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Packages of Practices for Sustainable, Ecofriendly Mariculture (Land-based Saline Aquaculture and Seafarming)

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1. Introduction

The problems of fast growing human population and protein deficit, particularly in the developing countries, continue to exert pressure on the fisheries resources available for exploitation in the wild waterbodies. The increasingly limited opportunities in the capture fisheries sector have generated considerable interest in aquaculture. The potential of aquaculture in meeting the increasing demands for fishery products, generating income and profits and contributing to sustainable food supplies is considered to be quite significant.

A recent report of the Consultative Group on International Agricultural Research stated that within the next 15 years, fish farming and searanching might provide nearly 40% of all fish for the human diet and more than half of the value of the global fish catch. According to a report of the FAO, the world aquaculture production is likely to increase by 2.69 times by 2025, growing from 19.3 million tonnes in 1992 to 26.9 million tonnes in 2000 and to 51.8 million tonnes in 2025. Marine finfish production by farming is expected

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to increase from 0.36 to 1.0 million tonnes, molluscs from 3.5 million tonnes to 8.9 million tonnes and seaweeds from 5.4 million tonnes to 9.8 million tonnes from 1992 to 2025. In India the 1995 production from coastal mariculture (mostly extensive to semiintensive systems of shrimp farming) was reported to be around 85,000 tonnes from an area of 0.12 million ha. The total mariculture production including shrimps, bivalves and finfishes is expected to increase to 2 million tonnes by the year 2025.

There is vast scope for the development of aquaculture in many areas, particularly in the tropics. However, the development of aquaculture is being increasingly subject to a wide range of environmental, resource and market constraints and scrutiny. The interaction of aquaculture with the environment may result in significant ecological changes. The expansion of aquaculture in recent years has led to substantial socioeconomic benefits. It is generally held that the majority of aquaculture practices have had little adverse effect on the ecosystems. Nevertheless, some cases of environmental changes in coastal areas have occurred due to, for example, intensive cage culture operations in Europe and shrimp farming practices in Southeast Asia, Latin America and the east coast of India. Aquaculture is competing for land and water resources and, in some cases, comes into conflicts with other resource users. There is growing concern about the effects of aquaculture operations and various types of industrial, domestic and agricultural pollution on the environment. In several cases, environmental problems have resulted from conversion of wetland habitats, nutrient and organic waste discharges, introduction of exotic species, chemical usage, and from the deterioration of water quality and increasing acquisition of suitable sites by the corporate sector for aquaculture.

The experiences gained from these issues have emphasised the urgent need for the development of sustainable aquaculture with due ecological considerations. It is now widely experienced and believed that diversification of the species base of mariculture production systems (growouts) in polyculture through a careful choice of species, compatible among themselves, would minimise the ill effects of monoculture systems.

2. Fish Supply and Demand

The proportion of fish eating people in India increased from 27.7% in 1987-88 to 39.7% in 1996-97. Assuming that this proportion would increase at least to 50%, the total fish eating population in India by 2020 will be around 650 million. Considering the optimum per capita nutritional requirement of fish of 11 kg/year, the total quantity of fish required for domestic consumption by 2020 will be around 7.2 million tonnes of which (at the present ratio of 2.7 million tonnes of marine fish production to 2.1 million tonnes of inland fish production i.e., 56.2% marine and 43.8% freshwater), 4.1 million tonnes of fish has to be realised from the marine fisheries sector and 3.1 million tonnes from freshwater capture fisheries and aquaculture. The projected marine products exports by 2020 A.D. is 0.9 million tonnes, and hence, the total marine fish production by 2020 A.D. has to be increased to 5 million tonnes. The current total marine fish production from the capture fisheries sector (2.7 million tonnes) and the coastal shrimp aquaculture sector (0.08 million tonnes) is 2.78 million tonnes.

Table 1. Marine fish production requirements of India by 2020 A.D.

I. Fishery resource potential		
Marine : 3.9 million t		
Inland : 4.5 million t		
Total 8.4 million t		
II. Fish production 1994-95 (Figures of Ministry of Agriculture)		
Marine : 2.69 million t (56.2%)		
Inland : 2.10 million t (43.8%)		
Total 4.79 million t		
III. Human population and fish requirement		
a. Expected human population by 2020 A.D.	1300 million	
b. Expected fish eating population by 2020	650 million	
c. Per capita nutritional requirement of fish	11 kg/yr	
d. Estimated requirement of fish for domestic consumption by 2020	7.2 m.t.	
IV. Marine fish production requirement		
a. Marine fish production required by 2020 for domestic consumption (56.2% of 7.2 million t)		4.1 m.t
b. Marine fish production required for export by 2020		0.9 m.t
c. Present export		0.3 m.t
d. Total requirement by 2020		5.0 m.t
e. Present production by capture		2.7 m.t
f. Present production by culture		0.08 m.t
g. Total		2.78 m.t
h. Additional quantity required		2.22 m.t
V. Sources of marine fish by 2020 for domestic and export markets		
a. By continuing the current annual yield (Capture: 2.7; Culture: 0.08)		2.78 m.t
b. From future capture fisheries beyond the 50 m depth (total from capture fisheries: 2.7 + 0.6 = 3.3 x 106t)		0.60 m.t
c. From future mariculture (80% shrimps, 10% bivalves & 10% finfishes)		1.62 m.t
Total		5.00 m.t

