilcephalus/ Liza tade*	*Etroplussuratensis*
Energy (Kcal/kg)	4000-4500	4000-4500	4000-4500
Protein %	45-55	27-35	30-32
Lipid %	6-18	6-9	6-8
Carbohydrate %	10-20	30-40	30-40

Floating feeds are appropriate for these fish. Indigenous technology for their production is available from Central Institute of Brackishwater Aquaculture (CIBA), Chennai, Tamil Nadu, India for both fish and shrimp feed.

Marine fish feed

Cobia, pompano and grouper are the species of marine fish for which breeding and seed production technology is available in India. Feeds for these species of fish are yet to be produced indigenously on a commercial scale because marine fish culture has still not grown to a commercial scale. Most of these fish have a protein requirement of above 40% and a fat requirement of above 10%. Fully floating or slow sinking feeds (especially for grouper) are required. The technological challenge is floating pellets cannot be produced with internal fat levels above 6%. This is overcome using vacuum coating of additional fat with a technology known as post-pellet liquid application (PPLA) which is yet to come to India.

Micro feeds

These are feeds below 1.5 mm in particle size or diameter. The starting size can be as low as 10 microns. They are used for larval nutrition, ornamental fish nutrition and nursery nutrition for the production of fish of stockable size. Hatcheries primarily depend on these feeds to overcome crisis situations when sufficient quantities of live feed cultures are unavailable or when the cultures maintained crash. First feed is normally microalgae which are less than 10 microns. Then comes the zooplankton range from 100 – 500 microns. Normally, rotifers and artemia nauplii are used to complete the hatchery cycle and wean the young fish to formulated feeds. Micro feeds are used to replace or even co-feed the larvae. The technology for production of these feeds is also extrusion in general and twin-screw extrusion

to be specific. This is an aqua feed segment where the entire requirement of this country is imported now, including the ornamental fish feeds and nursery feeds.

Larval nutrition and bioenrichment

Even though a combination of phytoplankton, artemia and rotifers generally used for feeding larvae in hatcheries, artemia and rotifers are nutritionally deficient especially in fatty acids. Copepods are copepodites are an alternative which is nutritionally complete as far as marine fish larvae are concerned. Copepod cultures are difficult to maintain. In such a situation the technique known as bioenrichment is used to enrich the larvae with the essential fatty acids. Rotifers and artemianauplii in nature feed on microalgae. They are also capable of feeding on any inert material provided. Thus, polyunsaturated fatty acid (PUFA) rich emulsions or algal products are used to boost the nutritional profile of rotifers and artemia and feed them to larvae in hatcheries.

On a commercial scale only shrimp hatcheries are in operation. Hatchery cycles close to four weeks are completed with live feeds and formulated feeds. Formulated feeds are of two types which are an algal replacement and another crustacean diet which can replace artemia nauplii. These products are also not produced in India which needless to say, falls in the micro feed segment.

Broodstock nutrition

In general, this is an area where researched information is scanty. There are a multitude of factors contributing to the reproductive success. In freshwater carps high protein and high lipid (up to 14%) diets are found to enhance ovarian development, spawning behaviour, fecundity, egg size, weight and spawning behaviour. In marine fish, it is more complicated. No single ingredient of formulated feed can be suggested. Functional nutrients like fatty acids, phospholipids and carotenoids have vital roles. There is interplay of vitamins, minerals and hormones. Sex reversal, temperature and water quality are a few other factors that complicates reproduction in fish. Therefore, raw seafood like cephalopod meat, roe, mussels, clam meat, formulated feeds and feed additives in combination are fed. Some fish do not feed after gonadal maturation and draws nutrition from stored nutrients which influence reproduction. Continuous spawners require a regular supply of high quality nutrients. It is also known that highly unsaturated fatty acids from marine oils, vitamin E, vitamin C and carotenoids like astaxanthin and some amino acids of marine origin has tremendous influence on sexual maturation and spawning of fish. Still, brood scientific brood stock management is not a part of hatchery management.

Feed technology

Shrimp feed is a steam cooked pellet which sinks with a water stability of more than three hours. As mentioned earlier it is produced using a pelletizer with ring die. Floating fish feeds for grow out are produced using single-extruders where the feed material undergoes phase transition where gelatinaization of starch and gelling of protein also takes place. Puffing of starch leads to formation of air pockets due to which the pellet floats. The main advantage of using a floating pellet on farm is that wastage of feed can be minimized to zero to derive the economic benefit. Laravl feed production is a mix of several technologies. Grinding of feed material to micro particles is done with the help of micronizers which

are mills meant for reducing the particles to micron range. Twin-screw extrusion is the basic process used. This is followed by use of technologies like marumerization or spheronization to obtain the desired shape and size. Other technologies used in larval feed production are microencapsulation and micro embedding according to need. Shrimp larval feeds are either micro particulate or microencapsulated.

Thus, aquaculture nutrition and feed technology requires knowledge of the nutritional requirements of fish and crustaceans. Knowledge of the feed resources and feed stuffs is also essential. Feed formulation and feed production methods to suit conditions in which the animal is reared is also essential. Finally, management of the use of nutritional inputs in any culture system is paramount to derive the desired benefits from an aquatic food production system.

Bivalve Farming in India

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Bivalve molluscs like clams, mussels and oysters are good sources of cheap and high quality protein, and their shells are used for ornaments and other industrial products. They are ideal species to culture because of their low position in the food chain. Farming of bivalves can also increase the income of small-scale fishermen faced with dwindling catches, as well as provide livelihood for unemployed people in coastal areas. According to the FAO, worldwide, aquaculture production has grown at an average annual rate of 8.4% since 1970 and reached over 63 million tonnes in 2011. In the global aquaculture production bivlaves production fluctuates between 14-21%. Of the Mariculture production of 18.3 million tonnes molluscs contribute about 75.5% (13.9 t). The share of the molluscs is contributed by bivalves such as oysters, mussels, clams, cockles, ark shell and scallops.

The Central Marine Fisheries Research Institute (CMFRI) in India developed bivalve farming technologies in the 1970s, but these were not widely adopted at the time. In 1993, CMFRI undertook an action research program to encourage farming of edible oysters (*Crassostrea madrasensis*), mussels (*Perna viridis* and *Perna indica*), clams (*Paphia malabarica*) and pearls (*Pinctada fucata*) along the southwest coast of India. Successful demonstration of the viability of bivalve farming led to the initiation

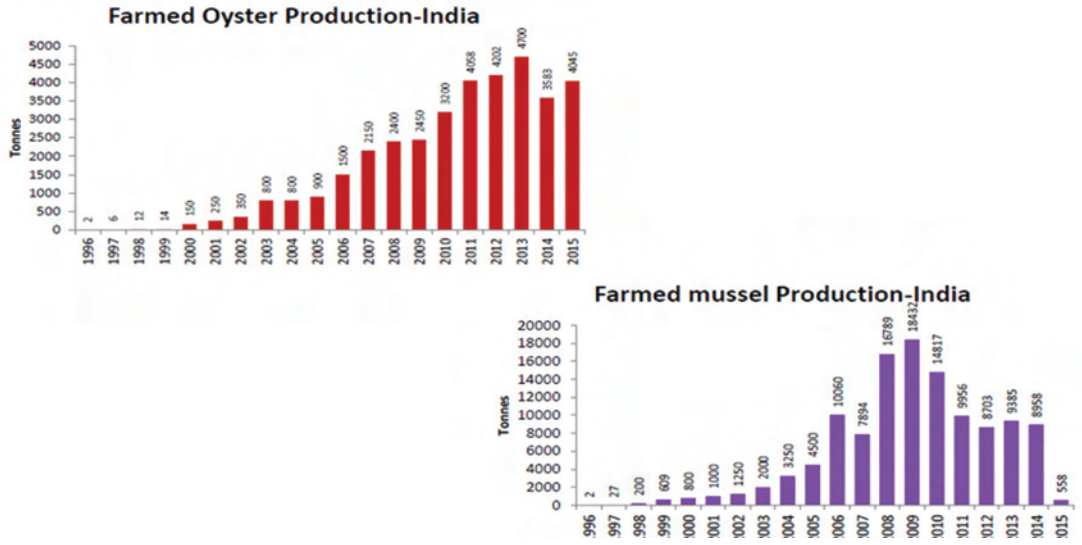

Fig. 1. Bivalve Mariculture production in India

of commercial farming of mussels and generated interest among farmers and entrepreneurs in developing production of pearls and farming of edible oysters.

For the farming of bivalve molluscs, a suitable farming site must have the following characteristics:

1. Spat/seed sufficient quantity and quality or spatfall
2. Area protected from prolonged flooding, strong winds and waves
3. Productive water;
4. Sufficient tidal current flow for transport of phytoplankton and oxygen and removal of wastes.
5. Water quality or physio-chemical conditions of the area must be suitable for growth and survival, especially salinity and temperature.
6. Area free from industrial wastes, sewage and other pollutants (Fujiya, 1970; PCARRD, 1983).'

Culture methods

The basic methods of farming bivalve molluscs are the bottom and the off-bottom culture methods. The bottom culture system is also called the broadcast or the bottom sewing technique. For the off-bottom culture system, this includes the stake or pole method, rack, raft and long-line method. The rack, raft and long-line method are also called the hanging or suspended culture technique. The stake and rack method are mainly used in shallow, intertidal waters while the raft and long-line methods are generally utilized in deeper, open waters. In the following discussion, the culture procedures practiced in the different countries will be described. Also, some data on the economics of the different farming methods will be presented.

Bottom culture

In the Philippines, the simplest way of farming oyster is the bottom culture technique. Numerous collectors like oyster shells, stones, gravel, tin cans, or any hard object are scattered over bottoms where spatfall is known to occur. The oyster beds are sandy or rocky, non-shifting and usually near the farmer's house. In some places, a mat made of bamboo splits tied together is used as a spat collector. The principal advantage of this method is the minimal amount of investment. A disadvantage, however, is that the collectors in the bottom can be washed away by strong currents or the cultured oysters can be buried under mud or sediments (PCARRD, 1983).

The oysters, *Crassostrea virginica*, and the clams, *Mercenaria mercenaria* and *Mya arenaria* are also cultured on the bottom in the United States of America (Castagna, 1970; Milne, 1979). The culture sites have a firm bottom and a moderate water current flow. Silt is removed by regular suction dredging and through flushing with water jets operated from work boats. The effect of siltation is also minimized by transplanting the stock once or twice during the culture period. For clam culture in Virginia, loses are incurred due to predation by crabs and starfish. Clams are protected through the use of screened boxes and trays, fenced enclosures and net coverings. Another method is by spreading a layer of shell, gravel or aggregate 25–75 mm in height. The clam seed eventually burrows through the layer which protects it from large predators.

Bottom culture of mussels, *Mytilus edulis*, has attained a high degree of mechanization in Holland. Farmers are allocated areas in the sea bed of the Waddenzee. These culture plots have a depth ranging from 3–6 meters. Prior to transplanting, unwanted predators are removed from the plots using a special roller dredge. Juvenile mussels, 8– 13 mm in length, are dredged from public grounds and spread over the private mussel beds where subsequent thinning is done to ensure better growth. The marketable size of 7 cm shell length is reached after 20 months of culture. Mussels are also transferred to the Rhine estuary to clean themselves of ingested silt and stored until market prices become favorable. A Dutch mussel farmer can produce 10 tons of live mussels per hectare per year (Hulburt and Hulburt, 1980).

Pole or stake culture

In France the mussel, *Mytilus edulis*, are grown using oak poles (bouchot culture). Poles, 3 m long and 20 cm in diameter, are driven into the sea bed with ½–2 m exposed above the ground. The bottom 30 cm of the exposed portion is wrapped with smooth plastic to minimize predation by starfish and crabs. The poles are spaced 1 m apart and arranged in rows with 3 m distance between rows. Seed mussels are collected in ropes placed in natural mussel beds and then wrapped around the oak poles. The mussels grow rapidly and fill the poles to several layers thick. The farmer resorts to periodical thinning of the stock and small specimens are placed in plastic net tubes, 2 m long and 15 cm in diameter. These flexible net tubes are wrapped around bare poles to start the growth process again. It takes 12–18 months for a mussel to reach the marketable size of 6–7 cm. Mussel growing areas are leased from the government and most bouchot operations are conducted as family enterprises, each having 15,000–20,000 poles. Each pole can yield 9–11 kg of mussels/yr and one acre can yield about 5 metric tons of mussels per year (Hulburt and Hulburt, 1980).

In the Philippines, mussels are grown on bamboo poles staked at ½ meter depth and one meter apart in soft, muddy bottoms. Mussels settle on the submerged bamboo stakes at a rate of 2,000–3,000 seeds per meter. Bamboo poles are regularly inspected to monitor growth as well as to eliminate predators like starfish and crabs. Mussels are harvested 6–10 months after stocking or when the animals reach 5–10 cm in length. Harvesting is done by pulling up the bamboo poles and loading them into a raft where the mussels are stripped off using an iron rod. In other cases, divers are hired to pick out the bigger mussels and the small ones left for the next cropping season. This selective harvesting results in two or more croppings within the 6–8 months of the culture period. Harvested mussels are initially cleaned by spading or stamping, then placed in baskets and shaken vigorously in seawater until they are clean of barnacles and dirt. Bamboo poles that are worn out are disposed while the good ones are cleaned for the next farming season. the stake method is a cheap and simple way of growing mussels but has also some disadvantages. The bamboos decay easily and it is sometimes difficult to coincide staking operations with spatfall. This culture system also facilitate siltation which makes bays and estuaries too shallow for mussel culture (PCARRD, 1983).

Rack culture

The basic design in the rack culture method is a structure fixed in the seabed which supports collectors like trap, ropes or shells tied on strings. In Japan, oyster seeds are collected by rens, which

consist of 2 m length of No. 16 galvanized wire containing 100 scallop or oyster shells. The rens are suspended from horizontal bamboo poles which are set below the low spring tide mark. Two types of frames are used to support the horizontal poles. The first consists of two crossed bamboo poles driven into the sea bed in the form of an X where the horizontal pole is tied in the crotch. The second framework consists of rectangular bamboo platform 1 m wide and 3–6 m long which is supported by four corner posts driven into the bottom. The collecting rens are then draped closely packed together over the horizontal bamboo poles. In the various prefectural laboratories, biologists monitor the plankton and put out the test collectors to forecast the setting peak of the oyster spats. The oyster farmers are then advised on the best time to put out their spat collectors (Fijiya, 1970; Koganezawa, 1979).

The spat collectors in the rack method used in Brittany, France are made of semi-cylindrical ceramic tiles. The tiles, 30 cm long and 12.5 cm in diameter, are arranged in pairs and stacked at right angles to one another with the concave surface facing downward. A stack is made up of 5–6 pairs of tiles measuring 1 m high and wired together for ease of handling. The tiles are covered with lime for easy removal of oyster seeds which are then transplanted to the oyster parks. A new light weight spat collector, consisting of a plastic mesh material of similar size and shape is now being used. These plastic collectors are immersed in a mixture of six parts lime to one part cement to improve adhesion of the oyster larvae. The spats are easily removed by simply bending the plastic collectors and then transferred to the oyster parks in Brittany. On the southern coast of Brittany, there are 500 individual parks of 2–4 hectares in size while the south coast has 200 oyster parks of 20 hectares each (Milne, 1979).

