CMFRI

Course Manual

Winter School on

Recent Advances in Breeding and Larviculture of Marine Finfish and Shellfish

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AN OVERVIEW OF GLOBAL AQUACULTURE AND CAGE FARMING

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Introduction

Aquaculture, the fastest growing food-producing sector, now accounts for almost 50 percent of the world's food fish and is perceived as having the greatest potential to meet the growing demand for aquatic food. Given the projected population growth over the next two decades, it is estimated that at least an additional 40 million t of aquatic food will be required by 2030 to maintain the current per capita consumption.

Aquaculture production

The contribution of aquaculture to global supplies of fish, crustaceans, molluscs and other aquatic animals continues to grow, increasing from 3.9% of total production by weight in 1970 to 27.1 % in 2000 and 32.4% in 2004. Worldwide, the sector has grown at an average rate of 8.8 percent per year since 1970, compared with only 1.2% for capture fisheries and 2.8 percent for terrestrial farmed meat production systems over the same period. Production from aquaculture has greatly outpaced population growth, with per capita supply from aquaculture increasing from 0.7 kg in 1970 to 7.1 kg in 2004, representing an average annual growth rate of 7.1%. World aquaculture (food fish and aquatic plants) has grown significantly during the past half-century. From a production of below 1 million t in the early 1950s, production in 2004 was reported to have risen to 59.4 million t, with a value of US $ 70.3 billion. In 2004, countries in the Asia and the Pacific region accounted for 91.5% of the production quantity and 80.5% of the value. Of the world total, China is reported to account for 69.6 percent of the total quantity and 51.2 % of the total value of aquaculture production.

The top ten producing countries for food fish supply from aquaculture in 2004 are indicated in Table. 1 along with the top ten countries in terms of annual growth in aquaculture production for the period 2002 – 2004. All regions showed increased in production from 2002 to 2004, led by the Near East and North Africa region and Latin America and the Caribbean with 13.5 and 9.6 percent average annual growth respectively.

World aquatic plant production in 2004 reached 13.0 million t (US$6.8 billion), of which 10.7 million t (US$ 5.1 billion) originated from China, 1.2 million t from the Philippines, 0.55 million t from the Republic of Korea and 0.48 million t Japan. Japanese kelp (*Laminaria japonica* – 4.5 million t) showed the highest production followed by Wakame (*Undaria pinatifida* -2.5 million t) and Nori *(Porphya tenera* – 1.3 million t). An additional 2.6 million t were reported by countries as"aquatic plants" and not further specified. The production of aquatic plants increased rapidly from 2002 to a total of 11.6 million t primarily duet to the increased production in China.

The growth in production of the different major species groups continues, although the increases seen so far this decade are less dramatic than the extraordinary growth rates achieved in the 1980s and 1990s (Table 2). The period 2000-04 showed higher growth in production of crustaceans in particular, and of marine fish. Growth rates for production of other species groups have begun to slow and the overall rate of growth, while still substantial, is not comparable with the significant rate increases seen in the previous two decades.

The top ten species groups in terms of production quantity and percentage increase in production quantity from 2002 to 2004 are shown in Table 3. Production of carps far exceeded than that of all other species groups, accounting for over 40 % (18.3 million t) of total production of fish, crustaceans and molluscs in 2004. Combinely, the top ten species groups account for 90.5% of the total aquaculture contribution to fisheries food supply.

Table 1. Top ten producers in terms of quantity, 2004

Producer	2002	2004	APR
	(Tonnes)		(Percentage)
China	27 767 251	30 614 968	5.0
India	2 187 189	2 472 335	6.3
Vietnam	703 041	1 198 617	30.6
Thailand	954 567	1 172 866	10.8
Indonesia	914 071	1 045 051	6.9
Bangladesh	786 604	914 752	7.8
Japan	826 715	776 421	-3.1
Chile	545 655	674 979	11.2
Norway	550 209	637 993	7.7
United States of America	497 346	606 549	10.4
TOP TEN SUB TOTAL	35 732 648	40 114 531	6.0
REST OF THE WORLD	4 650 830	5 353 825	7.3
TOTAL	**40 383 478**	**45 468 356**	**6.1**

Top ten producers in terms of growth, 2002 – 2004			
Myanmar	190 120	400 360	45.1
Vietnam	703 041	1 198 617	30.6
Turkey	61 165	94 010	24.0
Netherlands	54 442	78 925	20.4
Republics of Korea	296 783	405 748	16.9
Iran (Islamic Rep. of)	76 817	104 330	16.5
Egypt	376 296	471 535	11.9
Chile	545 655	674 979	11.2
Thailand	954 567	172 866	10.8
United States of America	497 346	606 549	10.4

Note: Data exclude aquatic plants. APR refers to the average annual percentage growth rate for 2002 – 2004.