This assessment shows that the country has to produce an additional 2.22 million tonnes of marine fish (over and above the present production of about 2.78 million tonnes) to meet the domestic (4.1 m.t) and export (0.9 m.t) requirements by 2020. However, the additional scope from the marine fisheries sector is only to the extent of another 0.6 million tonnes; i.e., a total of about 3.3 million tonnes although the estimated EEZ potential is about 4 million tonnes. Mariculture in coastal shrimp farms is expected to produce about 1.7 million tonnes including 80% shrimps, 10% bivalves and 10% finfishes (Table 1). However, the total seaweed culture potential alone is estimated to be over 4 million tonnes, which could be achieved in phases of, say, 2 million tonnes by 2020, i.e., 25% of the global estimated production of about 10 million tonnes by 2020 (Table 2). Besides, low saline soil water sheds of about 8.5 million ha also offer good scope of saline aquaculture (Table 3).

It is possible that any shortfall in the production from marine capture fisheries or mariculture would be offset by commensurate production from the freshwater sector. As against the projected production of 3.1 million tonnes of fish from freshwater capture fisheries and aquaculture by 2020, the production potential of this sector is estimated to be 4.5 million tonnes.

Table 2. Aquaculture potential of seaweeds in India by 2020 AD

Resource (in tonnes)	Period 2000	2005	2010	2015	2020
Agarophytes	80,000	3,35,000	5,96,000	6,50,000	7,00,000
Alginophytes	20,000	90,000	1,20,000	1,60,000	2,00,000
Carrageenophytes	40,000	2,85,000	5,04,000	6,50,000	7,00,000
Edible & Green Seaweeds	60,000	90,000	1,80,000	3,40,000	4,00,000
Total	2,00,000	8,00,000	14,00,000	18,00,000	20,00,000

(Maximum potential : 4 million tonnes)

Table 3. Mariculture potential in India (land-based saline aquaculture and seafarming)

Sl. No		T.A.(ha) Million	P.C.A.(ha) Million	C.C.A.(ha) Million	C.A.P. Tonne
1.	Coastal land based	2.5	1.2	0.12 (shrimps)	85000
2.	Hinterland saline soil aquiferbased	8.5	–	100 ha (Haryana) mullets, pearlspot, shrimp & giant prawn)	200 (milkfish.
3.	Seafarming				
i)	Actual seafarming				
a)	Open sea (EEZ)	202	1.8 (Inshore 0 to 50m depth)	2 ha (during 1996)	15 (mussel)
b)	Bays, coves & gulfs		10700 ha	Nil	Nil
c)	Mainland brackishwater lakes & estuarine mouths (Chilka, Pulicat, Ashtamudi, Vembanad etc)		2050 ha &PVT)	5ha (CMFRI oyster; 1996)	60 (edible during
d)	Inland lagoons & lakes		35000 ha	Nil	Nil
ii)	Stock enhancement programme				
a)	Searanching	18 (inshore 0 to 50m depth)	18 (inshore)	Nominal (shrimp, pearl oyster, clams and seacucumber)	Nominal
b)	Artificial fish habitat:				
	Bottom artificial reefs		1.8 (10% of inshore)	50 Reefs	10 t during Nov. to Mar.
	Floating fish aggregating devices		1.8 (10% of inshore)	150 FADs	(12% of total)

T.A. = Total area; P.C.A. = Potential cultivable area;
C.C.A. = Current cultivated area; C.A.P. = Current annual production

3. Current Marine Fisheries Problems and Solutions

Marine fisheries in India are characterised by the problems of stagnation in capture fisheries production and too many hurdles to coastal shrimp aquaculture during the current decade. Environmental and socioeconomic management of coastal aquaculture through the processes of diversification of shrimp aquaculture and seafarming is a challenging task. Coastal aquaculture and seafarming are very diverse in terms of the people involved, the resources used, the farming practices followed, and the environmental characteristics of the existing and potential sites. There are, however, opportunities for greater expansion, adaptation and integration in the onshore saline aquaculture sector (in inland saline ecosystem and coastal land ecosystem) and seafarming practices within the total mariculture development process. This could be achieved by progressively:

a. Expanding and diversifying coastal shrimp aquaculture to include other compatible candidate species.