For the Australian rack method, wooden collectors are used for the culture of the Sydney rock-oyster, *Crassostrea commercialis*. The wooden collectors are constructed by nailing four 2 m long, 2.5 cm^2 hardwood sticks between two 1 m rails. These frames are tarred to protect the sticks from teredos and borers as well as to provide a clear and smooth surface for the spats. The tarred frames are stacked together and wired to very sturdy racks made of two parallel rows of posts with 5 × 2.5 cm hardwood rails along each row. From the spatfall areas, the wooden collectors are transferred to the maturing areas until the oysters reach marketable size (three years later). The average annual production from Australian oyster beds is 0.91 ton per hectare. However, good areas under intensive cultivation have produced 5.2 tons of live oysters per hectare/year using the tray method, and 2 tons/hectare/year using the stick method (Bardach et. al., 1982; Milne, 1979).

In the Philippines, a variation of the rack method is made using polypropylene ropes of 12 mm diameter, arranged into webs and tied vertically to bamboo posts. A web consists of two 5 m parallel ropes positioned 2 m apart to which a 40 m rope is tied in a zigzag fashion at intervals of 40 cm between knots along each of the parallel ropes. Bamboo pegs, 20 cm in length and 1 cm in width, are inserted into the zigzag rope at a spacing of 40 cm between pegs. These pegs prevent the crop from sliding down the rope when it becomes heavy. Full stretched rope-web collectors are positioned 3 m apart along the rows. During harvest, rope webs are untied from the poles and lifted into the raft. Clusters of mussels are detached by cutting the byssal filaments with a sharp knife. Mussels are then placed in baskets and washed repeatedly with seawater before bringing them to the market. Web collectors are cleaned and dried before being used for the next culture season (PCARRD, 1983).

Raft culture

The raft used in mussel culture in Spain is made of a wooden framework of 5 cm^2 timbers and floats of concrete, steel, styrofoam or fiberglass material. The average size of the raft is 23×23 m which supports 700 ropes, each 9–m long. The rafts are anchored along the sides with large concrete moorings. Seed mussels, 6–8 mm, are gathered from natural mussel beds and placed inside a water-soluble rayon tube netting. The netting is wrapped around the ropes and by the time the netting has disintegrated, the mussels have attached themselves to the ropes suspended from the raft. The marketable size of 8-10 cm is reached after one year of culture. During harvest, mussel - laden ropes are hoisted aboard a work-boat with a large wire-mesh basket lowered under the ropes. The ropes are given a vigorous shake to remove the mussels. Small-sized mussels are wrapped into new ropes for transplanting while marketable mussels are transported directly to the processing facilities. Mussels sold fresh are required by Spanish law to be depurated for at least 48 hours. Production of mussels in 9–m rope is 113 kg live mussels per year and a single raft produces 80 metric tons of live mussels per year (Hulburt and Hulburt, 1980).

The Japanese raft for oyster farming has an average size of 8×16 m and carries 500–600 wire collectors. It is made of 10–15 cm diameter bamboo or cedar wood poles and bighead either by hollow concrete drums, tarred wooden floats or styrofoam cylinders. Most of the newly constructed rafts use styrofoam materials and these floats are usually encased in polyethylene bags to protect them from barnacles and other boring organisms. Rafts are tied together in rows 5–10 m apart and anchored at each end of the line. The Japanese oyster culture system is divided into two categories, one and two-year farming. In the one-year farming, oyster spats are immediately transferred to rafts where they remain until they reach marketable size. For the two-year method, oyster seeds are grown in racks placed in shallow waters for the first year and then transferred to the rafts for the second year. The average annual production is 223,000 metric tons of live oysters from the Japanese raft culture method (Fujiya, 1970; Koganezawa, 1979).

In the Philippines, raft culture is not widely practiced. A raft, 6×8 m, is made of a bamboo lattice structure from which ropes are hun and kept afloat by either metal or plastic drums, styrofoam blocks or ferro-concrete buoys. Spats are collected by nylon ropes hung from the bamboo framework at ½ meter apart with weights at the end of the ropes. When spats are 10–15 mm in length, they are thinned by hand and transplanted to growing ropes made of polypropylene, polyethylene, cabo negro and abaca. The growing ropes are hung from the raft at 1 m apart and their length would depend on the water depth at low tide. To avoid transplanting, mussels are collected and cultured on the same growing ropes (PCARRD, 1983).

Edible oyster farming in India

The oysters are highly esteemed sea food and considered a delicacy in USA, Europe, Japan etc. In India there isa growing demand for oyster meat in some parts of the country. It is one of the most widely cultivated species. As early as the first century BC the Romans were the first to develop simple methods of collecting oyster seed sand growing them for food, the Japanese developed 'Habitat culture technique' i.e., culture in nets fixed to bamboo poles during the seventeenth century and at the turn of the 20

century they evolved off bottom culture, especially hanging methods. The awareness about the vast potentialities for development of oyster farming in tropics is recent. Serious efforts are now being directed in its development under tropical conditions.

In India pioneering attempts were made by James Hornell in 1910 in developing Oyster Culture in erstwhile Madras state. Central Marine Fisheries Research Institute undertook scientific investigations at Tuticorin from early 70's and as a result, complete package of the technology is now available in the country. Vast stretches of backwaters, estuaries and bays spread over several lakh ha. are resent along Indian coast harbouring natural population of the oyster suggesting suitability of the habitat for oyster culture. Being filter feeders, the oyster converts primary production in the water into nutritious sea food.

Crassostrea madrasensis is the main species in India. It tolerates wide variations in salinity and inhabits backwaters, creeks, bays and lagoons and occurs, from the intertidal region to 17 m depth. Oyster farming technology developed by Central Marine Fisheries Research Institute is a simple and easily adaptable technique. Since 1993 concerted effort has been put in by CMFRI to popularize this technology. Kerala, is the first state to commercialize this technology and many coastal villagers have benefited from this. These farming activities have increased national production of farmed oyster from nil to 140 tonnes in 2000. One of the significant factors is that more than 80% of the oyster farmers in Kerala are women and they have emerged as productive, self reliant participants for improving the families' nutritional and living standards. Oyster seed are collected from estuaries by placing suitable collectors called cultch in the water column at appropriate period. During spawning seasons the spat collectors are suspend from racks.

Cultch is the term used for spat / seed collector. For suspended method of oyster culture cutch made of oyster shells have been found to be Ideal. Empty oyster shells are cleaned manually to remove the foulers and then washed to remove silt. A small hole is made on the shell and these are strung on 3mm dia nylon rope with a spacing of 15 to 20 cm between each shell (5 shells per meter rope). Such strings are called ren. The spaced rens can be used as such for grow out system. For seed collection purposes the shells are strung continuously without spacers (10 to 15 shells per meter) and after the attachment of seed they shells can be removed and restrung at the rate of 5 shells per meter which is the ideal density for grow out. If the oysters are to be grown by the tray method then empty shells or lime coated tiles can be placed in the trays for seed collection. Lime coated tiles gave encouraging results and on a single tile, as many as 120 larvae are known to settle.

One of the main factors that determine the success of the farming operation is the period when the clutches are placed for seed collection. If they are laid in advance of spatfall, they may be covered with silt or settlement of foulers , making them unsuitable for the oyster larvae to settle. The larval period in *C. madrasensis* is 15-20 days. The ideal time for laying the spat collectors in the water is about 7 -10 days after peak spawning (as determined by gonad examination and abundance of early larval stages in the plankton). Strong currents interfere with larval settlement and may result in poor spat collection.

Sheltered areas offering protection from strong wave action are preferred. From intertidal region to areas extending upto about 5 m depth can be considered for adopting suitable culture method. Similarly the culture technique is adopted depending upon the type of substratum. On-bottom culture method is substrate specific while off-bottom method has little to do with the nature of substratum. Large scale moralities have been reported in salinities below 10 and above 40 ppt when the natural oyster populations of *C madrasensis* were exposed for prolonged periods. The natural populations occur at a temperature range of 21 to 31 °C.

Farming methods

They are broadly grouped as bottom (on bottom) culture and off-bottom culture. Raft, rack, long-line and stake are used in the various off-bottom culture practices. The off bottom culture methods are advantageous over the bottom culture in the following respects.

1. Relatively rapid growth and good meat yield.
2. Facilities three-dimensional utilization of the culture area.
3. The biological functions of the oyster such as filtration feeding etc. are carried out independent of tidal flow
4. Silting and predatory problems are negligible.

Farm management

Periodic checking of the farms is essential. The main points to be checked are replacement of broken farm structure and resuspending loosened rens which touch the estuarine bottom. High mortality rates have been observed when the rens fall on the ground. To tide over these problems periodic checking is essential Predaters and foulers are also a menace to oyster farmers. Crabs, fishes, starfishes, polychaetes and gastropods are the predators of oysters. At Tuticorin predation of the oysters by the crabs *Scylla serrata* and *Pagurus sp.* has been observed on a small scale. Barnacles are fouler that settles on the wooden structures, trays and oysters. It competes for food with the oysters. It also increases the weight of the ren causing damage to the farm structure.

Harvest of oysters

The oysters are harvested when the condition is high. At Tuticorin good meat yield is obtained during March-April and August-September and along Kerala harvest is ideal during May in Vembanad and Chettuvaestuasry and during August-October in Ashtamudi Lake. Generally high condition index is obtained when the gonad is ripe prior to spawning. Harvesting is done manually.

Mussel farming in India

Mariculture of bivalves assumes greater importance in meeting the increasing protein demands of the human population. Bivalve groups such as oyster, mussel and clams are the most important cultivable organisms all over the world. Mussel farming has a long history that dates back to the thirteenth century. Mussels are farmed in many areas of the world with the most common species cultured being the blue

mussel, *Mytilus edulis*. The main producers of mussels are countries such as China, Korea, Spain, The Netherlands, Denmark, France and New Zealand, In 1997, 1.1 million tonnes of mussels were produced worldwide, with most production occurring in China (nearly 400,000 tonnes). The Indian mussel industry is modest and the maximum production attained is about 20,000 t. Of these, *P.viridis* and *P.indica* forms the most dominant cultivable species. The Central Marine Fisheries Research Institute (CMFRI) has developed eco-friendly techniques for mussel culture. Recently, CMFRI has taken up efforts to popularize mussel culture in all coastal districts of Kerala.

Kerala state is endowed with rich mussel resources and survey reveal that two species viz., *Perna viridis* (green mussel) and *Perna indica* (brown mussel) are present along the rocky shores. The latter is mostly restricted up to the south of Kollam from Cape Comorin in west coast and the former is distributed throughout. Annually about cape Comorian is west coast and the former is distributed throughout. Annually about 15000 t ofmussels are exploited from these regions. Currently farmed mussel production from Kerala state is estimated to be nearly 10,000-20,000 t.

Farming Techniques

Site selection: Open sea and estuarine areas free from strong wave action are suitable for farming. Clear seawater with rich plankton production is ideal for mussel culture. Moderate water current (0.170.25m/s at flood tide and 0.25-0.35m/s at ebb tide) will bring the required planktonic food and will carry away the excessive build-up of pseudofaeces and silt in the culture area. The water should have a salinity of 27-35 ppt. and temperature of 26^{O}C- 32^{O}C. Site should be free from domestic, industrial and sewage pollution.

Open sea farming

In open sea farming, the depth at the site should be above 5m without strong wave action, less turbulent and with high primary productivity. Long line and raft culture techniques are ideal for open sea farming. Mussels grown on long lines become smothered by naturally settling juvenile mussels and other fouling organisms. Effective utilization of easily available material for fabrication of long line and rafts can be done.

Disadvantages of this farming are the poaching and unpredicted climate changes. Protected bays are ideal for mussel farming Estuarine farming Compared to open sea, estuarine ecosystems with less turbulent and shallow depth (<4m) are suitable for mussel farming. Culture of mussels on horizontal ropes results in high productivity due to the effective utilization of the primary productivity Rack culture is ideal for estuarine conditions. Fluctuation in salinity during monsoon season and pollution through domestic and industrial waste are the main constraints in estuarine mussel farming. The farming practice of bivalve molluscs is either on bottom or off bottom culture methods. The bottom culture system is also called the broadcast technique. For the off-bottom culture system, this includes the stake or pole method, rack, raft and long-line method. The rack, raft and long-line method are also called the hanging or suspended culture technique. The stake and rack method are mainly used in

shallow, intertidal waters while the raft and long-line methods are generally utilized in deeper, open waters. Many culture techniques are used for growing mussels worldwide. Some of these are described below;

On-Bottom Culture

This method is widely used in Netherlands, Denmark and Germany. The culture is based on the principle oftransferring seeds from areas of great abundance where growth is poor to culture plots in lower density toobtain better growth and fattening of the mussel. The culture plots must have a firm substratum and less ofdrifting sand and silt particles. In Netherlands, the seeds are dredged from Waddenzee. The seeds are laid inintertidal areas to produce mussels with thick shells and strong adductor muscle. In the subtidal areas higher meatyield and thinner shells are produced fit for processingindustry. The whole process is highly mechanized fromcollection of seeds to harvesting and marketing. Waddenzeeand Zeeland are the important areas for mussel (*M. edulis*)farming. The mussels are distributed evenly by the farmers ifthe stocking is found crowded. The starfish problem is managed by salt treatment or removal using starfish nets. The filtering activity of the mussels produces silt which getsdeposited under the mussel carpet. This hinders the growth ofmussels. Chain harrow are used to level the ground. Theproduction by on bottom culture is about 8 Kg per m2 of mussel plot or 80 tonnes per hectare. An essentialpart of the on bottom Dutch mussel farming is the 'rewatering' process. Here before marketing the mussels, they are kept in special lots for 10-14 days for the process of eliminating the weak and damaged mussel.

Long line culture

This method is becoming very successful in open sea mussel farming. A rope is stretched horizontally near the water surface and maintained 1 -2 m from the surface with buoys. Mussels are grown on vertical ropes known as 'droppers' which hang from the horizontal rope for a length of 4m. Mussel seeds are collected from natural beds and transplanted onto the ropes into a continuous sock-like cotton tube, which is approximately 17.5 cm in width. Small mussels stripped from the collection ropes are inserted. This cotton sock is then wound around the dropper. The mussels grow and attach to the ropes using their byssal threads and the cotton sock slowly disintegrates and falls away. The droppers are placed a minimum of 0.5 m apart and have at least 4 m of free space from the bottom. In deeper waters the gap between the bottom of the line and the sea floor is greater. Anchor ropes extend from each end of the horizontal rope to anchors buried in the mud of the bottom. As the ropes are kept taut, there is no movement around the anchor to disturb the bottom as occurs when boats are anchored.

The density at which mussels can be cultured on long lines could be about 300 per meter, but depends on the food availability, which varies from site to site. Mussels grown on longlines can become smothered by naturally settling juvenile mussels and other fouling organisms. For this reason, most farmers prefer to position their farms away from heavy spat settlement areas to avoid layers of spat attaching to larger mussels.