Table 2. World aquaculture production: average annual rate of growth for different species groups

Time period	Crustaceans	Molluscs	Fresh water	Diadromous fish	Marine fish	Overall fish
1970-2004	**18.9**	**7.7**	**9.3**	**7.3**	**10.5**	**8.8**
1970-1980	23.9	5.6	6.0	6.5	14.1	6.2
1980-1990	24.1	7.0	13.1	9.4	5.3	10.8
1990-2000	9.1	11.6	10.5	6.5	12.5	10.5
2000-2004	**19.2**	**5.3**	**5.2**	**5.8**	**9.6**	**6.3**

Table 3.Top ten species groups in aquaculture production: quantity and emerging growth

Species group	2002	2004 (Tonnes)	APR (Percentage)
Carps and other cyprinids	16 673 155	18303 847	4.8
Oysters	4 332 357	4 603 717	3.1
Clams, cockles, arkshells	3 457 510	4 116 839	9.1
Miscellaneous freshwater Fishes	3 763 902	3 739 949	-0.3
Shrimps, prawns	1495 950	2 476 023	28.7
Salmons, trouts, smelts	1791 061	1 978 109	5.1
Mussels	1700 871	1 860 249	4.6
Tilapias and other Cichlids	1483 309	1 822 745	10.9
Scallops, pectens	1228 692	1 166 756	-2.6
Miscellaneous marine Molluscs	1389 586	1 065 191	-12.4
Top ten species groups in terms of growth in production of fish, crustacean and molluscs, 2002 - 04			
Sea urchins and other echinoderms	25	60 852	4 833.6
Abalons, winkles, conchs	2 970	287 720	884.3
Frogs and other amphibians	3 074	76 876	400.1
Freshwater molluscs	13 414	142 346	225.8
Sturgeons, paddlerfishes	3 816	15 551	101.9
Miscellaneous aquatic invertebrates	12 593	42 159	83.0
Flounders, halibuts, soles	35 513	109 342	75.5
Miscellaneous coastal fishes	386 160	878 589	50.8
Miscellaneous demersal fishes	16 638	31 531	37.7
Shrimps, prawns	1 495 950	2 476 023	28.7

The largest production for an individual species was the Pacific cupped oyster *(Crassostrea gigas* – 4.4 million t), followed by three species of Carp – the silver carp (*Hypophthalmichthys molitrix* – 4.0 million t), the grass carp *(Ctenopharyngodon idellus* – 3.9 million t) and the common carp *(Cyprinus carpio* -3.4 million t). In terms of value, shrimp culture is second in importance and has increased substantially in the 2002 – 2004 period.

Mariculture contributes 36.0 %of production quantity and 33.6 % of the total value and are mainly from high value finfish, and also a large amount of relatively low priced mussels and oysters. Although brackishwater production represented only 7.4 % of production quantity in 2004, it contributed 16.3 % of the total value, reflecting the prominence of high – value crustaceans and finfish.

CAGE AQUACULTURE: A GLOBAL OVERVIEW

Introduction

The on-growing and production of farmed aquatic organism in cages, enclosures has been a relatively recent aquaculture innovation. Although the cages for holding and transporting fish for short periods can be traced back almost two centuries ago to the Asian regions, commercial cage culture was pioneered in Norway in the 1970s with the increase in salmon farming. As in terrestrial agriculture, the move within aquaculture towards the development and use of intensive cage farming systems was driven by a combination of factors such as the increasing competition faced by the sector for available resources (including water, land, labour, energy), economies of scale and the drive for increased productivity per unit area and the drive and need for the sector to access and expand into new untapped open water culture sites such as lakes, reservoirs, rivers and coastal brackish and marine offshore waters.