b. Expanding inland saline aquaculture from the present experimental activities in Hariyana to all the States in phases (the total hinterland saline area is about 8.5 million ha)

c. Seeking to integrate small scale seafarming with the seafishing practices

d. Undertaking marine fisheries habitat enhancement through the construction of artificial reefs (AF's) and fish aggregating devices (FAD's) and searanching of premium stocks like shrimps, lobsters, crabs, groupers, mussels, pearl oysters etc, for the benefit of the coastal and hinterland communities and the industry (Table 3)

The implementation of these programmes would make it necessary to consider allocation of exclusive fishing and farming sites to the users over their respective areas of operation and also the protection of the standing stocks against the polluting effects of chemical-based industries.

4. Status of Coastal Shrimp Aquaculture

Coastal shrimp hatcheries and growouts have come up all along the Indian coast (Figs 1 to 4). Cultured shrimp (penaeids) production increased steadily from 1990-91 to the peak of about 90,000 tonnes during 1992-93 but declined to the current (1995- 96) 70,573 tonnes from an area of 0.12 million ha due to problems of diseases which struck the hatcheries and farms in the late 1994. With better farming practices, the production during 1996- 97 is expected to cross 100,000 tonnes. The current shrimp aquaculture situation could be characterised as follows:

a) Unfounded fears about the growth of shrimp farms along the Indian coast, and unnecessary hurdles to their sustained growth

b) Inadequate handling of the farm effluents till late 1994, but proper treatment and use subsequently

c) Extensive to improved extensive system of farming by small farmers (<5 ha) is predominant (over 80%) while semiintensive to intensive system of farming by big farmers is carried out in only less than 20% of the cultivated area.

d) Clandestine import of shrimp seedlings from some Southeast Asian countries during 1992-93 due to heavy seed deficit, paving the way for the establishment of over 170 hatcheries with 8 billion seed capacity (Fig. 4).

e) Occasional substandard consignments of imported feeds resulting in environmental and disease problems, and a serious, but temporary setback to the industry, especially along the east coast; establishment of CP feed mill at Red Hills, Madras (Chennai) and Higashimaru feed mill at Shertala, Cochin (Kochi) has reduced the need for import of feeds.

The problems outlined above are now being managed by the industry (small as well as large farms) through the adoption of:

a) Closed systems of farming in the growout farms involving the application of benovolent bacterial products.

b) Secondary aquaculture practices in the reservoirs, drain canals and bioponds.

c) Indigenisation of seed and feed production in commercial terms. The candidate species now being sought after for secondary aquaculture include the seabass,grey mullets, milkfish, groupers, breams, red snappers, seacucumbers, pearl oyster, clams, edible oysters, mussels and seaweeds.

Seed production technology for the commercial shrimp species such as *P. indicus, P. monodon, P. semisulcatus, P. merguiensis and P. japonicus* were developed way back in 1985 at the Narakkal (Kochi) Field Mariculture Centre of the CMFRI. Based on this technology one hatchery at Mopla Bay (Kerala) for P. indicus (10 million capacity) was established and commissioned during