Raft Culture

The basic principle of raft culture is similar to long line culture in that the mussels are suspended on droppers but these are suspended from the raft instead of the long lines. The raft itself is anchored to the seabed removing the need for several anchoring systems. Long line culture however, creates less of a visual impact, and the droppers can be spaced farther apart to maximize the use of the available phytoplankton. Raft culture is more suited to areas of dense phytoplankton and to smaller operations, as there is less scope for mechanical harvesting. This method of culture is used in the Galician Bays in Spain, Saldahna Bay in South Africa but has been abandoned by the New Zealand industry in favour of long lines. This method has its origin in Spain in the Galician Bay Mussel seeds (*Mytilus golloprovincialis*) settle profusely in the inter-tidal zone in the coastal waters of Galicia. These rias are sheltered, nutrient rich with 3-4 m of tidal range provide ideal environment for suspended mussel culture. The rafts are constructed using a wooden framework of timber and floats of concrete, steel, styrofoam or fiberglass material. These seeds are collected by scrapping the rocks with spade-like steel blades. Seeds can be collected by suspending ropes vertically from the rafts. The length of the mussel ropes varies from 6-9 meters according to the depth of the culture site. As the production is about 10 Kg of mussel per meter of rope, a raft having 600 to 1000 ropes of 6-9 meter may produce 30000 to 90000 Kg of mussel per year.

Rack culture

This is the simplest of the rope method used for greenmussel cultivation in India and Philippines. The mainpurpose of the pole is to support the structure. Inbetween these poles, ropes are suspended eithervertically or kept horizontally where the depth is alimitation. The construction is labour intensive but thesimplicity in harvesting and accessibility of local materials for farming purposes makes it very adaptable under local conditions. Mussel culture is fast becoming popular in the Malabar area since 1997 following the success achieved by CMFRI in rearing green mussel byrack culture in the backwaters. The simple methods employed for mussel farming was transferred to progressive farmers who took up mussel culture in thebackwaters. Soon they found the venture profitable. Demands came from new entrepreneurs for training and mussel farming spread from Kasaragod to Ponnani. Mussel culture in the backwaters of Kerala was first started in Padanna and Cheruvattur Panchayats in Hosdurg Taluk of Kasaragod district. Later it was taken to Elathur in Calicut district and Vallikunnu and Ponnani in Malappuram district. The total production in 2008 was 16,500 tonnes. Some of the constraints are regarding the availability of seed. Mussel farming is a decade and half old farming practice in India. This is a low investment activity with very good returns. If promoted properly, mussel farming can be used as a tool for women empowerment in the coastal areas and can stimulate a healthy socio-economic development in the area. Better post harvest technologies can develop attractive value added products. Since very good export markets are available for mussels there is further scope of extending the farming practice to suitable areas.

Seed collection and seeding on ropes

The site selected for collection of seed should be free from pollutants. Seeds collected from the submerged (sub tidal) areas will be healthier. After removing other organisms and weeds, the seeds

were washed thoroughly in seawater. About 500-750g of seed is required for seeding on one-meter length of rope. The ideal size of the seed is 15-25mm with 1-2g weight. The length of the rope is decided by considering the depth where the raft/ rack is positioned. While suspending the seeded rope on rack it must be tied in such a way that the upper seeded portion of the rope should not get exposed during low tide.

Nylon rope of 12-14mm or 15-20mm coir rope can be used for seeding. Old cotton net, cotton mosquito net or cheap cotton cloth are used for covering the seeds around the rope. Cotton netting of required width and length is placed on the floor and required quantity of seed is spread over the net from one end to another. The rope is kept above the net and is tightly stitched in such a way that the seeds spread uniformly around the rope. The cloth will regenerate within 2-3 days. By this time the seeds will secrete byssus thread and will get attached itself to the rope. To avoid slipping of the mussels, knots are made on seeded rope at a distance of 25cm. Placing split bamboo pegs in the rope (12-14mm) at regular intervals will also serve the purpose.

Grow-out-phase

The seed, which get attached to ropes, show faster growth in the suspended column water. If the seed is not uniformly attached, crowded portion always show slipping. To avoid slipping, periodical examination of seeded rope and thinning of the same is essential. The ropes also should be suspended in such a way that it will not touch the bottom as well as the seeded portion is not exposed for longer period during low tide. Seeded mussel on the upper portion of the rope shows faster growth due to the abundance of phytoplankton. For better growth the seeded ropes should be spaced at a distance of 25cm. In open sea-farming, growth of mussel is very rapid. They attain 110 mm in 56 months with an average growth of 13.5mm/month and an average weight of 35-45g.

This growth is observed in farms at various locations. In estuarine farming, mussels attain 75-90mm in 5 months with an average weight of 35-40g and an average production of 10-12 kg/m rope.

Constant vigil is required to see that the raft/rack is in position. Thinning may be done if necessary to avoid loss of mussel and to provide enough growing space. Periodic removal of fouling organisms like barnacles, tubiculous polychaetes and ascidians is to be done for improved growth.

Genetics and Selective Breeding in Mariculture

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"The aim of genetic selection and breeding is not to change individual fish, but rather the fish population. Hence, the ***'Mendelian Genetics'*** extended at the level of population is the ***"Population Genetics"*** and it is thus the most essential branch of science to understand the meaning of a population".

Population

In general, a population refers to a group of individuals of a species assembled/living at a place at a time. ***Statistically,*** a population is referred to a group or collection of individuals/items having similar properties. ***Biologically,*** a population refers to a group of organisms/individuals of a species functioning together as a unit at a given place and time.***Genetically,*** in population genetics, a population is defined as a group of interbreeding individuals. As a result of inter breeding there is gene exchange among the individuals of a population and hence they contribute to the gene pool of the offspring generation. The gene exchange is thus the main and important factor to define population. The population for a population geneticist means the ***"Mendelian Population"*** which is defined as a group of ***interbreeding individuals developed over both space and time*** sharing a common pool of genes, from which meaningful samples can be drawn and within which the characteristics under study follow the Mendelian rules of inheritance. The ***gene pool*** is taken as the sum total of genes in a population. In other words, the gene pool includes collectively all the genetic information distributed among all the individuals of a population.

Size of Population: The number of individuals constituting a population decides the size of the population. Therefore an individual is the unit of population. The number of individuals in a population should be large enough so that the sampling variation is as small as to be negligible. Thus, a population should not be affected by the sampling variation. Such a population which is not affected by the sampling variation is knows as large population and consists the number of individuals in hundreds or even in thousands rather than in tens.

The total number of individuals forming the population is important. The differential reproductive success of different individuals molds the genetic structure of a population in coming time. The counting of the number of individuals in a population is done for three purposes: to assure the existence of population, to determine the gene frequencies, and to estimate the role of chance factor played in the transmission of genes.

Change in genetic structure of a population

The organization of the genes into genotypes is the most essential part of population genetics. The genotypes are not transmitted to the offspring as such but they are broken during meiotic cell division as a requirement of genetic transmission from one generation to the next. Thus genotypes of the parents are broken into gametic pool and each offspring has its newly formed genotype different from its either parent. Therefore, the array of genotypes in a population is re-determined in each generation. For example, the heterozygous parent (*Aa*) may not have any heterozygous offspring. The gametes produced by a heterozygous parent (*Aa*) contain either *A* or *a* allele which may unite with any allele of opposite sex and thus parental heterzygosity is not transmitted directly to the offspring. The relative genotypic frequencies in a population are determined by some biological forces *viz*. breeding behavior, genetic factor (mutation) and environmental factors (migration, selection, sampling process in small population) which act on individuals by affecting their survival and reproduction. Thus the genotype frequencies from one generation to the next are under the control of these forces.

Among the breeding behavior, the simplest and important one is the random breeding or random fertilization which followsno principle (criteria) for breeding of individuals of opposite sex and individual of one sex has equal chance to breed with any individual of the opposite sex. The main feature and consequence of random breeding in a large population is that the relative gene frequencies and genotype frequencies remain constant from generation to generation and thus there is no change in genetic structure of large population under random breeding. This is called as genetic equilibrium. The genetic equilibrium is disturbed if the breeding is non-random and if any of the genetic and environmental force is in action. Any force is capable to change the genetic equilibrium from one generation to the next. There are a number of situation and environmental factors (migration, selection and sampling) to disturb the genetic equilibrium.

Most of the captive populations are not ideal to maintain the genetic equilibrium in view of the man's activities and the role of nature. The ideal population is in which no disturbing force comes in action to upset the genetic equilibrium and the random breeding results in a genotypic distribution consistent with the frequencies of genes. However, the fish breeder is interested to change the existing genetic structure of the population in a desired direction to exploit the existing genetic variability to make the animals more productive and more useful. Therefore, breeders are not interested to maintain the existing genetic structure of the breeding population and they make their efforts to achieve high performance of their animals. This is achieved in a number of ways.

The ***first*** is the selection of the better production animals and to eliminate the low productive and inferior ones. This is called the artificial selection. ***Secondly***, the selected animals are bred following certain criteria rather than allowing random breeding. Thus breeding is non-random (assortative). ***Thirdly***, the breeders keep their captive population in relatively small size. This results in small population size which upsets the genetic equilibrium in two ways. One is that inbreeding is inevitable in small population size which changes the genotype frequencies of next generation. The other effect of small population size is that the possibility of expected genotypic frequencies is low due to lesser number of

animals according to the probability because higher number of events makes the expectation more close to reality. Thus smaller number of animals in the herd results in the occurrence of errors in sampling due to chance events. This leads to differentiation of gene frequencies in local populations resulting from sampling.The ***fourth activity*** of fish breeders is the trade breeding under which the animals are sold or transferred to another breeder and thus migration of animals occurs which further increases the possibility of gene flow (migration) from one corner to other corner of the country or the world.

It is thus obvious that most of the conditions for genetic equilibrium are not fulfilled. The fish population size maintained under captive conditions in India is small, the breedings are not random but selective breeding is practiced andthe animals are migrated for a number of reasons. Therefore, the genetic equilibrium is not observed in hatchery and farm conditions in all practical situations and the change in genetic structure of populations is likely to occur. The change can be brought to favourable direction and magnitude after having the knowledge and being aware of the genetic effects. Therefore, it is most essential for a breeder to know the process of change in genetic structure of populations under the influence of various forces. There forces capable to change the genetic structure of a population can be classified in several ways as under-

Natural Vs. artificial factors: Both nature and manmade interventions disturb the existing genetic equilibrium and contribute to changes in the genetic structure of the population. The factors which are under the control of nature to upset the genetic equilibrium are the mutation (change in genetic structure of a gene) and the natural selection. The natural selection operates through differential fertility and viability.The manmade activities include artificial selection by way of selective breeding and preferential breeding (non-random breeding), migration of animals through purchase or transfer, and to keep small population size leading to inbreeding and sampling error (random drift).

Factors involved at individual and population level: The first is the change at gene level (mutation) whereby the genetic structure of gene is changed and produces a new gene. The second is the change at population level by gene flow (migration), selection, small population size, and by a change in breeding system from random breeding to preferential breeding (non-random breeding).

The second category of forces brings a change in gene frequencies between generations and consequently result a change in genotype frequencies. These forces include gene mutation, gene flow (migration), selection, small population size and disassortative breeding. The genetic changes brought by the forces of second category are permanent even after switching to random breeding. This is because these forces involve the change in gene frequencies.

Amount and direction of change: On this basis all the forces are divided into two groups. The first group is of the deterministic or systematic forces which are also called as the vectorial process. The second category is the stochastic process or random or dispersive forces. Among the systematic forces are the mutation, migration and selection which tend to change the gene frequencies predictable both in amount and direction. The dispersive process arises in small population. The change brought by dispersive process is predictable only in amount but not in direction.

Data recording and its importance

If the purpose of selection is to improve a production trait, the first step is to measure or record this trait on all animals in the population, and then estimate the average and standard deviation. Selection is then practised by selecting those animals, which have highest breeding values. A fishhatchery or farm is a dynamic and complicated enterprise having the objective of increasing the productivity and profit. In order to achieve the objective of increasing the productivity and changes, activities and requirements for which the fish breeder has to keep the records and get useful information for taking right decisions about selection of genetically superior animals on the basis of their breeding values.

The data or records are essentialin a hatchery or farm for the following purposes:

- To know the pedigree and history of each brooder pertaining to the production, reproduction and health performance.
- This helps to compare the between farm or between hatchery performance of brooders
- The breeding value for different economic traits can be estimated which help in culling and selection of animals for breeding purposes which in turn bring the genetic improvement of future generations.
- Based on the production performance the feeding requirement can be estimated.
- This also helps in research and development planning.
- To know the health status by keeping records of the daily treatment of animals.

Selection and its Response

Selection is applied to change the fish population for making genetic improvement in performance. The selection is a process of giving preference to certain individuals in a population to reproduce than other individuals which are denied the opportunity to produce next generation. Therefore, selection is the choice of individuals to produce the next generation. In genetic terms, the selection is a process of differential reproduction and survival of genotypes which may be natural or artificial or both.

The selection, without creating any new gene, changes the genetic structure of the population by changing the frequency of genes and genotypes. The frequency of desired genes is increased in the population through selection at the expenses of the frequency of undesirable or less desirable genes. This is the genetic effect of selection. The selection is more efficient for dominant genes at low frequency but it is relatively easy to select for a recessive gene.

The characters are controlled by genes. Therefore, with the increase or change in the frequency of desirable genes, the phenotypic mean of the character of offspring generation is also increased or changed. The change in performance of offspring generation due to artificial selection is known as **response to selection or genetic change or genetic gain**. Now the point of discussion here is that how the performance of the offspring generation of selected parent is changed.

Intensity of selection

The intensity of selection denoted by *"i"* is the mean deviation of the selected animals in units of i_p of the trait *i.e.* it is the number of i_p of the trait by which the mean of the selected group is above the population mean before selection. The intensity is expressed as:

$i = S/i_p$

Factors affecting selection response

The change in performance due to artificial selection known as response to selection depends on the following factors:

1 Additive genetic variability in the trait (i_A)

2 Intensity of selection (i)

3 Accuracy of selection (r_{ap})

4 Population size

Additive genetic variability in the trait (i_A)

The selection acts on additive genetic variability. The variation in breeding values (BV) of the individuals within the population is the raw material to act for artificial selection. The selection will not be effective to bring change if there are no genetic differences among animals. Therefore if $V_A = 0$, the R = 0. The magnitude of R increases with the increase in differences in B.V. between animals. However, the genetic variability of a trait (B.V.) within a population is determined by the population and the characters and hence it is beyond the control of breeder. It is therefore better to exploit other factors like intensity and accuracy of selection.

Intensity of selection (i)

The intensity of selection depends on the proportion (p) of the population selected. When p is small, the selection is said to be more intense or rigorous. But when p is large (increase in proportion selected) then there is decrease in intensity of selection. The R will be more when p is small. This is a straight forward way to improve the rate of genetic progress. If all fishes are selected, the S will be zero and no change in offspring mean will occur. The change occurs if some of the best fishes are selected. Therefore, the proportion of fishes selected should be less.

Accuracy of selection (r_{ap})

The selection is effective only when the animals with highest B.V. are selected. The true B.V. of fishes is not known. This requires one or more sources of information to know the estimate of B.V. of fish. The information to estimate the true B.V. of a fish may be collected on the performance of the fish itself and or of its any close relative. The estimate of true B.V. so estimated should be as much accurate as it can be to make the selection more accurate. The accuracy of selection is taken as the correlation between the true B.V. of a fish and the source of information (Selection criteria) which is denoted as r_{ap}

where A is the true B.V. and P is the selection criteria. The selection criteria may be a single record of average of repeated records of the fishes itself or on any relative *viz*. dam or average performance of a group of relatives like full sibs, half sibs or offspring groups.