Although no official statistical information exists concerning the total global production of farmed aquatic species within cage culture systems, there is some information on the number of cage rearing units and production statistics being reported to FAO by some member countries. In total, 62 countries provided data on cage aquaculture for the year 2005.

The cage aquaculture sector has grown very rapidly during the past 20 years and is presently undergoing rapid changes in response to pressures from globalization and growing demand for aquatic products. Fish consumption in developing countries will increase by 57% from 62.7 million metric t in 1997 to 98.6 million t in 2020. By comparison, fish consumption in developed countries will increase by only about 4 percent, from 28.1 million metric t in 1997 to 29.2 million in 2020. Rapid population growth, increasing affluence and urbanization in developing countries are leading to major changes in supply and demand for animal protein from both livestock and fish.

Production

Total reported cage aquaculture production from 62 countries and provinces accounted to 2412167 t (excluding China) and the major cage culture producers in 2005 are Norway (652306 t), Chile (588 060 t), Japan (272 821 t), United Kingdom (135 253 t), Vietnam (126 000 t), Greece (76 577 t), Turkey (78 924 t), and the Philippines (66 249 t).

Major cultured species, cage culture systems and culture environments

To date commercial cage culture has been mainly restricted to the culture of higher value (in marketing terms) compound-feed-fed finfish species, including salmon (Atlantic salmon, Coho salmon and Chinook salmon), most major marine and freshwater carnivorous fish species (including Japanese amberjack, red seabream, yellow croaker, European seabass, gilthead seabream, cobia, sea raised rainbow trout, Mandarin fish, snakehead) and an ever increasing proportion of omnivorous freshwater fish species (including Chinese carps, tilapia ,*Colossoma* and catfish) However, cage culture systems employed by farmers are currently as diverse as the number of species currently being raised, varying from traditional family –owned and operated cage farming operations (typical of most Asian countries; to commercial cages used in Europe and the America.

In terms of diversity, altogether 40 families of fish are cultured in cages, but only five families (Salmonidae, Sparidae, Carangidae, Pangasiidae and Cichlidae) make up 90 % of the total production and the family Salmonidae alone is responsible for 66 % of the total production. At the species level, around 80 species are cultured in cages of which *Salmo salar* alone accounts for about 51%, and another four species (*Oncorhynchus mykiss, Seriola quinqueradiata, Pangasius spp* and *Onchorhynchus kisutch)* account for about another one fourth (27%). Ninety percent of the total production is from only eight species (in addition to the ones mentioned above: *Oreochromis niloticus, Sparus aurata, Pagrus auratus* and *Dicentrarchus labrax*) the remaining 10 % are from the other 70+ species.

On the basis of the information gathered from the regional reviews, the cold water Atlantic salmon is currently the most widely cage-reared fish species by volume and value and its aquaculture production increased over 4000-fold from only 294 tonnes in 1970 to 1235 972 tonnes in 2005 (Valued at US$4 767 000 million), with significant production of more than 10 000 t from Norway, Chile, the United Kingdom, Canada, the Faroe Islands, Australia and Ireland. (Table 4).

Prospects

Cage culture has great development potential. For example, intermediate family-scale cage culture is highly successful in many parts of Asia and one of the key issues for its continued growth and further development will not be how to promote but rather how to manage it. However, there is also an urgent need to reduce the current dependence of some forms of cage culture systems in Asia upon the use of low value/ trash fish feed inputs, including those for Pangasid catfish and high value species such as Mandarine fish, snakehead, crabs and marine finfish.

Table 4.Total reported Atlantic salmon *Salmo salar* Aquaculture production in 2005 (FAO, 2007)

Country	Quantity in tones	(% of global total)
Norway	582 043	(47.02%)|
Chile	374 387	(30.24%)
United Kingdom	129 823	(10.49%)
Canada	83 653	(6. 76%)
Faroe Islands	18 962	(1.53%)
Australia	16 033	(1.30%)
Ireland	13 764	(1.11%)
United States of America	9 401	(0.76%)
Iceland	6 488	(0.52%)
France	1 190	(0.10%)
Russian Federation	204	(0.02%)
Denmark	18	(0.10%)
Greece	6	(0.02%)
Total	1 237 977	

Source: FAO, 2007

Most of the top marine and brackish cage aquaculture producers are found in temperate regions,(Table 5) while the top species include salmonids, yellowtails, perch-like fishes and rockfishes.(Table 6).