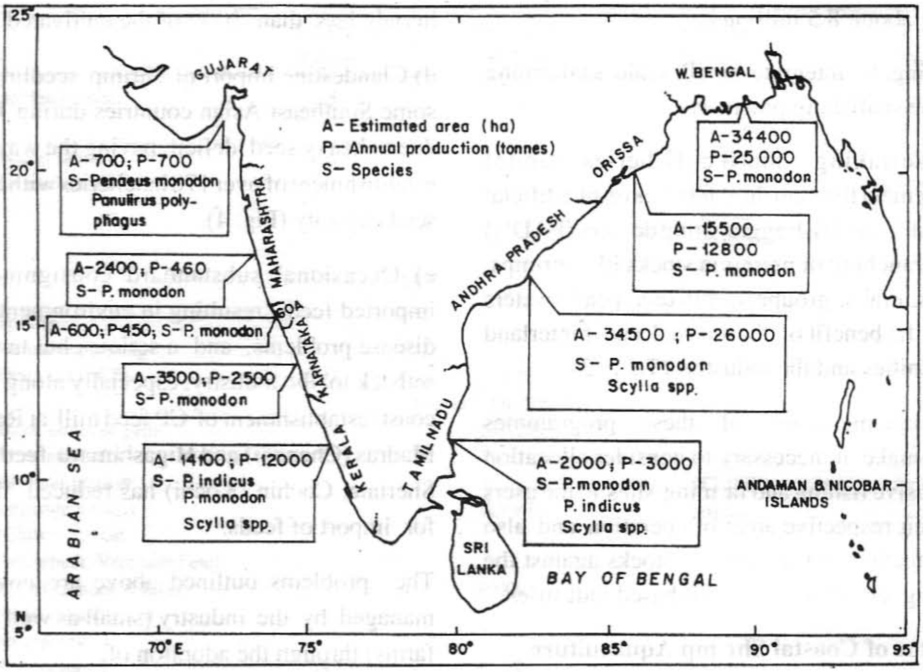

Fig. 1. Cultivated areas and annual production of crustaceans in different maritime states of India (1994-95)

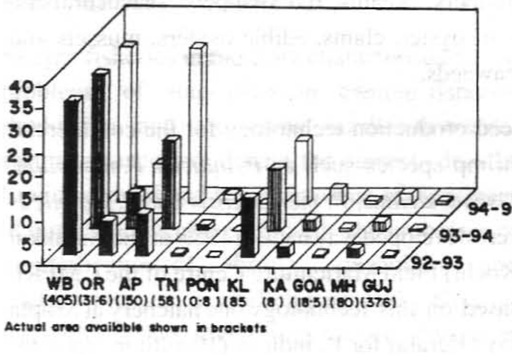

Fig. 2. Area currently under shrimp farming in different states

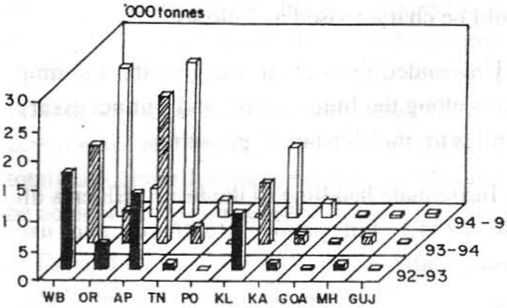

Fig. 3. Culturaled shrimp production in different states

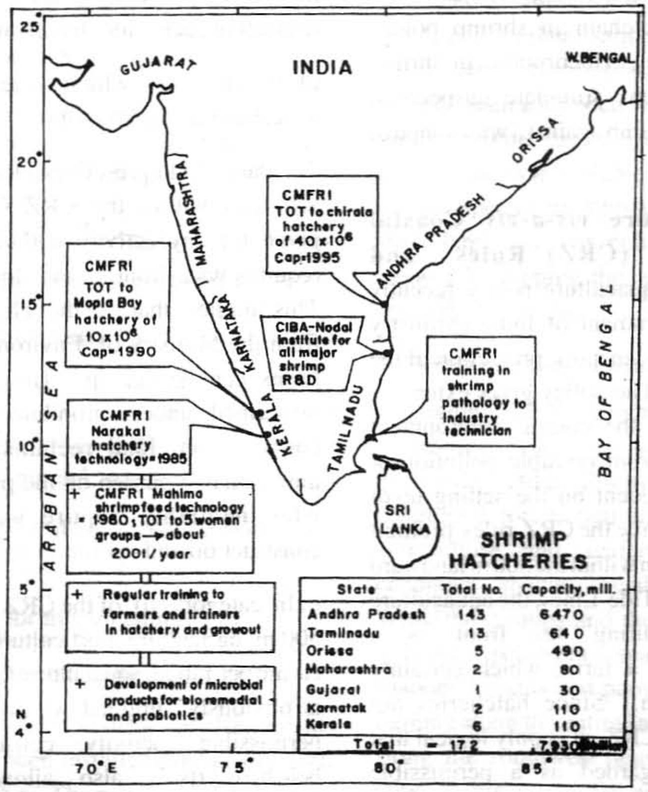

Fig. 4. Shrimp hatcheries and CMFRI's contributions

January-March, 1990. Another shrimp hatchery for *P. monodon* (40 million capacity) had been established at Chirala, Andhra Pradesh under CMFRI consultancy. This hatchery was commissioned in March 1995 and 5.2 million seed (PL 20) was produced in three runs (Fig.4). However, it was only with the establishment of two public sector commercial hatcheries, one each in Andhra Pradesh and Orissa by the Marine Products Export Development Authority using imported technologies, private sector hatcheries began to be established on a large scale.