The r_{ap} is equal to square root of heritability (r_{ap}=h). Thus if h^2 estimate is higher, ther$_{ap}$ will also be higher. The h^2 is an indication of the reliability of phenotypic value as a guide to the breeding value (B.V.) because the h^2 shows the correspondence between B.V. and phenotypic value. In other words, the h^2 shows the extent to which the B.V. constitutes the phenotypic value. Thus is directly correlated to h^2as r_{ap}= h which is a measure of the accuracy of selection. It is, therefore, that for maximum accuracy of selection, the r_{ap}must be as high as possible to make the selection accurate. Thus selection will be more accurate when the h^2 of the trait is high.

The accuracy of selection can be increased by the following methods:

1. **Minimize the environmental variance:** It can be minimized by providing uniform environment, by use of multiple records to estimate h^2, by adjusting the data for environmental effects, by accurate measurement of data, and by analyzing the data based on contemporary group mean.

2. **Combined Selection:** When two or more criteria of selection are used to estimate an individuals' true breeding value (BV) it is called as the combined selection. This means to supplement the individuals' performance belonging records with those of its relatives. This gives more accurate estimate of B.V of the individual. The family selection may be used to support individual selection when h^2 of a trait is low. It is better to select an individual with better record belonging to a superior family compared to an individual with similar performance belonging to a mediocre or inferior family. The half sib family selection is better than FS family selection.

   The reason being that family selection is more effective when the environmental variations common to all the members of a family are as small as possible. This means that environmental similarities among family members should be low. The common environmental variance is less among half sibs than among full sibs. Thus, the environmental correlation among F.S. is more than among H.S. Secondly, the F.S. family selection reduces the genetic variability in the population and also results in a certain amount of inbreeding. The selected parents based on F.S. family averages are more closely related. Thirdly, the effective selection intensity is also reduced for a given testing facility for F.S. family selection.

3. **Selection based on future performance:** The selection should be based on the future performance (most probable producing ability or the expected producing ability) of the animal with more number of records.

4. **Population size**

   The effect of population size on response to selection can be viewed in terms of inbreeding and genetic drift. The inbreeding is unavoidable in a population of small size. But inbreeding is less when the animals of both sexes are equal which is not possible in fish breeding for the reason that

fewer individuals of either sex may be required according to species under selection. This needs to estimate the effective population size (Ne). The Ne is the number of individuals that would give rise to the same rate of inbreeding, if they breed in the manner of an idealized population, in which the rate of inbreeding is ÄF = 1/2N.

Criteria of selection

The performance records of ancestors and collateral relatives of the individual are also used as selection criteria to estimate the breeding value of an individual for the trait under selection.

Selection based on pedigree

The pedigree is a list or record of ancestors in the past few generations of the individual. The ancestors are the parents, grand parents, great grand parents etc. The pedigree having information on the economic characters of the ancestors is useful in selection of an individual. The B.V. of an individual is estimated on the basis of the performance of the ancestors. The selection criteria based on ancestors performance is called as the pedigree selection.

Basis of pedigree selection

An individual receives genes from his ancestors. The percentage of ancestral genes is halved in each generation. This decides the genetic relationship between an individual and his ancestor(s). This relationship is reduced to half in each generation. It is thus important to consider more recent ancestors (parents) rather than distant ancestors (great grand parents) for pedigree selection. This inclusion of more remote ancestors results only in marginal gain in accuracy of selection due to the halving process and sampling nature of inheritance. The pedigree selection adds very little to the accuracy of estimateing the B.V. of an individual if the information on individual are available. The significance of pedigree is decreased when information are available either on the individual or its family members (sibs and offspring).

Guides to pedigree selection

The following factors determine that how much attention is to be given to pedigree selection.

- The degree of genetic relationship of the individual with its ancestor –more closely related ancestors should be given more emphasis.
- Heritability of the character-the pedigree selection is more accurate for traits of high heritability.
- Environmental correlations among the individuals used in the prediction.
- Information available on ancestors.

Practical difficulties to use pedigree selection

- The ancestors' records are always not available.
- The pedigree records are destroyed with passage of time.

- Most of the characters have low heritability.

Merits of pedigree selection

- It is less costly as only compilation of pedigree is required.
- Allows selection at younger age and provides first hand information.
- It is helpful in multistage selection.
- It is useful for sex limited traits and traits expressed in later life or after death of animal.
- It is helpful when two individuals have similar performance but one belongs to a better pedigree.

Demerits of pedigree selection

- There is a disadvantage of using pedigree selection that all animals of similar pedigree are culled out inspite of the fact that an individual may be of good merit and free from recessive allele causing defect.
- Some pedigree gets undue emphasis and favoured irrespective of the true merit of the individual. Better environment is provided to the offspring of favoured pedigree.
- It introduces non random biases because pedigree records are for different environmental conditions.
- Pedigree selection provides no basis of selection among individuals which are descendants of the same ancestor.

Selection based on collateral relatives

The selection criteria to estimate the B.V. of an individual may be the information (Performance records) of its collateral relatives. An individual's collateral relatives are those which are not related with the individual on direct genes donor-recipient basis but receive common genes from their common ancestor(s) e.g. full sibs, half sibs, cousins, etc. The collateral relatives should be more closely related to the individual and these are full sibs and half sibs. The more closely related collaterals to the individual are likely to have more common genes possessed by the individual and can provide more accurate information about the individual. The more closely collaterals can be grouped as full sib families and half sib families. The family mean of these collateral relatives then form the basis to select the superior individual. The procedure to estimate the B.V. of an individual on the basis of family mean is called the family selection or sib selection depending upon the inclusion or exclusion of individual's own record in estimating the family mean. The selection criteria is called as family selection when the individual's own record is included to estimate the family mean but the selection criteria is called as the sib selection when the individual's own recorded is not included in estimating the family mean.

Sib Selection

It is the selection of an individual based on its sibs performance. The sibs may be full sibs or maternal half sibs or paternal half sibs. Thus sib selection is of two types *viz*. Full sib selection and half

sib selection. The sib selection is practiced for the following traits for which the measurements on the individual are not available or recorded –

- Slaughter traits
- Sex limited traits
- Threshold traits like disease resistance
- Traits with low heritability in species with high reproductive rate so as many sibs are measured in short time
- The full sib (F.S) selection is more accurate than half sib (H.S.) selection. However, the H.S. selection is favoured for the following reasons:
  - Half sibs are easily available in more numbers than F.S.
  - The rate of inbreeding is more for F.S. selection than H.S. selection. The inbreeding counter balances the effect of selection.
  - The F.S. correlation is more likely to be increased by c-effects (common environment shared by F.S.). The intra class correlation (t) is rh^2 for H.S. and rh^2+c^2 for F.S. where c^2 is the added contribution of maternal or common environmental effects. This reduces the accuracy of F.S. selection.

Family Selection

The selection criteria are known as family selection when based on the performance of the sibs plus the individual's own record. The family selection like the sib selection is of two types of sibs *viz* Full sib family selection and Half sib family selection. The family selection is also taken in another way *viz*. as a unit of selection. Based on the family mean the whole of the family is selected or rejected as a unit of selection.

Common environment (c-effects)

The environmental effects which are different for different families but same for all members of one and the same family are known as common environmental effects denoted as c-effects. The family members share common environment during pre and post natal stage. The c-effects thus create resemblance within family members over and above the resemblance due to having common genes and this contributes to the variance between families. This increases the intra class correlation (t) among family members. The c-effects are more for F.S. than for H.S. To some extent the half sibs also share common environment *viz*. all the offspring of a sire being born almost at the same time and being reared together are likely to be subjected to similar environmental conditions like climatic conditions, feeding regime and management practices etc.

When environmental similarities (c-effects) are present among family members, the intra class correlation among the phenotypic values of family members (t) is increased equal to the amount of c-effects as ($t+c^2$) where C^2 is the portion of the total variation caused by differences in c-effects among

families. This makes the denominator larger and hence the regression is decreased. Thus the c-effects decrease the accuracy of sib and family average.

Advantages of family selection

- The family selection can improve the characters of low heritability in species with high reproductive rates so as to get many sibs in a short time.
- The family selection does not allow the generation interval to increase
- Family selection is a support to individual selection because it is better to select an individual from a superior family.

Disadvantages or limitation of family selection

The family selection to be effective requires large family size and more number of families to avoid inbreeding as well as to increase the intensity of selection. In view of this it can be inferred that –

- Family selection is costly of space particularly when the breeding space and testing facilities are limited. The limited facilities reduce the intensity of selection.
- The family selection as a unit of selection results in inbreeding and thus limits the genetic diversity. This is because only few families represent the next generation.
- The F.S. family selection can only be applied in species with high reproductive rates to get large family size.

Within family selection

It is the selection criteria when individuals are selected on the basis of their performance expressed as deviation from their mean. The individuals that exceed their family mean by the greatest amount are selected. Thus it is opposite to family selection because family mean is given no weight. This selection criteria is preferred when c-effects are important *i.e.* when a large component of environmental variance is common to all members of a family. A large component of environmental variance common to members of a family arises when the different families differ in the environment to which they are exposed. Thus the families differ largely due to differences in environment and hence whole family get good or poor environment. The selection within family eliminates the environmental differences among families.

The within family selection economizes the breeding space and minimizes the rate of inbreeding. In within family selection, each family contributes equally to the parents of next generation, when single pair breedings are made and two individuals from each family are selected as replacement of the parents.The within family selection is better than individual selection when the sib correlation (t) is very high and caused largely by environmental effects. The within family selection operates on a large amount of additive variance within families.

Selection and Breeding for Disease resistance:

There are three possible methods to identify and select the individuals for differences in resistance/ susceptibility to a certain disease/parasite. These are as under:

- Occurrence of the disease under normal environmental conditions,
- Inoculation of animals with pathogen causing the disease, and
- Use of indicators of resistance.

The first method to identify the resistant animals on the basis of the incidence of the disease is not effective in the sense that under the changed environmental conditions the resistant become susceptible. The second method of inoculation is not likely to be applied because of the objections to deliberate infection with pathogenic organisms. The third one requires very great efforts and research to find a better indicator of genetic resistance; which do not require deliberate exposure to pathogens.

The efficiency of individual selection and family selection on the basis of the incidence of the disease with two visible classes is discussed. The effectiveness of selection depends on the selection differential which, in turn, depends mainly on the proportion selected. But in case if threshold characters (all or none characters), the selection differential depends on the incidence rather than on the proportion selected. Selecting all the resistant individuals or only a portion of them will give their mean as the mean of the resistant group. Thus, selecting a smaller proportion than the incidence, does not give an added advantage. It is, thus, evident that maximum selection differential is achieved when the proportion selected is equal to the proportion of resistant individuals. The individual selection is less effective when the difference between the two (incidence of resistance and proportion selected) is more. Further, the individual selection is less effective when the proportion of resistant individual is very low, but the family selection is more effective. An individual's phenotype as resistant or susceptible is not precisely known whereas the family is more precisely known for the proportion of affected members of the family. However, the precision depends on the family size and on the incidence of a disease in the family.

Conclusion

Although aquaculture as a biological production system has a long history, systematicand efficient breeding programs to improve economically important traits in the farmedspecies have rarely been utilized until recently, except for salmonid species. This meansthat the majority of aquaculture production is based on genetically unimproved stocks. In farm animals the situation is vastly different: practically no terrestrial farm production is based on genetically unimproved and undomesticated populations. This difference between aquaculture and livestock production is in spite of the fact that the basic elements of breeding theory are the same for fish and shellfish as for farm animals. One possible reason for the difference is the complexity of reproductive biology in aquatic species, and special consideration needs to be taken in the design of breeding plans for these species.

In aquaculture, selection programs are not commonly used by the industry and for many species production still rely completely on catching wild broodstock and/or fry. There is no obvious reason for the lack of efficient breeding programs in aquaculture. The economic important traits in fish and shellfish appear to be little different from those in farm animals and plants. Selection response is usually higher in fish and shellfish than in farm animals. One reason for the scarcity of breeding programs in aquaculture species is that the reproductive cycle is often complex, and so is frequently not fully understood, and is therefore not able to be completed or controlled in captivity. This is the case particularly for marine species. Another factor contributing to the scarcity of breeding programs in aquaculture species may be the deterioration of the stock simply because of a rapid build-up of inbreeding as a result of using few broodstock each generation (and without identification to prevent re-use). This is a problem in all species with high fecundity. Because there has been little interest in developing breeding programs in aquaculture, the information about phenotypic and genetic parameters of economically important traits are quite limited for most of the species farmed. Before a breeding program can be established, breeding goal must be defined; estimates of genetic variance, heritability, phenotypic and genetic correlations among traits must be available. There is therefore a great need to run breeding experiments in order to get reliable estimates of genetic parameters for economically important traits in the most important farmed species.

The applications of molecular techniques in aquaculture are promising, but still somewhat uncertain. While high costs seem to be the only hindrance for widespread application of DNA markers for identification purposes and marker assisted selection, the situation regarding commercial use of genetically modified fish is more complex. Although the potential importance of gene transfer technology is large, a major concern relates to the possible impact, which release or accidental escapes of gene-modified individuals may have on natural ecosystems. Other technologies are also rapidly emerging which are either being used or are likely to be used in the future in the aquaculture species. For example micro-array technology has the potential to contribute very large amounts of information on the genes and pathways of genes, which affect the economic traits in aquaculture species.

Economic Analysis in Mariculture

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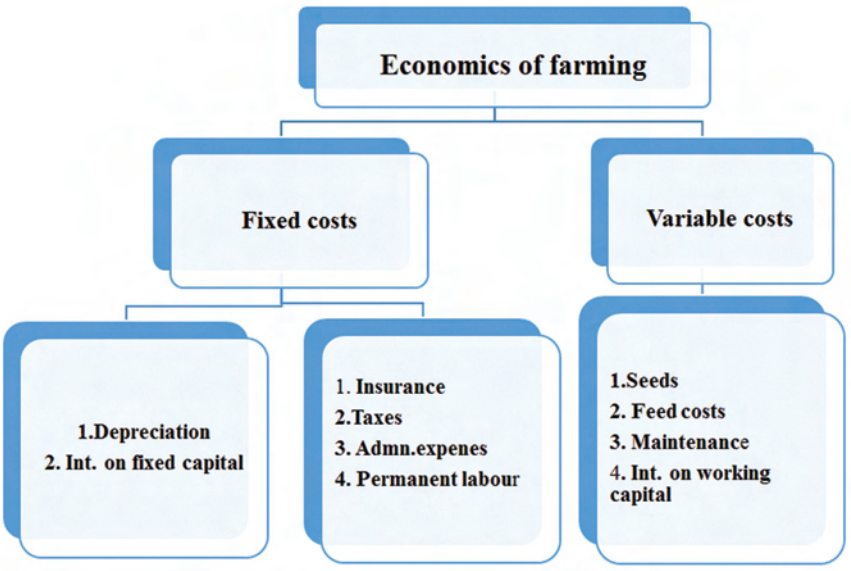
The marine fish landing in the country is stagnating around four million tonnes. The estimated landings in 2016 was 3.63million tonnes (CMFRI, 2017). The increasing awareness on the nutritive value of fish has increased the demand for fish. Sea ranching, artificial reefs and mariculture are the potential alternatives for augmenting fish production from the sea when the production (harvest) from marine fisheries reaches a stagnation phase, with limited scope for further expansion. Mariculture is one of the best alternatives, which can be practiced by the fishermen more effectively and the Govt. of India has taken several measures for augmenting fish production through promotion of mariculture activities in the coastal waters. Mariculture systems include in-shore and off-shore and maintain a constant high saline water conditions. In-shore mariculture systems include clams, mussels, oysters and other molluscs, which are wild-caught or hatchery-reared seed grown on the sea floor or on suspended nets, ropes, or other structures. Off-shore mariculture refers to large intensive fisheries in off-shore fish pens.