Table 5. Production of the top ten marine and brackish water cage aquaculture countries

Country	Quantity (Tonnes)	in percent of total
Norway	652 306	27.5
Chile	588 060	24.8
China	287 301	12.1
Japan	268 921	11.3
United Kingdom	131 481	5.5
Canada	98 441	4.2
Greece	76 212	3.2
Turkey	68 173	2.9
Republic of Korea	31 192	1.3

Table 6.Production (tonnes) of the top ten species / taxa in marine and brackish water cage aquaculture (excluding PR China)

Species	Quantity (tonnes)	%of total
Salmo salar	1219 362	58.9
Oncorhynchus mykiss	195 035	9.4
Seriola quinqueradiata	159 798	7.4
Oncorhynchus kisutch	116 737	5.6
Sparus aurata	85 043	4.1

Pagrus aurata	82 083	4.0
Dicentrarchus labrax	44 282	2.1
Dicentrarchus spp	37 290	1.8
Oncorhynchus tshawytscha	23 747	1.2
Scorpaenidae	21 297	1.0

However, the intensive cage culture of high value finfish is growing fastest and there are important social and environmental consequences of this growth and transformation of the sub-sector. Similar to global trends in livestock production, there is a risk that the fast growth of intensive operations can marginalize small-scale producers and high production at different levels of intensity can lead to environmental degradation if not properly planned and managed. Considering that most of the cage aquaculture takes place in the fragile yet already much pressured coastal environments, there is increasing agreement that particular emphasis has to be given to the environmental sustainability of the sub-sector.

Integrated cage farming

Cage culture systems need to evolve further, either by going further offshore into deeper waters and more extreme operating conditions and by so doing minimizing environmental impacts through greater dilution and possible visual pollution or through integration with lower-trophic-level species such as seaweeds, molluscs and other benthic invertebrates.

The rationale behind the co-culture of lower-trophic- level species is that the waste outputs of one or more species groups (such a cage reared finfish) can be utilized as inputs by one or more other species groups, including seaweeds, filter feeding molluscs and /or benthic invertebrates such as sea cucumbers, annelids or echinoderms. However, while there has been some research undertaken using land based systems considerably further research is required on open or offshore mariculture systems.

Cage aquaculture will play an important role in the overall process of providing enough (and acceptable) fish for all, particularly because of the opportunities for the integration of species and production systems in near shore areas as well as the possibilities for expansion with sitting of cages far from the coast.

Capture based aquaculture

It is well known that the ready availability of seed in commercial quantities is one of the major constraints in the development and expansion of mariculture. The increasing exploitation pressure on the wild stocks of many major marine fisheries has led to overexploitation and consequent decline in their catch and hence the only sunrise sector to augment seafood production is through marine farming. Eventhough seed production technologies have been developed for many marine finfish and shellfish species it still remains a fact that 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 are 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. Eventhough the production of seeds of the concerned species by development of commercially viable technologies is the ultimate answer for development of sustainable mariculture practices, it still remains a fact that many of these technologies are still in the emerging state and may take many more years for standardization on a cost effective level . Since the marine food production from the capture sector is declining, marine farming has to be developed and expanded urgently and it is not advisable to wait for the standardization of seed production technologies for all the concerned species. In this context, the concept of capture based aquaculture can be considered as a mid way point between fishing and aquaculture and requires to be developed into a sustainable commercial activity for augmenting the seafood production.