Most of the formulated feeds used in India are imported ones and cost above Rs. 60/kg, which is beyond the reach of the small farmers. The Mahima shrimp feed developed by the CMFRI is a low cost indigenous formula involving a simple technology, which is suitable for production in the farm site itself. The cost of the feed is Rs 30 per kg (half the cost of imported feeds), and its FCR of 1.5 : 1 equivalent to that of the imported feeds, and is both farmer friendly and ecofriendly. Protein rich shrimp diets result in high nitrogen and phosphorus inputs into the effluents. Therefore, intensive shrimp farms currently tend to use feed in which the lipid level is increased from 8.5% to 13.5%, carbohydrate from 28.5% to 48.8%, and the protein level reduced from 40% to 20%. The use of such low-protein, high-lipid- high-carbohydrate, low-pollution shrimp diets coupled with increased aeration and probiotics in intensive shrimp farms has been found to be quite profitable and totally free from disease problems. Aeration and probiotics speed up aerobic decomposition of organic wastes and enrich the detrital food chain in shrimp ponds. There is also a tendancy to incorporate in shrimp feeds glucans which stimulate unspecified immune reaction in shrimp against a wide range of diseases (New, 1996).

Shrimp Aquaculture *vis-a-vis* Coastal Regulations Zone (CRZ) Rules and Regulations: The aquaculture policy recently declared by the Government of India (Ministry of Agriculture, 1992) ensures protection of the coastal environment. The policy gives extensive guidelines on how the coastal environment should be protected from possible pollution or other damages consequent on the setting up of aquaculture farms. While the CRZ rules prohibit any type of construction within the 500 m landward from the HTL (High Tide Line), the aquaculture policy demands ensuring sea front as a condition for starting a farm, which certainly involves construction. Since hatcheries are permitted within the CRZ, it is only logical that aquaculture is also regarded as a permissible activity within the CRZ, but with appropriate provisions for effluent treatment and reuse or control measures, on which the aquaculture policy pronounced by the Government of India is also quite eloquent. The relevant extracts from the concerned Acts, Rules and Notifications are stated below (i.e., The Notification dated the 19th February, 1991 framed under Section 3(1) and 3(2)(v) of the Environment (Protection) Act 1986 and Rule 5(3)d of Environment (Protection) Rules, 1986, Declaring coastal stretches as Coastal Regulation Zone (CRZ) and Regulating Activities in the CRZ).

a) The 1991 Notification imposes restrictions on industries, operations and processes in the CRZ, defined as the land between the low tide line (LTL) and the high tide line (HTL).

b) Under 2 (iii) of the 1991 Notification setting up and expansion of fish processing units including warehouse are prohibited. This restriction seems too harsh and unreasonable

c) Hatcheries, which inevitably require a waterfront are permissible

d) Para 3 (1) prescribes clearance for certain activities within the CRZ. Clearance shall be given for any activity within the CRZ only if it requires waterfront and foreshore activities. This implies that if the clearance is obtained from the Ministry of Environment, aquaculture farms can be set up. However restrictions prescribed under prohibited activities such as construction, land reclamation etc. impose unreasonable burden on the part of the farmers who inevitably require waterfront for the construction and operation of farms.

e) In category III of the CRZ between 200 m to 500 m, agriculture, horticulture, salt manufacture etc are permitted; aquaculture (aquatic agriculture) is obviously implied within agriculture as a permissible activity; construction of hotels/ beach resorts is also allowed with prior approval, in this zone. The Aquaculture (Regulation) Act 1995 of the State of Tamil Nadu permits aquaculture activity within the 500 m zone, albeit with some environmental safeguards. Moreover, it should be emphasised that the present coastal shrimp farming activities are restricted only to the salt-affected coastal areas totalling 2.07 million ha (Table 6), which would otherwise remain only fallow. With the introduction of shrimp farming, besides utilizing these fallow lands, considerable prosperity has been created in the rural coastal sector.

5. Present Status of Seafarming

There is no commercial seafarming activity in India at present. However, in order to promote seafarming, the CMFRI has established during 1995 a total of eleven experimental seafarms, one each at:

(1) Andhakaranazhi near Cochin for mussel and pearl culture

(2) Dalavapuram near Quilon for edible oyster culture

(3) Adimalathura near Thiruvananthapuram for mussel and pearl culture

(4) Tuticorin for pearl culture

(5) Tuticorin for edible oyster culture

(6) Mandapam for mussel and pearl culture

(7) Madras (Ennore) for mussel culture

(8) Dharmadam near Calicut for edible oyster and mussel culture

(9) Padanna near Calicut for edible oyster and mussel culture

(10) Mangalore for mussel culture

(11) Karwar for mussel culture

The seafarm (longline system) of 400 m^2 at Adimalathura has been installed over an artificial reef at a depth of 25 m. The results of these farms are quite encouraging and are dealt with in the subsequent sections. It should, however, be mentioned here that consequent on the establishment of these demonstration farms by the CMFRI, over 20 mussel and edible oyster farms have been established in late 1996 in the northern Kerala backwaters, estuaries and closeshore bays under financial support from IRDP-TRYSEM, and these farms are expected to be harvested in April-May 1997. Similar is the case with the Ashtamudi backwaters near Quilon where over a dozen edible oyster farms would come to the first harvest in January-February 1997 and the second harvest in May 1997.