Mariculture

Mariculture has the potential to augment production and incomes through coastal as well as open sea farming. India has vast areas of suitable coastal waters, lagoons and bays which can be utilized for mariculture.The main groups of marine resources farmed in India are crustaceans, finfishes, molluscs and seaweeds. Seed production and culture of marine finfishes has been expanding in the recent past in many parts of the world, but in India, it is only an emerging sector. The potential cultivable candidate finfishes are groupers, cobia, rabbitfish, seabass, pompano, snappers and sea bream. Lack of availability of hatchery-produced seeds on a commercial scale is the major bottleneck for large-scale marine finfish farming. The availability of seed from wild is often unpredictable, and hence, the development and standardization of seed production techniques for a few commercially important species is receiving research priority. The economic analysis of commercially important mariculture systems such as cage farming in the open sea, brackishwater and mussel farming in India are discussed in this lecture.

Components of ecnomic evaluation in mariculture

The success of the adoption of any innovation or new technology lies in its economic performance. The rate of return per rupee invested is the economic indicator that guides the investor to choose a particular enterprise or practice. Besides, the analysis of the economic performance serves as an indicator for the investor to allocate his resources in the enterprises. This becomes very much essential, since the resources are scarce and the investor is interested to invest his scarce capital resource in that enterprise that gives the maximum return for his investment.



The economic evaluation mainly comprises costs and returns of farming The economic performance of any mariculture activities can be assessed by working out the following cost and return indicators and financial feasibility of any enterprise (Narayanakumar, 2009).

Table 1. Indicators of economic performance of a mariculture enterprise

Sl.No.	Economic Indicators
1	**Initial investment** a) Fixed installationsb) Land (if any)c) Major accessoriesd) Minor Accessoriesd) Others
2	**Total Investment**
3	**Fixed cost (For crop duration of six months)**a) Depreciationb) Insurance (2% on investment)c) Interest on Fixed capital (12%)d) Administrative expenses
4	**Total Annual Fixed cost (A)**
5	**Operating costs**a) Cost of seedsb) Cost of feeding and other labour chargesc) Interest on working capital (6%)
6	**Total Operating or Variable cost (B)**
7	**Total cost of production [(4)+(6)]**
8	**Yield of the fish variety (in kg)**
9	**Gross revenue [(8) * Price per kg]**
10	**Net income [(9)-(8)]**
11	**Net operating income [(9)-(6)]**
12	**Cost of production (₹ /kg)[(7)/(8)]**
13	**Price realized (₹ /kg) (9)/(8)**
14	**Capital Productivity (Operating ratio) (6)/(9)**
15	**Rate of return over investment (9)/(2)**

As seen from the table, the different economic indicators of the economic performance of any mariculture enterprise are worked to assess its performance. This will serve as the guidelines to the institutional agencies that are extending the financial support to the enterprise.

Financial performance

The financial performance of an enterprise is analysed by working out various types of indicators as given below.The financial feasibility analysis is done using the following **capital budgeting techniques** with appropriate assumptions on the duration of the farming, annual days of operation, inflation of costs and returns and related parameters. Three indicators will be estimated namely, **Net Present Value (NPV), Benefit Cost Ratio (BCR) and Internal Rate of Return (IRR).**

- NPV determines the present net worth of the stream of cash inflows over cash outflows. The cash inflows and outflows are discounted at particular rate

$$NPW = \sum B_n(1+d)^{-n} - \sum C_n(1+d)^{-n} + \sum V_T(1+d)^T - \sum I_n(1+d)^{-n} \ldots\ldots (1)$$

Where,

B_n cash inflows in period **n**

C_n cash outflows in period **n**

V_T the salvage value realized in the terminal year of the investment

I_n investment made in the year **n**

- **Benefit Cost Ratio** is the ratio of sum total of annual discounted net cash flows over the economic life of the investment to the investment.

$$BCR = \frac{\sum B_n(1+d)^{-n} - \sum C_n(1+d)^{-n} + \sum V_T(1+d)^T}{\sum I_n(1+d)^{-n}} \ldots\ldots\ldots\ldots (2)$$

- **Internal Rate of Return** is that discount rate which makes the NPW equals to zero. It is that discount rate which equates the net cash flows during its economic life with the initial investment.

$$IRR = \sum B_n(1+r)^{-n} - \sum C_n(1+r)^{-n} + \sum V_T(1+r)^T - \sum I_n(1+r)^{-n} = 0 \ldots\ldots\ldots (3)$$

Where,

r internal rate of return

The actual procedure adopted to calculate IRR is by linear interpolation as follows

$$IRR = \left[\text{Lower Discount Rate}\right] + \left\{\left[\text{Difference between the two discount rates}\right]\left[\frac{\text{NPW at lower discount rate}}{\text{Absolute difference between The NPW's at the two rates}}\right]\right\}$$

..... (4)

The Central Marine Fisheries Research Institute has developed and popularized technologies for marine culture of finfishes, shell fishes, pearl culture and ornamental fish farming. Economically viable mariculture technologies such as open sea cage farming, mussel farming, edible oyster farming are adopted by the fisherfolk in many of the coastal states. Cage culture experiments were carried out at 14 different locations along the west and east coast of the country from Veraval in Gujarat to Balasore in Orissa. The economic and financial feasibility considerationsplay a crucial in the successful adoption of any new technology. The initial investment cost on cage structure, operating expenses such as feed, seed and labourcost as well as consistency in yield and prices decides the economic viability of cage farming. The initial investment on a 15-meter diameter cage was 8 lakhs and that of 6m diameter was 4 lakh during the experimental trials. With further research interventions and participatory methods, the size and cost of the cages were further reduced to suit various locations as well as brackish water areas in the country.

The resources suited for culture inopen sea cages are seabass, cobia, groupers and pompano.On an average, 2-4 tonnes of fish can be produced in a 6-meter diameter sea cage. The economics of seacage farming in Goa for cages of 6m dia are presented in Table 2. The gross revenue earned varied from ₹ 6 lakhs for cobia to ₹ 7 lakhs for seabass for aculture period of 7 months. The average price received varied from 300/kg for cobia and ₹ 350/kg for seabass.The cost of production per kg was ₹ 143/kg for seabass and ₹ 156/kg for cobia.

Table 2. Indicative economics of fin fish farming in sea cages (Goa, 2016)

Particulars	Goa (Sea cage of 6m diameter and 4m depth)	
	Sea bass	Cobia
Cage structure (GI pipe) including nets	1,10,000	1,10,000
Expenses on mooring & Other fixed expenses (refrigerator, containers, etc.)	40000	40000
Gross fixed cost	1,50,000	1,50,000
Seed cost	65,000	50,000
Feed cost	90,000	1,30,500
Labour charges	36,000	36,000
Harvesting charges	10,000	10,000
Boat hire & fuel charges	30,000	30,000
Interest on fixed capital (12%)	18,000	18,000
Annual depreciation	27,000	27,000
Miscellaneous expenditure	10,000	10,000
Total operating cost	2,86,000	3,11,500
Gross revenue	7,00,000	6,00,000
Net operating income	4,14,000	2,88,500
Cost (₹/kg)	143	156

Source: Computed by authors

Cage farming technology has been popularized in the backwater areas also inmany of the coastal states. Kerala state in the Southwest coast of India with an estimated potential brackishwater area of 1.26 lakh ha area comprising 0.65 lakh ha of brackish waters and 0.46 lakh ha of backwater canals has tremendous scope for cage farming in the country. There was a large scale penetration of cage farming technology among the fish farmers in Kerala through the promotional schemes by the state department of fisheries and research institutions like CMFRI.

Table 3. Indicative economics of cage farming in brackish water cages (Kerala, 2017)

Particulars	Cost/Revenue (₹)
Cage structure including floats, nets and cage frame (8mx 4mx 4m)	
Rectangular cagesStocking density: 3000 seabass +1000 *Etroplus*	80000
Accessories- freezer, baskets	20000
Interest on FC(12%)	12000
Depreciation(20%)	20000
License fee	1500
Labour@ ₹ 12000/month	84000
Seed (sea bass 3000 nos @ ₹ 40 and Etroplus 1000 nos@ ₹ crores 10)	130000
Feed: sea bass (FCR1:5)	288000
Feed for *Etroplus* (FCR1:1.2)	12000
Miscellaneous expenses : transport, harvest	25000
Interest on working capital (6%)	32430
Total Operational cost	572930
Total cost (Op cost+ fixed cost)	604930
Gross Revenue-Seabass 2400 kg@ ₹ 500/kg	12,000,00
Gross Revenue-*Etroplus* 120 kg @ ₹ 450/kg	54000
Total revenue	12,54,000
Net profit	6,49070

Seabass and Etroplus composite culture, Culture period: 7months

Source: Computed by authors

Sea bass, Tilapia, pearlspot, red snapper and carangids are the major varieties cultured. The survival rate varied from 80-90% in different locations. The types of feeds used and feed conversion ratio varied with fish varieties.

For 8m x 4m x 4m cages the stocking density varied from 1000 -2000 numbers for seabass to 6000 numbers for Tilapia.The feed conversion ratio (FCR) varied from 1:6 for seabass, 1: 1.5 for *Etroplus* and 1:1.25 for Tilapia.The net profit earned was 6,49,070 for the composite culture of seabass with *Etroplus*. The cash flow analysis was done for a five-year investment period to assess the financial feasibility of investment in brackishwater cages at a discount rate of 15%. The net present value of investment was ₹ 7,76,017, benefit-cost ratio was1.35 and IRR was 68%.

Mussel and edible oyster farming

CMFRI has developed technologies for farming of mussels and edible oysters in the early seventies which wasfurther refined for commercial production. The Institute has conducted a series of experiments on location testing in various estuaries and sea along the west coast of India. Mussel and edible oyster farming are practiced by the coastal fisherfolk in Kerala, Karnataka, Goa and Maharashtra. Stake culture, on-bottom culture, long-line culture, raft culture, rack culture, etc. are followed for mussel and oyster farming. The Indian mussel industry has attained a maximum production of about 20,000 tonly (Mohammed, 2015). The economic analysis of mussel farming showed anet operating income of ₹ 88,000 from 200 strings using rack method of farming in Kerala (Table 4). Lack of proper marketing opportunities currently constrains the mussel and edible oyster industry in the country.

Table 4. Economic analysis of mussel farming in Kerala

Particulars	Costs/Revenue(₹)
Fixed cost	
Rack construction(Poles and rope), 20 bamboo poles@ ₹ 300/pole, 4kg3-4mm rope @ ₹ 250/kg and labour charges	10000
Operational cost	
Seeds(200kg seeds@ ₹ 50/kg)	10000
Stocking(cloth, rope, coir etc.) and labour charges	8700
Labour charges for Rack maintenance&harvesting @ ₹ 750 for 7 MD & miscellaneous expenses	7800
Interest on fixed capital (12%)	1200
Depreciation	3300
Total cost	31000
Gross revenue (1.4t/rack @ ₹ 85/kg)	119000
Net operating income	88000
Cost (₹ /kg)	22

Source : Shinoj *et. al. (2017)*

Mariculture activities such as cage farming, sea weed farming, edible oyster and mussel culture are profitable ventures and offer promising scope for enhancing the fish production and incomes of coastal fisherfolk in India. Developing economically viable and sustainable seed production techniques and attracting large scale investment in the public and private sector for commercial seed production and farming of finfishes and institutional support for marketing will help to boost the mariculture production in the future.

Status of Freshwater Fish Farming in India

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Introduction

Fish is an important source of protein, rich in essential amino acids. It is also a good source of calcium, vitamin A and $B_{12,}$ apart from possessing a high content of polyunsaturated fatty acids *i.e.*, Omega-3 fatty acids. The persons in all stages of their life who cannot obtain sufficient nutrients from cereal-based diets would be benefited from the inclusion of fish in the diet.

Aquaculture is the fastest growing animal food-producing sector, growing at a rate more than 7% annually. In addition to supplying dietary essentials for human consumption, aquaculture provides excellent opportunities for employment and income generation, particularly in the more economically depressed rural areas. According to the report of FAO(2016), 60 million people are directly engaged, part time or full time, in primary production of fish, either by fishing or in aquaculture, supporting the livelihoods of 10–12 percent of the world's population.

Globally India stands 2nd in culture fisheries production. There is steady increase in aquaculture production in the country, and stands at about 5.77 MMT in 2015-16. Indian aquaculture has demonstrated a six and half fold growth over the last two decades, with freshwater aquaculture contributing over 95 per cent of the total aquaculture production. The three Indian major carps, namely catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) contribute the bulk of the production, followed by silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) forming a second important group. Average national production from still water ponds has increased from 0.6 t/ha/year in 1974 to 2.9 t/ha/year at present, with several farmers even demonstrating production levels as high as 8–12 t/ha/year (Jayasankar, 2014). The technologies of induced carp breeding and polyculture in static ponds and tanks have virtually revolutionized the freshwater aquaculture sector and turned it into a fast growing industry. The research and development programs of the Indian Council of Agricultural Research (ICAR) as well as the development support provided by the Indian Government through a network of Fish Farmers' Development Agencies (FFDA) have been the principal vehicles for this development. Additional support has been provided by several other organizations, state departments and financial institutions. In addition, the sector has been witnessing increased interest in diversification with the inclusion of high-value species including medium and minor carps, catfishes, murrels, etc. While carp and other finfishes are grown for the domestic market, a large proportion of freshwater prawn (*Macrobrachium rosenbergii*) production was exported. In recent times freshwater prawn production has declined, while production of white legged shrimp *Litopenaeus vannamei* has increased by leaps and bounds.

Fish contributes substantially to the domestic food security of India which has a *per capita* consumption of 11kg (Jayasankar and Barik, 2015). With freshwater aquaculture being a homestead activity in several parts of the country, besides adding to the nutritional security, it also helps in bringing additional income to rural households. Considering the substantial contribution, aquaculture makes towards socio-economic development in terms of income and employment through the use of unutilised and underutilised resources in several regions of the country.

Aquaculture in village water bodies (VWB) in India, in general, utilizes poly carp culture and is practiced with the utilization of low to moderate levels of inputs, especially organic-based fertilizers and feed. The main problems faced by fish farmers are poaching, water scarcity and credit. Even then, there has been a marked shift in the intensity of fisheries in some states. This change is brought about by the entrepreneurial acumen of individuals who with the help of innovative management practices shaped the way fishing is practiced in the multi-use and multi ownership VWB across India. With the consumption of fish rising steadily, the rising demand for fish can be met only if the growth in aquaculture occurring in the VWB is sustained.

Major players in freshwater aquaculture in India

Andhra Pradesh, West Bengal, Bihar and Chhattisgarh are among the top producers of freshwater fish through aquaculture (Fig 1).