Capture Based Aquaculture (CBA) is the practice of collecting 'seed' material – from early life stages to adults – from the wild, and its subsequent on-growing in captivity to marketable size, using aquaculture practices (FAO, 2004). It is well understood that eventhough hatchery technologies have been developed for many high value species, the technologies still remain to be perfected and hence fish farmers have to depend on 'seed' available from the wild. Capture based aquaculture 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. The species/ groups harvested as wild juveniles at the different countries / regions where CBA is practiced include shrimps, milkfish, eels, yellowtails, tunas and groupers. Eventhough CBA could be considered as an unsustainable aquaculture practice in the long run due to the successive stock depletion to the wild stock, there are some aspects which highlight the importance and potential of this practice. It is generally considered that further development of marine aquaculture is possible only by the increase in mass production of juveniles in hatcheries. But it remains a fat that much of world's coastal aquaculture can still be expected to come from the supply and availability of capture-based juveniles. Many of the environmental concerns associated with the grow out of juveniles produced in hatcheries like transfer of diseases and 'genetic pollution' of wild stocks are not encountered in CBA. As capture based aquaculture potentially generates higher profits than other aquaculture systems, the market demand for the products and species cultured is high and it is likely that efforts to promote this activity in future will increase significantly.

The potential marketability, its growth rate, and its ability to function under culture conditions and economic consideration are the main criteria for the species selected for CBA. Eventhough carnivorous species are more expensive to rear, these species command higher market prices and compensate for the high feeding costs. Most species farmed under CBA are carnivorous. The species/groups used in capture based aquaculture include molluscs (oysters, mussels, scallops), crustaceans (shrimps, crabs) and finfish (eels, grey mullets, milkfish, yellowtail, groupers, rabbitfish, tunas). Among these, four groups *viz*. groupers, yellowtails, eels and tunas are of special significance due to their rapid grow out and high market demand. Groupers are popular foodfish farmed in Southeast Asia owing to their fast growth, efficient feed conversion, high market prices and reduced catch from wild sources. The demand for groupers has grown markedly over the last two decades in parts of South-East Asia. The value of live groupers depends on the species (ranges from US $ 8-31 / kg). The amberjack or yellowtail (*Seriola* spp) is another good candidate species for the diversification of farmed fish products because of its high growth rate and good performance in captivity. Yellowtails have a good market especially in Japan and has developed over the last 30 years due to capture based aquaculture production. It can be processed and marketed as a range of products – whole, fillets, steaks etc. The farmed fish is considered superior in quality to wild caught fish and fetches a much higher price in the market. Eels are also important for CBA as they are considered delicacy in many countries and have highest demand in Western Europe and Japan and fetch upto US $ 32/kg. Global demand for eels exceeds 2,00,000 t annually and hence CBA for eels has developed into a specialized industry. In the recent past there has been a rapid increase in the practice of capture based tuna farming especially the bluefin tunas viz. *Thunnus thynnus thynnus* in the North Atlantic and Mediterranian, *Thunnus thynnus orientalis* in the North Pacific and *Thunnus maccoyii* in Australia. These developments have been due to the market demand for *'sushi'* and *'sashimi'* products in Japan. There are production centres in Japan, Australia, the Mediterranian and Mexico. The preference for the bluefin tuna is due to the higher prices in the Japanese market. Farmed bluefin tuna for the uncooked fish market (*'sushi'* and *'sashimi'*) has become a top quality product, with its higher fat content it is particularly suitable for *'sushi'*. The fish that are raised by CBA can, not only achieve substantial weight gains, but more importantly increases in fat content, thus becoming more valuable. On the Japanese market, 1 kg of top quality tuna can be sold upto US $ 600.

Capture based aquaculture can be considered the midway point between fishing and aquaculture, yet as a commercial activity it constitutes a distinct sector. A very significant proportion (millions of metric tonnes) of the total foodfish (finfish, crustaceans and molluscs) aquaculture production reported by FAO is obtained through the on growing of wild caught juveniles (eels, grouper, yellowtail, tunas, milk fish, mullets, most molluscs and some marine shrimp is derived from CBA). Most of the production in CBA is from molluscs. Among finfishes eels, tunas, groupers and yellowtail represent a large proportion of the total volume and an even larger proportion by value. The total value of these four groups exceeded US$ 1.7 billion in 2000. It qualifies to be considered as a separate and distinct entity within the aquaculture sector because it has its own special culture characteristics. CBA is an economic activity that is likely to continue to expand in the short term, both for those species currently under exploitation and possibly with others that may be selected for aquaculture in the near future. In the case of shellfishes like mussels the activity will certainly continue in view of the large scale availability of natural seeds. It is felt that with effective regulations and management practices, the capture based aquaculture offers good scope and potential for the artisanal and industrial sectors in the years to come.