6. Opportunities for Inland Saline Aquaculture

Results of the culture of marine fish and prawns in the saline soil ecosystems in Haryana (Tables 4 & 5) conducted by the Central Institute of Fisheries Education (CIFE), Bombay have indicated great potential for saline aquaculture in all the hinterland saline ecosystems which are estimated to be about 8.5 million ha (Table 6). Saline-alkali soils occurring in arid and semiarid areas in India are considered to be unfit for agriculture as the soluble salts are a great limiting factor. Special attempts have been made to utilise these lands for the culture of marine fish and prawns by tapping the ground saline aquifer through tubewells.

7. Diversification of Mariculture

Depending on the geographical and ecological diversities, there are vast differences in the availability and suitability of areas which can be developed for mariculture (land-based saline aquaculture and seafarming) and also in the candidate species available for cultivation. While the shrimps and the finfish (grey mullets, milkfish, pearlspot, seabass, groupers, red snapper, breams and pompanos) are suitable for farming along the entire Indian coast (particularly along the southwest and southeast coasts), the other items could be cultured along narrow geographical ranges; e.g., the seacucumber along the coasts of Tamil Nadu and Lakshadweep; pearl oyster along the coasts of Tamil Nadu (Gulf of Mannar & Palk Bay), Kerala, Gujarat, Lakshadweep & Andaman Islands; edible oyster in Andhra, Tamil Nadu, Kerala, Karnataka and

Table 4. Physicochemical properties of water in the Sultanpur (Haryana) saline aquaculture farm during 1984-85

Salinity	6.0 to 15.6 ppt
D.O	6.35 to 8.7 mg/l
CO_2	2.5 to 4.1 mg/l
pH	7.35 to 8.35
Temperature	5.8 to 36.8°C
Total alkalinity	90 to 117 mg/l

Table 5. Composite culture of fish and prawn in a 0.025 ha pond in the Sultanpur (Haryana) saline aquaculture farm during 1984-85

Species	Durat ion	Rates of stocking No./ha	Area (ha)	Stocking Size No. Stocked	Stocking Size Mean length (mm)	Stocking Size Mean weight (g)	Harvest Size Mean length (mm)	Harvest Size Mean weight	Total harvested weight (g)
Penaeus monodon	10 months	40,000	0.025	10,000	20	0.06	200	72.7	362.5
Mugil cephalus	10 months	10,000	0.025	2,500	25	1.0	400	525.5	787.5
Chanos chanos	10 months	10,000	0.025	2,500	25	1.0	415	520.0	842.5
Etroplus suratensis	10 months	15,000	0.025	3,750	30	1.75	150	140.0	542.5

The production rate was: *P. monodon*: 1450; *M.cephalus*: 3150; *C.chanos*: 3370: *E.suratensis*: 2170 kg/ha/yr

Gujarat; mussels in Andhra, Tamil Nadu, Kerala, Karnataka, Goa and southern Maharashtra; windowpane oyster and red clam in Andhra (Kakinada Bay); clams in Kerala, Karnataka, Goa and Maharashtra; and the seaweeds mainly in the Gulf of Mannar, Gulf of Kutch, Kerala backwaters, Chilka lake, Pulicat lake, and the lagoons and lakes in Lakshadweep and Andaman & Nicobar islands. However, it is very important to note here that the CMFRI's location testing efforts have proved beyond doubt enormous potential for pearl culture in Orissa, Andhra, Karnataka and southern Maharashtra in both onshore captive systems close to the shore and inshore seafarms.

8. Packages of Mariculture Practices

8.1. Microbial biotechnology for sustainable shrimp aquaculture

8.1.a. Shrimp diseases: Diseases seldom appeared as a major problem in the traditional extensive type of shrimp culture systems. But with the development of large scale farming, incidences of diseases and mortalities emerged as a major threat in most of the countries.

Many of the microbial agents of shrimp diseases form part of the natural microflora of marine and brackishwater ecosystems. These microbes are opportunistic pathogens and cause disease when shrimps are subjected to stress. Poor environmental conditions constitute the most important factor responsible for stress and disease in aquaculture systems. Shrimp diseases are caused by viruses, bacteria, fungi, parasites, algal toxins, mycotoxins in the feed, nutritional deficiency, adverse environmental conditions etc. (Fig. 5).