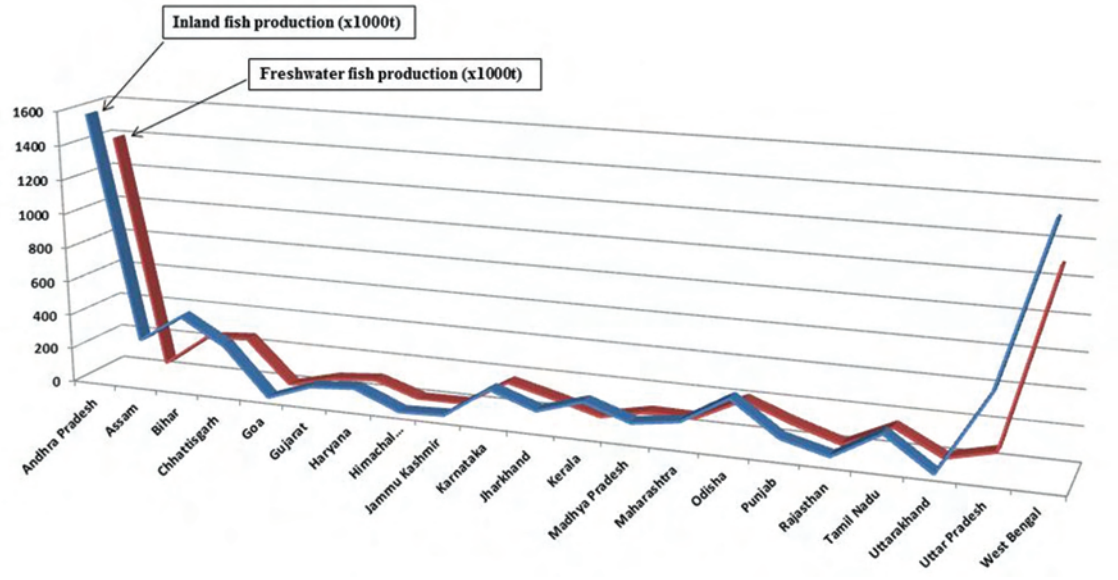

Fig 1. State-wise inland and freshwater aquaculture fish production in India (Source: FAO, 2016; DADF, 2017)

Andhra produces around 15 lakh t of fish of which 92% is exported to other states. West Bengal has a production of around 14 lakh t of fish, but they still import fish mainly from Andhra to meet the burgeoning domestic demand. Bihar and Chhattisgarh together produce around 6 lakh t; while the former state has negligible import and about 20% export, the latter imports about 25% from Andhra for

domestic consumption. Assam produces about 2.5 lakh t fish but still imports around 30% of their fish requirement due to high demand. Jharkhand produces about 1 lakh to freshwater fish, but again imports 20% of requirement for domestic consumption. Cage culture of pangas is poised to boost freshwater fish production in Jharkhand significantly (Jayasankar, 2014).

Aquaculture resources

Aquaculture resources in India include 2.42 million ha of ponds and tanks; 1.07 million ha of beels, jheels and derelict waters; 0.12 million km of canals; 3.15 million ha of reservoirs and 0.72 million ha of upland lakes that could be utilised for aquaculture purposes. Ponds and tanks are the prime resources for freshwater aquaculture, however, only about 0.8–0.9 million ha is used for aquaculture currently. Ponds in eastern India are typically homestead ponds of less than 1 ha in size. In several parts of the country ponds and tanks are state-owned or communal and are leased out for periods of 3–5 years (Katiha *et al.*, 2005). See Fig 2 for species-wise production figures of various states in India.

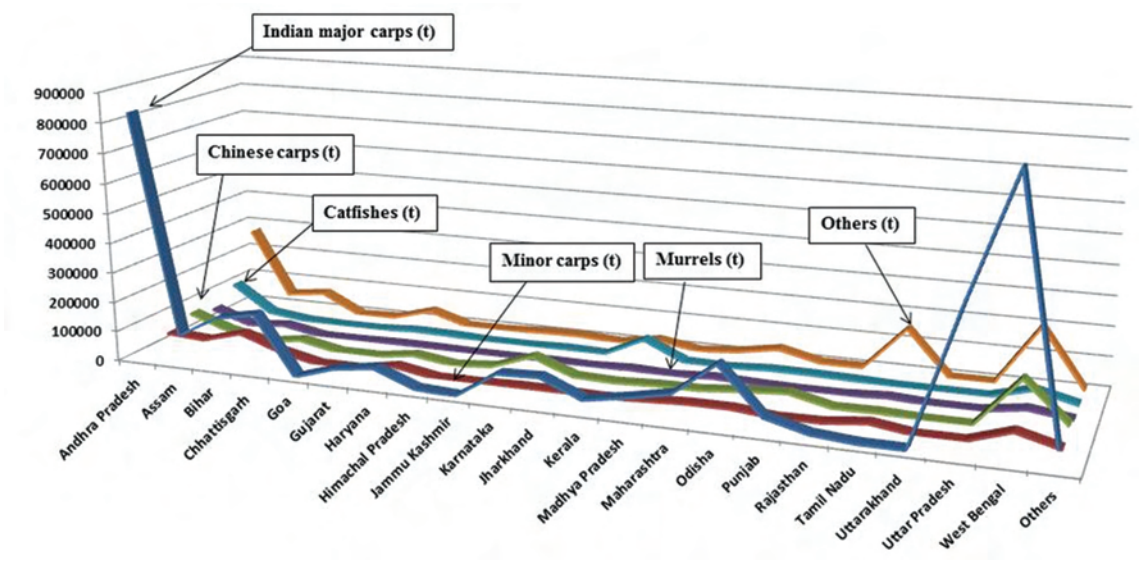

Fig 2. Species-wise freshwater aquaculture fish production in various states of India (Source: FAO, 2016; DADF, 2017)

Culture of carps

The culture systems adopted in the country vary greatly depending on the inputs available in any particular region as well as on the investment capabilities of the farmer. While extensive aquaculture is being carried out in comparatively large water bodies with stocking of the fish seed as the only input beyond utilizing natural productivity, elements of fertilization and feeding have been introduced into semi-intensive culture. Different culture systems such as composite carp culture; sewage-fed fish culture; weed-based carp polyculture; biogas slurry-fed fish culture; integrated fish farming with poultry, pigs, ducks, horticulture, etc.; and pen culture have been standardized with optimum achievable production rates of 3–6 t/ha/yr(Sinha *et al.*, 1973). Intensive culture systems like cage culture and running-water

fish culturehave given productions of 10–15 and 20-50 kg/m^2/yr respectively (Tripathi *et al.*, 2000; Katiha *et al.*, 2005).

Carp culture is based around the polyculture of the three Indian major carps (catla, rohu and mrigal) as well as composite carp culture of the three Indian major carps with the three exotic carps (silver carp, grass carp and common carp). Standard practices in carp culture include: i. Stocking of carp at combined densities of between 4,000–10,000 fingerlings/ha; ii. Pond fertilization with organic manures from cattle or poultry as well as inorganic fertilisers like urea and single super phosphate; and iii. Provision of supplementary feeds mainly in the form of a mixture of rice bran/wheat bran and groundnut/mustard oilcake in equal ratio. In spite of the fact that the country also possesses several other cultivable medium and minor carp species which show high regional demand, including, *Labeo calbasu*, *L. fimbriatus*, *L. gonius*, *L. bata*, *L. ariza*, *Cirrhinus mrigala*, *Puntius sarana*, *Hypselobarbus pulchellus*, *H. kolus* and *Amblypharyngodon mola* as well as several others, commercial farming of these species has been almost non-existent or picking-up slowly. Currently in India in commercial aquaculture system *C. catla* and *L. rohita* constitute about 20 and 75 per cent in total Indian major carps, while *C. mrigala* constitutes only about 5% (FAO, 2016).

Culture of catfishes

The pond culture of catfish involves mainly magur (*Clarias magur*) and singhi (*Heteropneustes fossilis*) and is practiced in states like Assam, Bihar, West Bengal and Odisha (Thakur and Das, 1986). Though modern farming techniques for these species advocates monoculture at stocking densities of 20,000–50,000 fingerlings/ha, inadequate availability of juveniles has restricted these as a component in carp polyculture systems. Considering the high market demand for catfish and the availability of a huge potential resource in the form of swamps and derelict waters, commercial farming of these species is being given important attention at present. In recent years, attempts have also been made to develop the culture of non-air breathing catfishes like *Pangasius pangasius*, *Wallago attu*, *Sperata seenghala*, *S. aor* and *Ompok pabda* (Kumar, 2016). Culture of exotic catfish pangas, *Pangasianodon hypophthalmus* has shown phenomenal growth during 2008-2010; in Andhra Pradesh around 10% of the area in Krishna-Godavari delta area has been occupied by this single species. Other than the illegal entry from Bangladesh, pangas seed has been produced in West Bengal. Many other states including Chhattisgarh, Jharkhand, Bihar etc. have shown increasing interest in culture of pangas. Production levels are around 15-50 t/ha/year (Jayasankar and Giri, 2013).

Culture of other finfishes

The other finfish species of importance include climbing perch (*Anabas testudineus*), murrels (*Channa striatus* and *C. marulius*) and tilapia (*Oreochromis mossambicus* and *O. niloticus*) (Khan, 1969).

Culture of freshwater prawn

Successful breeding and larval rearing of the giant river prawn (*Macrobrachium rosenbergii*) and the monsoon river prawn (*M. malcolmsonii*) provide scope for the farmers to diversify their culture

practices. *M. rosenbergii* is the largest and fastest growing species being farmed and possesses considerable demand both in domestic and international markets. *M. rosenbergii* is cultured either alone or in combination with carps. Monoculture of giant river prawn is mostly confined to earthen ponds with moderate stocking densities of between 20,000–50,000/ha, fertilization and supplementary feeding can result in a moderate yield of 600–1,500 kg/ha/8 months using single stocking and both single/multiple harvesting. Polyculture of freshwater prawn juveniles as densities at 10,000–15,000/ha alongside carp at 3,000–4,000/ha has also been demonstrated to be economically viable(Tripathi *et al.*, 2000).

Non-conventional culture practices

Sewage-fed fish culture and paddy-cum-fish culture are two important culture systems practiced in certain areas of the country. Sewage-fed fish culture in bheries in West Bengal is an age-old practice. About 5,700 ha are presently utilised for fish culture using the input of primary-treated sewage and produces over 7,000 tonnes of fish per annum, mainly consisting of the major and minor carps. The culture system usually involves multiple stocking and multiple harvesting approaches, with harvest size usually in the range of 300–500g. Though stocking densities of 10,000–20,000/ha are common, densities as high as 50,000/ha has also been reported from several farms (Jayasankar, 2014).

Paddy-cum-fish culture is undertaken in medium to semi-deepwater paddy fields in lowland areas with fairly strong dykes to prevent the escape of cultivated fish during floods. Trenches and pond refuges in the paddy fields provide shelter for the fish. The system mostly relies on natural stocking, however, modern farming techniques involving major and minor carps stocked at the densities of 5,000–10,000/ha alongside freshwater prawn are also practiced in several areas. Production levels of 3.5 tonnes of rice and 0.5–1.0 tonne of fish/ha can be achieved in a well-managed paddy-cum-fish farming systems within a year(Jayasankar and Das, 2015).

Fish seed production

Collection of spawn and hatchlings from rivers and other natural water bodies is a traditional method of obtaining Indian major carp seed. The quality of the product is low and the cost of transportation from the seed collection grounds to the fish growers is high. The period of collection is very short and the quantity of the annual collection fluctuates considerably with the variation of climatic conditions. In fact, a rapid decline in both quantity and quality of collection has resulted from the deterioration of river environments in recent years.

Since the latter part of the fifties, Indian scientists have successfully achieved artificial breeding of Asiatic carps (including major Indian and Chinese carps) by application of the hypophysation technique. This achievement has significantly contributed to the methodology of fish seed production and supply of right kind of fish seed to the farmers. Carp hatcheries in both the public and private sectors have contributed towards the increase in seed production from 6,321 million fry in 1985–1986 to around 40,000 million fry (produced by around 2000 hatcheries) at present(Jayasankar and Das, 2015).

Resource renovation & horizontal expansion

It's relevant to ponder as to why the potential of 4-5tonnes/ha/year productivity in ponds not realized and national average hovers around2.9 tonnes/ha/year. The reasons could be many, such as erratic monsoon resulting in poor rains or flood like situation, both of which are undesirable; improper maintenance of ponds resulting in poor holding capacity and thus poor production. Renovation of such ponds is to be done by de-silting. Increased water use efficiency is critical, which is only about 50% efficiency currently. *In situ* water harvesting, construction of water harvesting structures inter-basin transfer of water are measures to improve water use efficiency. Water conservation and increased fish production go hand in hand. Horizontal expansion is a possibility since out of 2.414 million ha of ponds and tanks, only about 50% is presently exploited. However, with multiple demands for land and water use, the option of horizontal expansion might not be much effective (Jayasankar and Das, 2015).

Vertical expansion – species and system diversification

Other than Indian major carps, breeding and culture technologies of diversified groups of freshwater species, such as minor carps, barbs, catfish, pabda, freshwater prawn (genetically improved), climbing perch and murrel have been standardized, which is in the right direction for increasing productivity. Intercropping of minor carps and barbs in conventional major carp culture, mono culture of catfish and prawns or their polyculture with major carps and mono sex tilapia culture would also ensure enhanced productivity.

Diversification in system and practices can also bring about increased fish production and productivity as below:

- Cluster farming-based fish seed rearing
- Shallow/rain fed ponds to be utilized exclusively for seed rearing – stunted seeds
- Seed supplied to perennial ponds for stocking – multi stocking and multi harvesting
- Waste water aquaculture system
- Rice-fish culture system
- Integrated farming systems – homestead ponds
- Cage/pen culture in open water systems.

Quality seed with good genetics, involving improved economic traits is highly desirable. Many hatcheries maintain broodstock in poor genetic conditions. Science-led improvement of broodstock quality involves selective breeding, genome manipulation, marker-assisted selection, transgenesis and genome selection (Sinha and Jayasankar,2014). Prohibitive factors against stocking with fingerlings are time, cost and pond facilities. Stocking with fry in grow out ponds often result in poor growth and poor production. In Andhra Pradesh stocking with stunted fingerlings (Yearlings and "Zero point") at the rate of 5000 numbers/ha has led to significantly increased carp production(Jayasankar and Das, 2015).

Feed technology and feed management

Feed is the most expensive component of aquaculture, costing about 60-70% of the total expenditure. Supplemental feeding has not still caught up with the small and marginal farmers, due to lack of awareness and high cost. However, it is understood that nowadays in West Bengal almost every farmer is feeding cultured fish. Conventional feeding results in high FCR, close to 3-4. There is stiff competition for feed concentrate from the poultry and dairy sectors. In Andhra Pradesh pellet feed balanced nutrition are provided in pangas culture. Farm made feeds made from locally available cheap plant materials would substantially reduce feed cost; further complete replacement of fish meal is also possible for carps. There is need to establish low cost feed mill in regions where freshwater aquaculture is prospering. Current production of feed concentrate is 44 MMT, while the demand is 143 MMT indicating deficiency of 69%(Jayasankar, 2014).