Indian scenario

Although we have vast cultivable brackishwater coastal areas, the mariculture production is about 80 to 100 thousand tonnes annually chiefly from organized shrimp aquaculture. The techno-economic and commercial viability of mariculture in Indian conditions is yet to be demonstrated and practiced except for shrimp and a few bivalves. The potentially cultivable candidate species in India include about 20 species of finfishes, 29 crustaceans, 17 molluscs, 7 seaweeds and many other species of ornamental and therapeutic value. Many mariculture technologies are very simple, eco-friendly and use only locally available infrastructure facilities for construction of farm, feed and seed and hence the entire farming can be practiced by traditional fishermen. Another advantage is that most of our brackish and coastal areas are free from pollution and suited for aquaculture. But hardly 10% of the potential cultivable area is presently used for aquaculture in spite of growing demand for cultured shrimp, bivalves, crabs, and lobsters etc., all of which are in high demand in the export market. In addition a fast growing trade of marine ornamental fishes and other tropical marines has also emerged in the recent years which opens up the possibility of culture and trade of these organisms.

Shrimp culture

One of the principal and highly valued aquaculture products is the marine shrimp. In the global shrimp farming scenario, the tiger prawn *Penaeus monodon* is the dominant species followed by *P. vannamei*, *P. meguiensis, P. indicus* and others. The current aquaculture production of India is 100000 t from an area of 0.12 million ha. spread over West Bengal, Kerala, Andhra Pradesh, Tamil Nadu and Karnataka. Production-wise, *P. monodon* contributed 75% and *P. indicus* 20%. There has been an unusual rush towards shrimp culture and more and more entrepreneurs entered the arena which often led to the disproportionate growth of semi-intensive farming along Andhra and Tamil Nadu. As a result in order to meet the seed requirements, many hatcheries for prawns came into existence. (70 hatcheries with a total capacity of 3900 million seeds of *P. monodon, P. indicus, M. rosenbergii* etc.) at different parts along both the coasts. Similarly more than 30 feed mills operate along different parts of the coast with an annual production capacity of 60000 t of prawn feed. In the process of semi-intensive culture, the carrying capacity of the environment was not taken care of and the consequent environmental stress led to out break of diseases and widespread mortality.

The fast growth of shrimp aquaculture faces a number of social, ecological and economic issues, mainly on account of improper planning and uncontrolled growth of the enterprises. Past experiences reported from various parts of Asian countries indicated that if shrimp culture is not scientifically managed with due consideration for environmental health, the practice will not be sustainable. The major complaint voiced against shrimp culture include, conversion of agricultural land, salinity ingression, destruction of mangroves, displacement of labour, outbreak of viral/ bacterial diseases and social conflicts between user groups. The recently introduced intensive culture practice is characterized by the use of high levels of inputs like fertilizers and feed. This system yielded production up to 8 tonnes per ha but at the same time increased the organic load to the medium causing pollution and stress to the ecosystem leading to outbreak of diseases. Due to serious criticism from the environmentalists, the supreme court of India examined the whole issue and banned semi-intensive and intensive shrimp culture in 500 m belt along the coat of India.

For sustainable development and management of shrimp farming the following measures are suggested.

1. Scientific extensive and semi-extensive farming
2. Two tones/ ha/ year/ production for extensive and five tones/ ha/year from semi-extensive in two crops.
3. No construction within the natural mangrove area or ecologically sensitive wetlands swamps etc.
4. Conversion of agricultural land for aquaculture should be discouraged.
5. Environmental impact assessment (EIA) should be made at the planning stage itself for farms above 40 ha.
6. Stocking density should be less than 5 PL sq m^{-1} and 15 PL sq m^{-1} for semi-extensive farms
7. Use of wet diets to be avoided
8. Use of inorganic fertilizers, pesticides, hormonal growth promoters and antibiotics in the farm should be avoided.
9. Introduction of imported shrimp seed and use of exotic seed should be prohibited.
10. About 10% of the total pond area to be provided for wastewater treatment.