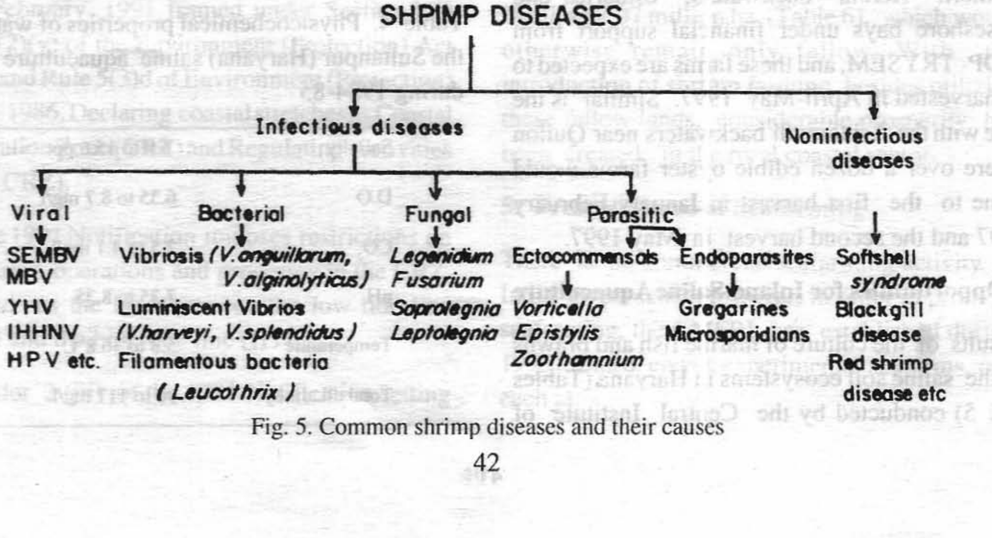

Fig. 5. Common shrimp diseases and their causes

Table 6. Salt-affected soils in India (area in '000 ha)

State	Coastal	Hinterland	Total
Andhra	283.3	530.0	813.3
Bihar	–	400.0	400.0
Gujarat	302.3	912.1	1214.4
Haryana	–	455.0	455.0
Karnataka	86.0	318.0	404.0
Kerala	26.0	–	26.0
Madhyapradesh	–	242.0	242.0
Maharashtra & Goa	88.0	446.0	534.0
Orissa	400.0	–	400.0
Punjab	–	519.5	519.5
Rajasthan	–	1122.0	1122.0
Tamil Nadu	83.5	256.5	340.0
Uttar Pradesh	–	1295.0	1295.0
West Bengal	800.0	–	800.0
Total	2069.1	6496.1	8565.2

(i) Viral diseases: Some of the important viruses known to affect P. monodon are: Monodon baculovirus (MBV), systemic ectodermal and mesodermal baculovirus (SEMBV), yellowhead virus, infectious hypodermal hematopoietic necrosis virus (IHHNV), hepatopancreatic parvo-like virus (HPV), lymphoid organ parvo-like virus (LOPV), type C baculovirus, baculovirus penae, reo- like viruses etc. Among these viruses, the whitespot disease causing virus, i.e., SEMBV caused severe economic losses in Japan, China, Thailand, Indonesia and India. In India, the disease was first noticed towards the end of 1994 along the east coast. The disease spread very rapidly to the other parts of the country and by 1995 almost all maritime states where shrimp culture was being carried out were affected by this disease. Apart from a number of shrimp species, this virus has been reported to affect other crustaceans including crabs and barnacles.

In the case of viral diseases, chemotherapy is not effective once the disease has set in because viruses are intracellular pathogens and any chemicals affecting viruses will affect the host tissue also. Hence, prevention of the disease is the most important strategy. The methods of prevention include stocking of healthy larvae maintence of good water quality and pond condition - disinfection by liming, chlorination, halogen treatment, use of iodophores, reservoir concepts etc. prevention of entry of carriers improving the disease resistance of the host using immunostimulants

(ii) Bacterial diseases: *Vibrio* spp are the most common among the various bacterial agents known to cause problems in shrimp culture. These bacteria are the predominant flora of the marine environment and several species such as *V.alginolyticus, V.parahaemolyticus, V.vulnificus etc.* have been involved in shrimp mortalities. Luminiscent vibrios, *V.harveyi* and *V.splendidus* cause severe mortalities in hatcheries. The filamentous bacteria such as *Leucothrix* may be found as ectocommensals and may cause mortality due to hypoxia and impairment of moulting.