Disease diagnostics, surveillance and management

Disease incidences and outbreak happen along with intensification of farming activities. Little/no information is available on actual crop loss in fish culture due to diseases. It is estimated that due to argulosis Rs 29500/- per ha per year is lost (Sahoo, P.K., personal communication). National Surveillance Programme for Aquatic Animal Diseases is a new hope now to identify, document and analyze prevailing and emerging diseases in aquaculture sector. Research on immunology, microbiology, molecular biology and nanotechnology needs to be strengthened for addressing the fish health management issues. Available tools for this include quarantine protocols, diagnostics, immunoprophylaxsis, probiotics, bioremediation and chemotherapeutics (Jayasankar, 2014).

Technology interventions for aquaculture development

Central Institute of Freshwater Aquaculture (CIFA), in Odisha, India has developed few technologies on breed improvement, hatchery, seed quality verification, broodstock diet, fish health management, species diversification and post-harvest value addition, which would speed up freshwater aquaculture development in the region (Jayasankar, 2014 and 2017). Improved variety of rohu, "Jayanti" is a step forward to improve farm productivity(Das Mahapatra *et al.*,2016). A notable achievement is a PCR-based kit developed to check seed quality in carps (Mohanty *et al.*, 2016).

Major constraints for development of aquaculture

Major constraints of aquaculture development in India are availability of good quality seed, land tenure, social issues like poaching, water availability, feed availability, access to technology at grass root level, climate change and credit facility.

The anticipated positive impact of rise in temperature might not always be existent since events like increased eutrophication could negatively impact aquaculture in India. Climate change will impact on water availability, weather patterns and extreme rain events (De Silva and Soto, 2009). Lack of access to credit is a perpetual problem in aquaculture sector, and partnerships between publicly funded national agriculture research institutes and the private sector are key drivers of technological progress.

Public-private investments in researching and developing genetically improved fish strains have the potential to provide attractive economic returns to the private sector and to meet a public need for improved seed quality (Roy, 2015).

Policy

Since inland fishery is a state subject, the states decide on the policies regarding utilization of the resources. The state governments prepare policies keeping in mind the livelihoods of the rural poor. The state governments prefer handing over the fishing resources to co-operatives of the local communities. Leasing policy is the main instrument in the hands of the government to effect any change in the sector. Most of the initial funding for propagating culture fishery in inland water bodies came from the FFDA program of the central government with an initial World Bank Assistance. It provides technical, financial and extension support to fish farmers for taking up culture-based fishery in village ponds and tanks (Katiha *et al.*, 2005).

Conclusion

It is apparent that strategies for increasing fish production from freshwater aquaculture should be directed towards horizontal and vertical growth of the industry. The National Aquaculture Development Plan also envisages expansion, intensification, and diversification of culture systems (Gopakumar *et al*. 1999).Fish requirement by 2025 is expected to be of the order of 16 MMT, of which at least 12 MMT would need to come from the inland sector and aquaculture is expected to provide over 10 MMT. Indian aquaculture has to come up with timely strategies to cope with the future challenges of increased fish demand, selective consumers' choices, production of safe and quality fish protein, tapping the export earning, etc. These all have to be done in the face of increased land and water scarcity, climate change, competition from other agriculture sector, labour shortage, shortage of raw materials besides satisfying the Code of Conduct for responsible aquaculture and HACCP in farming. Therefore, the researchers and development machineries in the freshwater sector have their task cut out to maintain pace of the aquaculture development at sound & sustainable level and to ensure quality fish protein towards achieving the goal of Blue Revolution.

Exotic Fishes in Indian Aquaculture

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Introduction

Aquaculture is one of the fastest growing food producing sectors in the world growing at pace of over 8% since 1970. As of 2012, the number of species registered in FAO statistics was 567, including fin-fishes (354 species, with 5 hybrids), molluscs (102), crustaceans (59), amphibians and reptiles (6), aquatic invertebrates (9) and marine and freshwater algae (37)(FAO 2014). India stands second in global fish production and has shown spectacular growth during the past six decades from meager 0.75 million tonnes in 1950-51 to 9.34 million tonnes in 2013 (Basavaraja 2015). Aquaculture in India has evolved as a viable farming practice over last three decades with an annual growth rate of 6-7%, with a production of 4.65 million tones in 2013, placing second highest in the world in cultured fish production, constituting 7.75% of world production (Basavaraja 2015). About 95% of India's aquaculture production has been through inland aquaculture, owing to the large scale culture of carps and other species. Aquaculture plays an important role in socio-economic upliftment, employment generation and improving nutritional security of the country.

Though India is rich and diverse in aquatic genetic resources, the index of biodiversity utilized for aquaculture (BUA) is of the order of 0.13 (85% from Indian major carps; 5% air-breathing fishes; 10% rest all species together) (Ayyappan *et al*., 2011), clearly indicating the domestication of resources that can provide sustainable utilization is not proportionate with the level of biodiversity and agro climatic environment. Therefore, diversification of aquaculture with new candidate species to enhance the production, exploring the various aquatic resources and agro climatic environments, is the need of the hour.

Carps form the main stay of the country's aquaculture production and substituting the entire major carp component from the culture system is a remote possibility. In such situation, successful introduction of any new species largely depends on its compatibility with the major carps. Many indigenous species viz *Labeo calbasu, L fimbriatus, L gonius, L. bata, Cirrhinus cirrhosa, C reba, Punitus sarana and P pulchellus* catfish like *Pangasius pangasius, Horabagrus brachysoma, Ompakpabda, O bimaculatus, Speratas eenghala, S aoretc* having regional importance, growth potential and consumer acceptability, have been brought to the main stream of culture and tried for their wider domestication all over the country (Jayasankar and Das 2015). Since availability of mass scale seed production and standard rearing technologies are prerequisite for the promoting the culture of any species, efforts are on to standardise their culture technology. But there an urgent need to cater to the demands of the growing population and with availability of tailor made aquaculture practices and basic information, it is easier for them

to adopt the exotic species,hatchery and culture operation and research into exotic species have opened a large number of employment opportunities. Overall, exotic species have served as agents for crop diversification for rural poor. Welcomme (1998) defined 'Exotic animals' as "species occurring outside of its natural range". According to Kottelat& Whitten (1996) An introduced species, (exotic) is any species intentionally or accidentally transported and released by man outside its natural range. The interest and objectives in use of exotics is mostly commercial in nature.

The use of exotic aquatic species to increase food production and income has been an established practice since the middle of the 19th Century. The ancient Romans and medieval European monks transported common carp, *Cyprinus carpio*, and redfin perch, *Perca fluviatilis*, around Europe and the Roman Empire and Greeks. Advances in controlling the spawning of salmonids, primarily rainbow trout *Oncorhynchus mykiss* in the mid-1800s led to increased exportation of these fish to other areas (Welcomme 1988). Recent advances in trade and transport have made large-scale movements of many different species over great distances possible. To a large extent, exotic fishes are directly related to the global development of the aquaculture industry and the concomitant demand in many countries for new species for culture.

Reasons for the Introduction of Aquatic Exotic Species globally

Reason	%
Aquaculture	38.7%
Fisheries	8.7 %
Angling/Sport	7.9 %
Accidental	7 %
Ornamental	7.3 %
Unknown	15.4 %
Other (research, control, bait)	14.5 %

Of the 1155 fish introductions for aquaculture globally only 6.8% and 0.7% were considered ecologically and socio-economically adverse respectively but 45% and 24.5% were beneficial (Bartley & Casal,1998). For example, the introduction of the freshwater sardine *Limnothris samiodon* to Lake Kariba, Zimbabwe is the best example of success with an introduced fish. Other alien species Mossambique tilapia (*Oreochromis mossambicus*) and Nile tilapia (*O. niloticus*) contribute to inland fish production in reservoirs and lakes in Asian countries such as Sri Lanka and Indonesia (De Silva &Funge-Smith2005). The production of the African cichlid tilapia is much higher in Asia than in most areas of Africa. Introduced salmonids in Chile forms an important aquaculture industry and is responsible for approximately 20% of the world's farmed Salmon. The production of *Litopeneaus vannamei* in Thailand and China represents the country's lion share of total marine shrimp production in (Briggset al.2004).

Exotic fish in Indian scenario

Blue revolution in the country laid took off in 1971 with the launching of nationwide demonstration on Composite culture of Indian and exotic fishes under the All India Coordinated Research Project (AICRP). This has made huge impact in national aquaculture expansion. The three Indian major carps

form the lion's share of the aquaculture produce and the exotic carps viz silver carps, grass carp and common carp, forms the next important group in the country. The Introduction of polyculture techniques with exotic species resulted in maximum use of all available niches. Wise use of exotic contributed significantly to aquaculture production by utilizing vacant niches. Introductions of exotic fish species are an important part of anthropogenic activities concerning aquatic ecosystems (Garcia-Berthou, 2007). In India, over 300 alien fish species including 291 ornamental species, 31 aquaculture species and 3 larvicidal fishes are recorded (Table 1). These introductions may be intentional or unintentional (Lakra*et al.*2008; Singh and Lakra, 2011, Singh, 2014). Many of them are illegally introduced and historical information such as the source, place and period of introduction is unknown.

Historical perspective

During the period 1870-1947, exotic fish were introduced in India *viz* Gamefishes: brown trout (*Salmo truttafario*), rainbow trout (*Oncorhynchus mykiss*); Food fishes: *Tinca tinca*, *Cyprinus carpio* (European strain), *Osphronemus gourami*; Larvicidal fishes*: Gambusia affinis*. Trout was the first exotic food fish introduced in 1863 by the British people for angling purposes. Later, two trout species Rainbow trout, *Oncorhynchus mykiss* and brown trout, *Salmo truttafario,* were brought into India. Atlantic salmon, *S. salar*were brought in the Kashmir in 1960, but failed to establish. These species have been re-established in the states of Uttarakhand, Arunachal Pradesh and in the Nilgiris in Tamil Nadu, Later brook trout, *Salvelinus fontinalis* has also been adopted for aquaculture in the Himachal Pradesh and Jammu and Kashmir.

Three varieties of the Prussian (German) strain of common carp, *viz*. the scale carp *(Cyprinus carpiocommunis),* the mirror carp (*C. carpiospecularis)* and the leather carp (*C. carpionudus)* were introduced from Sri Lanka in 1939.

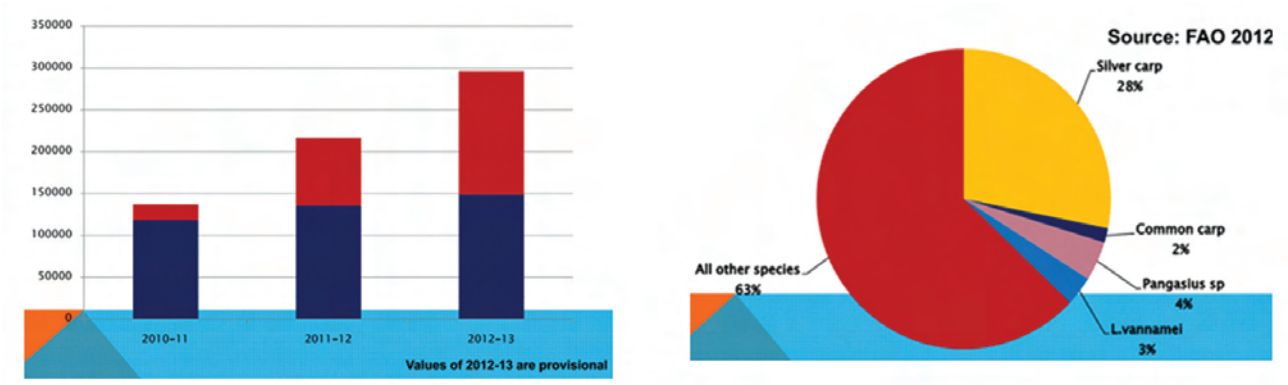
Tilapia, *Oreochromis mossambicus,* was first introduced into pond ecosystems in 1952 and thereafter stocked in several reservoirs of south India for augmenting production (Sugunan 1995). Two species *O. mossambicus* and *O. niloticus* are predominantly available in the country found in almost throughout the country.

During 1950-2000, 14 exotic fish/ shrimp species introduced into India

Salmonids	*Salvelinus fontinalis, Onchorhyncus nerka, Salmo salar*
Tilapia	*Oreochromis mossambicus* and*O. niloticus*, red tilapia
Common carp	*Cyprinus carpio (*Chinese strain*),*
Silver carp:	*Hypophthalmichthys molitrix*
Grass carp	*Ctenopharyngodon idella*
Punti Barb	*Puntius javanicus*
Big head carp	*Aristichthys nobilis*
African Catfish	*Clarias gariepinus*
Red bellied pacu	*Piaractus brachypomus*
Malaysian catfish	*Pangasian odonhypophthalmus*
Pacific white shrimp	*Litopenaeus vannamei*

Of the 31 alien fish species recorded from aquaculture in India twelve fish species are used commonly under aquaculture in the country (Singh and Lakra, 2011). Culture of some species such as *Pangasian odonhypoththalmus, Oreochromis niloticus, Piaractus brachypomus, Aristichtys nobilis, Onchorhynchus mykiss,* and *Litopenaeu svannamei* have picked up during recent years (Singh, 2014).

Exotic fishes have contributedsignificantly to the country's aquaculture production from 1990 onwards. The estimated annual average production of alien species fit for human consumption amounts to around 18.2 to 34.5% of the annual average production of marketable fish cultured in India Over 2 lakh tonnes of Pangas and 1 lakh tonnes of pacu are produced annually. Share of exotic shrimp has increased up to 50% of the total cultured shrimp production. Similarly, the ornamental fish trade in India is also dominated mainly by alien fish species such as gold fish, Angel, Guppy, Swordtail, Oscar, Platy, Cichlids, Tetras, Gourami, Sucker mouths, Pacu etc. which have been introduced from different parts of world, mainly from Asia.



Contribution of Exotic fish total aquaculture

(Share of exotic shrimp increased upto 50% in the total cultured shrimp production) (Contribution of Exotic fish total aquaculture)

Advantages of introduced species:

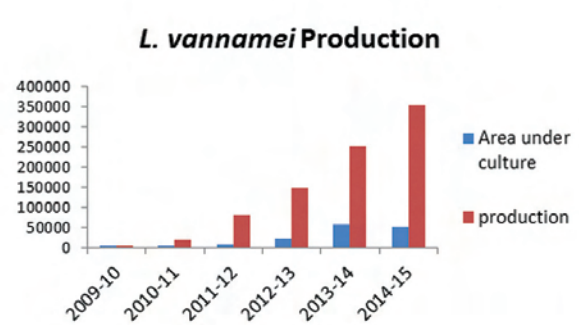
- Availability of tailormade aquaculture practices like easy to breed, ready availability of seed at the door step of the farm and easy to culture;
- Relatively higher production over indigenous species (pangas can grow upto 3 kg in an year, where Indian major carps grow upto 1.5 kg);
- compatibility with agro-ecosystems (e.g. can integrated with rice farming or can grow in upland areas);
- source of alternative income (via sale of table fish or seeds), improves livelihood of people (poor people can buy, due to relatively lower market price, resulting in improved nutrition, improved income and employment opportunities)

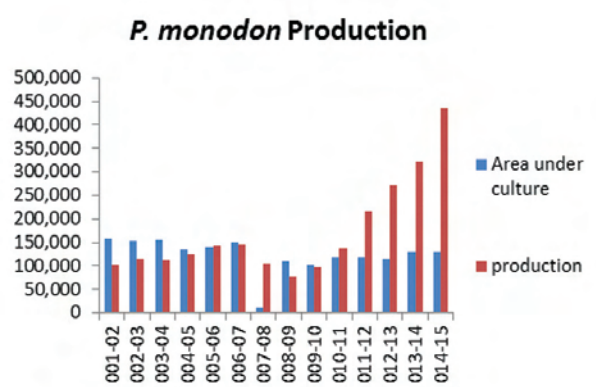
- Can use for waste recycling/ local resources, weed control e.g. grass carp and for mosquito control.
- Alien species often command a higher market price than native fishes in international markets but rated low priced for domestic consumption (DeSilva *et al.*,2009)
- In ornamental sector, many fishes are easy to breed and rear, Many species are very attractive and have high market value. Easy to maintain in the tanks and pools.
- Some exotic species can survive very well in adverse conditions for example Tilapia, African catfish etc.
- Species like *Clarias gariepinus* can be fed with any type of feeding material, which is cheaply available to farmers, hence good profit in culture.
- Availablity of SPF stocks of species like *Litopenaeus vannamei*.