Lobster and crab culture

Increasing demand for live lobsters and crabs 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 many maritime states juvenile lobsters, *Purulei* of *Panulurus homarus, P. ornauts, P. poyphagus* and *Thenus orientalis* are grown in captivity and the eyestalk ablated lobsters attained 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 R.50000/- from a pond of 70 m^2. Recently experimental success was obtained in the seed production of *T.orientalis* and *Scyllarus rugosus*. Similarly, the juveniles of crabs such as *Scylla serrata, S. tranquebarica, Portunus pelagicus,* etc. are fattened in tanks, cages and earthen ponds with a growth rate o 10-29 g per month. The estimated production rate in ponds ranged from 500 – 700 kg per ha. The lobster and crab fattening is slowly getting commercialized in Kerala, Andhra, T.N. and Gujarat. The fattening of young ones caught from wild requires only little inputs and technological application.

Molluscan mariculture

Molluscs form about 18 % of global aquaculture production.

Mussel culture

The green mussel *Perna viridis* and the brown mussel *P. indica* are employed for culture mainly by raft culture and long line culture methods in the coastal water of 3-10 m depth. The production rates varied from 5 kg m^{-1} rope in 5-6 months. Mussel farming in the estuaries of south-west coast was initiated in 1996 and now groups of farmers in coastal areas have taken up mussel culture as a small scale farming activity with good profit. Being in the lower part of the food chain, mussels are energy efficient and cause least pollution to the culture system and the environment. The annual average farmed mussel production in the country in recent years has been estimated as 10,0 00 tonnes mainly from Kerala. Green mussel is farmed by the rack and – rope method. Mussels are seeded and hung from wooden racks constructed in the estuaries where depth is usually less than 3m. During the last two years, on-bottom farming is also done in North Kerala. Several financing organizations like the North Malabar Gramin Bank, the Cooperative Bank and developing agencies like the Aquaculture Developmental Agency of Kerala, the BFFDA and institutes like Integrated Fisheries Project have helped in supporting the growth of mussel farming industry in Kerala

Clam culture

With the decline in shrimp culture, many farmers have switched over to clam culture in their shrimp farms in South Asian countries, as clam meat has demand in the export market with a net profit on investment on 77.5% in India. Species such as *Anadara granosa. Paphia malabarica, Meretrix, Katelysia* and *Villorita cyprinoides* are suitable species for clam culture along our brackish and coastal waters. CMFRI has perfected bottom clam culture technologies for various backwater and estuarine bodies. An attractive production rate of 39-42 tonnes ha.$^{-1}$ in 5-6 months has been achieved. Clams too have a short energy efficient food chain with little impact on either the culture system or the environment.

Oyster culture

The edible oyster *Crassostrea madrasensis* had been found to be ideal for culture as it is fast growing. CMFRI has also developed appropriate indigenous technology for edible oyster culture in brackish water areas, location tested and was found successful for commercialization. Its production rate ha^{-1} is 10 tonnes ha^{-1} in 5-8 months. Off-bottom culture in stake and long-line, rack and ren (rack culture) on strings yielded high rate of production ha^{-1} with natural spat settled on oyster shell strings as the source of seed. The impacts on the environment on oyster culture are less serious.

Pearl culture

Pinctada fucata is the abundant and most frequently used species for pearl oyster culture and pearl production. CMFRI has perfected the techniques for pearl oyster hatcheries, mother oyster rearing, pearl oyster surgery, nucleus implantation and quality pearl production. The survival rates were 40% at spat settling time, 80% at mother oyster rearing and 30% at pearl production. All the rearing and pearl culture activities are carried out in shallow sheltered bays with more than 5 m depth in cages suspended from rafts. Recent attempts to culture pearl oysters in on-shore tanks by the Institute have also proved to be successful. Efforts are also being made to produce black pearls from black lip pearl oyster *Pinctada margaritifera.* The quality and colour of the cultured pearl largely depend on the genetic make-up, colour of the nacre of the shell of the mother oyster, besides the culture site, depth, light penetration, feed, water quality, minerals and trace elements in the culture medium. The most desired depth to obtain good quality pearl is 5-10 m depth along the coast. Siltation and sedimentation at culture sites during the period of culture can have a harmful effect on the survival and pearl production.

Abalone Culture

Abalones are marine gastropods of the genus Haliotis and are known for the production of gem quality pearls and also for their succulent meat. *Haliotis varia* is the commercially important species along the Indian coast. CMFRI has developed methods for the seed production and culture of this species.