Litopenaeus vannamei

Litopenaeus vannamei is one of the most desired species for aquaculture throughout the world. It has contributed nearly 90% of total shrimp production in world. This species is native to the Eastern Pacific and has been transplanted to other parts of world by virtue of its monetary value, market demand, fast growth, high survival, disease resistance and ready acceptance of artificial feed. When farming of Black tiger shrimp (*Penaeus monodon*) in India began to decline due to disease outbreaks, aquaculture of *L. vannamei* attracted farmers because of its fast growth, disease resistance, availability of specific pathogen free (SPF) and specific pathogen resistant (SPR) brood stock and ability to tolerate high density and low salinity, lower protein requirements (and therefore production costs), high survival during larval rearing, and some marketing advantages.

At present *L. vannamei* occupies 28% (50240 acres) of total area under shrimp culture with production share of 44.85% (353413 t) (2014-2015) which indicates this species occupies major share in country's aquaculture status.(MPEDA 2015). Introduction of *L. vannamei* in our freshwater system has been a huge success in terms of high yield of 10-15 t/ha and has become popular among the prawn farmers





within a short period. The entry of *L. Vannnamei* in India has showed a significant milestone in country's shrimp farming as well as seafood export.

Issues of concern for small-scale farmers: It has been observed that only semi-intensive and intensive culture is considered as economical. But shrimp farming sector in India comprises of > 90% of small farmers (less than 2 ha water area) and ETS is mandatory for *L. vannamei* culture irrespective of the size of the farm, putting a significant strain on these small-scale farmers in India who are really 'resource –poor'.

Ways to adopt vannamei culture for small-scale farmers: Cluster based management concept of BMP programs can be good option for adopting *L. vannamei* culture with common reservoir and common ETP and assistance from the Govt. for the modification required infrastructure for ensuring biosecurity. Profitability of low-density extensive cultures which could be adopted by resource poor small farmers must also be investigated.

Future concern: Regional trade with countries facing anti-dumping duties in the US market is growing significantly, excess supply of fresh shrimp from neighboring countries leads to price decrease and low profit margin, further expansion will lead to a further drop in price and increase competition among neighboring countries.

Problems with *L. vannamei* culture

- **Health risk**: Introduction of exotic viruses which might affect the native shrimp species.
- **Ecological risk** – escape into natural environment and establishment thereby affecting the biodiversity.
- **Environmental risk** – intensive culture leads to high nutrient load in the system.
- **Social risk** – social unrest is bound to result if big investors enter the field and disturb the traditional and improved traditional system of farming that is being practiced by the small farmers.
- **Market risk** – globally increase in supply will result in further reduction in price and we have to compete with established players in the field.

Striped catfish *Pangasian odonhypopthalmus*,

Pangasian odonhypothalamus is an exotic freshwater catfish that has been introduced into the culture system in west Bengal illegally before the same species was permitted in Indian waters by Govt. of India in 2009 (Jayasankar&Giri, 2013). This species was adopted for culture for various reasons *viz* faster growth rate of achieving 1.5 kg in 6 month; Low cost of production; low sensitivity to dissolved oxygen stress and other factors. Many consumers prefer pangas over the carps in view of the fewer number of bones in the flesh. Most of the farmers have undertaken pangas farming in Andhra Pradesh as an alternative in the areas which have suffered losses in shrimp farming and in low productive area. Presently country is able to produce 200,000mtper annum (Jayasankar&Giri, 2013). There is no denying

fact that arrival of pangas in India has signalled a significant milestone, representing the first major component of diversification in the otherwise carp-dominated freshwater aquaculture scenario. With this species country could able to achieve average production yield of 30 t/ ha/yr (Jayasankar&Giri, 2013). The pangas fish is found to be most compatible with IMCs in polyculture also. An estimated 10-15% of farmers stock Pangas in polyculture. The state of west Bengal has been found to be hub of seed production of *P. hypopthalamus* in the country, producing 300 to 500 million fry every year (Jayasankar&Giri, 2013). Seed production is also carried out in other parts of the country such as Andhra Pradesh and Chhattisgarh in a minor scale. Total farming period of pangas farming extend from 8 to 10 months with an avg monthly growth increment of 150g. A production of 50mt per ha can be achieved under different stocking practices.

- The cost of production of Pangas in India is around Rs 60-65/kg at present. In 2012-2013 pangas yielded a price of Rs72-75 Rs/kg. Such cost of production downgrades the scope of export of pangasfrom India to other countries. Other countries such as Vietnam government provide financial assistance for exporting this fish.
- Contrary to the belief regarding the colour of the meat, none of the domestic processors expressed a problem with colour of the meat.
- Value addition in pangas needs improvements. Encouragement for market places, processing industries, enhancing market avenues, and tapping rural markets needs lot of attention.
- Govt. of India extends financial assistance through NFDB funded schemes for Pangas farming in the form of back-end scheme and financial assistance is extended to the tune of Rs. 50000/ha. Banks have also started providing loan for pangas farming. However such assistance is lacking for increasing marketing potential of pangas in the country.
- Growth potential of striped catfish under current scenario in India reveals that they lack genetic potential for high yields. Proper measures need to be developed to minimise transport stress to the seed. (Jayasankar&Giri, 2013)

Highly volatile and fluctuating market situation in pangas marketing is one of the major problems facing the fish farmers.

Tilapia

Tilapia is a highly versatile fish and one of the most popular aquaculture enterprises worldwide with more than 135 countries producing this fish. It is suitable for low technology farming and is often known as 'Aquatic chicken' chiefly because of its potential to meet the nutritional demands of the booming global population. Tilapia is a favourite in a wide spectrum of producers who primarily target domestic and regional consumers rather than export. Global production of tilapia was around 3.85million tones in 2011 (Salin, 2015).

The earliest introduction of tilapia *Oreochromis mossambicus* was during 1952, but while it could not develop into a successful aquaculture industry, the fish soon escaped into the natural water bodies,

where it contributed towards inland fish production in India. Culture is very widespread in all kinds of water bodies including small ponds, cages, public canals and water ways, hence, this species has great potential in the Indian context with regard to the growing demands and efficient use of different water bodies. Recently Ministry of Agriculture, DAHDF, Govt. of India has given clearance to some private farmers to culture *O.niloticus* using formulated guidelines; keeping in view the increased demand for fish (Subrath Ghosh and Datta 2014).

Red-bellied Pacu

Pacu is an inhabitant of the Rio Orinoco and Amazon River basin in South America. This fish was introduced as cultivable food fish into some Asian countries such as Taiwan, Malaysia, China, Thailand and Bangladesh. In 2001 this fish entered illegally into India, particularly to the fish farming regions of West Bengal and then to Andhra Pradesh via Bangladesh (Lakra and Singh 2011; SubrathGhosh and Datta2014).

Culture and breeding of this exotic fish was clandestinely started inWest Bengal and lately, it has become popular, particularly the states of Andhra Pradesh, Orissa, Kerala and Maharashtra (Lakra and Singh 2011). It attains 1.5 -2.5 Kg body weight in a year in pond with proper supplementary feeding. Over one lakh tonnes of cultured pacu is presently produced annually. Polyculture of pacu with major carps, especially rohu is an emerging aquaculture practice in Andhra Pradesh (Nair and Salin, 2007). Farming of Pacu is also reported from Assam and Tripura in both mono and polyculture system along with carps, some farmers in UP have observed better growth and overall economy in polyculture with IMC over monoculture systems (Subrath Ghosh & Datta 2014).Overall this fish is not ferocious and aggressive in nature, unlike its close relative piranha that possesses razor sharp teeth (Singh, 2014).

Concern: Even though red bellied pacu has not been introduced legally in India, the eastern and north eastern states of India are major importers of this fish in frozen state from Bangladesh for consumer who cannot afford to buy fishes like major carps. However, till now as there is no clearance, ie legal/ official permission from Government authorities for culture of Pacu in India, authorities will have to judge and decide whether this fish is to be allowed to multiply in the country in context of its possible rapid expansion of this species in India aquaculture system (Subrath Ghosh&Datta2014).

Exotic trouts:

Efforts to develop trout farming in India have borne fruit, especially in Jammu and Kashmir and Himachal Pradesh as result of controlled breeding, hatchery management and production of balanced feed. About 23 trout hatcheries in different hill states produce more than 100 tonnes annually, most of which is produced in raceways.

Barbonymus gonionotus

Anexotic medium carp, introduced to India in 1972 to control aquatic weeds. It is commonly called 'silver barb', 'Thai barb', 'Java carp' and 'Tawes'. The fish is an omnivore, but prefers to eat soft weeds like Hydrilla, Najas, Ceratophyllum, etc. The fish can grow 700-800 g/ year in a culture pond. The initial growth rate of the fish is as fast as Indian major carps. Although the fish was introduced in

the 1970s, the culture potentiality of this species was only realized during the late 1990s. The fish is now already being cultured in West Bengal, Assam and other north-eastern states. It is a highly preferred fish and fetches the same market price as that of Indian major carps.

African catfish*:Clarias gariepinus* was illegally introduced in India during1990s, since then the culture of this fish has rapidly spread, using animal waste as cheap feed, in many parts of the country illegally. African catfish *is a* very hardy species tolerating a wide range of temperature (12-36 ± 1°C) as well as salinity (<14 ppt), which facilitate easy culture and marketing in live condition. Culture of this species is legally banned because of its predatory and voracious nature, which threaten indigenous species.

Ornamental fishes

Ornamental fish industry thrives well in India, mainly with the exotic ornamental fishes. The ornamental fishes were introduced from different parts of the world by fish hobbyists, mainly from Asia, but here are no clear records or information available documenting the timing and/or source of these imported species. More than 200 exotic aquarium fish species are now bred in different parts of the country(Ghoshetal., 2003) and provides a promising livelihood alternative for many people. Govt. of India has encouraged many development projects in ornamental fish industry through NFDB and MPEDA in almost all the states of India. Kerala Government also initiated a major programme for exporting the ornamental fishes.

Major concerns

Even though exotic fish culture in India is gaining momentum among farmers, it has also some negative impacts such as prolific breeding, predation or competition by the introduced species affecting indigenous biodiversity, gene pool contamination, negative environmental impacts, loss of indigenous species, potential for disease introduction; low demand (low price); and price drop of indigenous species due to cheaper price of introduced species.

Conclusion

In the past, no heed was paid to the risks of introductions or the latter were not thoroughly premeditated, often because the negative impacts of the alien fish species became apparent only sometime after the alien species were introduced and established in the ecosystem. Over the last two decades, the aquaculture entrepreneurs have been demanding imports of many new fish strains and varieties for improved production and competition in the world market, hence it has proved very difficult to avoid introduction of alien species. Though exotic species have provided socio-economic benefits for a vast number of poor people in the region yet, environmental, socio-economic and biodiversity issues are important considerations for authorities to check and regulate importation of any alien fishes in India. There is an urgent need to develop a well-planned research program to assess the impacts. The governments should carefully weigh both the positive and negative impacts for each species before making any national or regional policy. In considering the history of introductions both helpful and harmful one issue that stands out above all is the need for decisions to be well

informed and carefully considered. The responsible introduction of an alien species requires that it be carried out in a way that will minimize the risk of harm to indigenous biodiversity. Careful planning of introductions, for example through a risk assessment process, can help to identify and minimize the risk of negative impact as well as to maximize the benefits.

National Bureau of Fish Genetic Resources (NBFGR), Lucknow has undertaken studies on impact of exotic fishes in India. There is a National Committee for Introduction of Exotic Aquatic Species in Indian Waters under the Union Ministry of Agriculture, to check and regulate importation of alien fishes in India. At the national level, quarantine and health certification programmes have been initiated as an integral part of much broader strategies aimed at protecting the natural environment and natural faunas from the deleterious impact of alien fish species and pathogens. A national Plan and Quarantine guidelines have been developed by NBFGR for execution by the aquaculturists and other stake holders culturing alien fishes in India.

Fish species specific guidelines have also been developed particularly for introduction of *O. niloticus, Pangasian odonhypophthalmus* and *Litopenaeus vannamei* and ornamental aquarium fishes. The quarantine facility required for alien fish species introduction has also been designed and can be adopted under public–private partnership mode. The aquaculturists and farmers are advised to comply with the available regulatory mechanisms for all alien fish species along with sanitary and phyto-sanitary standards.

Some exotic species are giving good production in Indian waters and good profit but care need to be taken when unauthorised species are being cultured in India. Proper impact assessment is required before taking up the culture of species. Otherwise there is likely chances of escaping the fish into nature and get established, causing threat to indigenous fishes of the country.

Table 1: Fish species introduced in India.

Fish Species	Year	Origin	Reason
Salmo truttafario	1863- 1900	UK	Sport fishing
Oncorhynchus mykiss	1907	Sri Lanka & Germany	Sport fishing
Salvelinus fontinalis	1911	U.K.	Sport fishing
Oncorhynchus nerka	1968	Japan	Sport fishing
Salmo salar	1968	U.S.A.	Sport fishing
Carassius carassius	1870	U.K.	Experimental culture
Tinca tinca	1870	U.K.	Aquaculture
Osphronemus gourami	1916	Java & Mauritius	Aquaculture
Cyprinus carpio(German Strain)	1939	Sri Lanka	Aquaculture
Oreochromis mossambicus	1952	Africa	Aquaculture
Cyprinus carpio (Bangkok strain)	1957	Thailand	Aquaculture
Ctenopahryngodon idella	1957	Japan	Aquaculture
Hypophthalmichthys molitrix	1959	Hong Kong	Aquaculture

Barbonymus gonionotus	1972	Indonesia	Aquaculture
Aristichthys nobilis	Illegally	-	Aquaculture
Clarias gariepinus	Illegally	-	Aquaculture
Oreochromis niloticus	Illegally, recently Govt. Of India has given clearance	-	Aquaculture
Red Tilapia (*Oreochromis sp.)*	Illegally	-	Aquaculture
Piaractus brachypomus	Illegally	-	Aquaculture
Pangasian odonhypophthalmus	Illegally but legalised during 2009	-	Aquaculture
Litopenaeus vannamei	After 2-year trial farming Govt. made legal on 2008	-	Aquaculture
Guppy (*Poecilia reticulata*)	1908	South America	Larvicidal
Top Minnow (*Gambusia affinis*)	1928	Italy	Larvicidal
Live bearers (27 species)		Various countries	ornamental
Egg layer (263 species)		Various countries	ornamental

(Source: Bijukumar 2000)

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