Cephalopod Culture

CMFRI has developed methods for the culture of the cuttlefish *Sepiella inermis, Sepioteuthis lessoniana* and *Sepia pharaonis* in the laboratory conditions. However scaling up of the methodologies for commercial level production has to be attempted further.

Marine finfish culture

The marine finfish aquaculture is at an experimental stage in India. The lack of commercial level hatchery production technologies and grow-out methods are the main constraints for the development marine finfish farming in India. The potential species available in Indian waters include milkfish (*Chanos chanos*) mullets, Asian seabass (*Lates calacarifer*), several species of groupers, snappers, breams, pompano and ornamental fishes. Small scale farming is being practiced in certain areas which fully depend on the availability of seeds from the wild. Grouper fattening in cages and ponds is also picking up at different parts of east coast to meet the increasing demand for live export. The marine ornamental fish trade is also gaining momentum. CMFRI has successfully developed seed production technologies for clown fish and few species of damsel fishes which are in high demand in the tropical marine ornamental fish trade.

Seaweed Culture

Seaweeds constitute about 28% of worlds total aquaculture production. Seaweeds are cultured vegetatively using fragments of seaweeds and also using tetraspores and carpospores. Vegetative propagation of *Gracialria* *edulis*, *Gelidiella acerosa* and *Sargassum weightii* has been developed and the technology has been demonstrated for industrial application. A production rate of 5 kg per m^2 in the case of *G. edulis* 3 kg in the case of *G. acerosa* in about 80 days has been achieved by CMFRI. Recently the fast growing seaweed *Kappaphycus alvarezii* had become much popular and commercial level culture of this seaweed is being practiced in some parts of the coast. In the open system seaweed farms are vulnerable to stem damages, water pollution and excessive blooms besides the grazing by fishes. Production of good quality agar/carageenan and development of an appropriate marketing system are the major bottlenecks for the development of seaweed industry in India.

Marine cage farming

For the first time in India a marine cage was successfully launched and operated at Visakhapatnam, in the east coast of India by the Central Marine Fisheries Research Institute. This was totally designed and fabricated at Regional Centre of CMFRI, Visakhapatnam with the help of IIT Kharagpur, a local Diving Company and Visakhapatnam port Trust .The cage was found very sturdy and was able to withstand water currents, waves and winds. The inner diameter of the floating cage was 15 m. It was provided with an outer catwalk structure for free working, and stabilization. The cage net was about 15m in diameter and about 6 m. deep. It was protected by an outer predator net to prevent damaging the cage net by large fish/mammals. On the top of the cage railing, a bird net has been provided to prevent attacks by birds. The entire net was kept in position by ballast and ropes tied to the mooring chains. The cage was provided with a shock absorber on the mooring chain to withstand and absorb the pressure of winds currents etc. The total volume of net in the water was about 850 cubic meters. It could hold up to 25 to 30 tonnes of live fish at a given time without any congestion. The cage was moored at a depth of 11m, about 300m from the shore line. This area in spite of being under influence of high underwater currents, strong waves, and winds and generally rough the cage was intact. Since the stabilization and standardization of several parameters of the cage in its natural condition required time, only limited fish seed of Asian seabass (*Lates calcarifer*) was stocked during the first stocking as a trial. Successful harvesting was done after four months.

The indicative economic projections based on the experiment are: Capital investment (one time) - 15 lakhs, working capital for each crop of 7 months duration - 16 lakhs. The expected yield is about 25 tonnes and expected revenue is about 35 lakhs/ crop. The economic indicators are; pay back period 7 months, Benefit cost ratio at 20% discount rate is 1.99, annual rate of return to capital is 1.19% and capital turnover ratio is 2.54. All these parameters indicate the economic viability of cage culture under the assumptions. The present success will herald a new beginning in marine cage farming and capture based aquaculture in India.

Mariculture and cage farming is still in its infancy in India. Many Asian countries like China, Japan, Taiwan, Philippines, Indonesia, Thailand and Vietnam have made substantial progress in the commercialization of many seed production and farming technologies of marine species. Research and development on commercial level seed production technologies of high value finfish and shellfish, popularization of sea cage farming and evolving suitable policies for sea farming are the key areas to be focused urgently to make mariculture as a significant seafood production sector in our country.

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