(iii) Fungal diseases: Among the fungal pathogens of shrimp, *Legenidium* is the most prevalent in larval and early postlarval stages. Mortality may reach 100%. *Fusarium, Saprolegnia, Leptolegnia* etc. are the other fungal pathogens of shrimps.

(iv) Parasitic diseases: Ectocommensals such as *Epistylis, Vorticella* and *Zoothamnium* attach on the eyes, gills, appendages and body surfaces causing respiratory and locomotory difficulties. *Endoparasites* such as the gregarines and the microsporidians may cause mortalities.

(v) Non-infectious diseases:

(a) Chronic softshell syndrome - due to nutritional and environmental factors

(b) Red shrimp disease - due to the presence of aflatoxins in feed, poor water quality etc.

(c) Blackgill disease - due to the presence of toxic substances in water, organic loading etc.

(d) Dull hardshell disease - due to excessive calcium and phosphorus mobilisation as a result of overfeeding

Most of the disease control methods are based on preventive measures. They are:

(i) use of healthy postlarvae for stocking

(ii) quarentine measures

(iii) use of adequate balanced diet

(iv) use of genetically resistant stock

(v) use of immunostimulants

(vi) chemotherapy (chemicals and antibiotics must be used with utmost caution to minimise the danger of residual effects and development of antibiotic resistant strains)

8.1.b. Biotechnological tools for disease problems: Disease problems in aquaculture can be controlled with the application of various biotechnological methods. The four critical areas where microbiological and biotechnological approaches have impacted or will significantly impact aquaculture are development of tools for environmental management including the use of probiotics and bioremediation, development of sensitive, rapid and inexpensive diagnostic tools, development of vaccines against bacterial, viral and parasitic pathogens, development of tools for the nonspecific enhancement of immunity (immunostimulants).

The workhorses of biotechnology are the microbes, and today, they seem to provide many solutions to manmade problems. Biotechnological answers are emerging rapidly not only for detoxifying the environment through bioremediations, but also to enhance our natural resource utilisation by bioconversion and application of probiotics. The four major categories of biotechnological applications involved in solving environmental problems include: environmental monitoring bioremediation, ecoprotection.

(i) Environmental monitoring: Nearly 80% of shrimp diseases are caused by stress induced by environmental factors. Bioindicators (such as the Daphnia and trouts in freshwater systems) could be used as indicators of pollution. But bioindicators are difficult to maintain as they are extremely sensitive. Hence, single cells of an organism are used as biosensors. Toxins that affect the metabolism of microorganisms also affect their respiration. Production of carbondioxide leads to measurable pH changes. Rodtox is a biosensor developed in Japan for measuring the biological oxygen demand (BOD) which indicates the increased oxygen use by organisms or the toxins based on the inhibition of respiration. GBT Tox Alarm is a biosensor from Germany, which can detect even 0.1 ppm of cyanide. In the US, the luciferace enzyme from the firefly is used as a biosensor. It detects intracellular levels of ATP, the energy indicator of living organisms. However, these sensors could be used only to monitor the environment in batches, and not in a continuous mode.

(ii) Bioremediation and ecoprotection: Detection does not lead to cure. Hence, coupled with the use of biosensors, bioremediation has to be resorted to, using microbes of novel catalytic capabilities. Bioremediation steps include: (1) the selection of microorganisms possessing specific ability to detoxify unfavourable chemicals, (2) development of enzymes and proteins that can catalytically convert these wastes, and (3) bioprocess technology to harness these abilities. *Pseudomonas* strains detoxify through a number of enzymatic steps encoded by genes contained in their megaplasmids. Some strains also produce enzymes that can breakdown the nitrogenous compounds to ammonia and carbondioxide rather than to some other byproducts. Specific, nonpathogenic, pigmented, spore-forming bacterial species of *Bacillus* isolated from sediments of Pokkali ponds at Narakkal (Cochin) are found to inhibit the growth of pathogenic bacteria like *Vibrio anguillarum, Aeromonas* and *Escherichia coli* by competitive growth or by producing antagonistic antibiotics.

Table 7. Species of *Bacillus* of probiotic value

Species	Characteristics
1. *Bacillus cereus mycoides* (*Bacillus subtilis* group)	Colonies over the surface with curving filaments radiating out from the central growth, feathery appearance; growth may be dry, gummy, moist white, greyish white, yellowish, brown or black
2. *Bacillus megaterium* (*Bacillus subtilis* group)	Colonies smooth white butyrus, shiny, rod shaped Gram-positive
3. *Bacillus mucosis*	Colonies mucoid, semi-transparent, resmbling drops of paste
4. *Bacillus agglomeratus*	Colonies small, round, greyish
5. *Bacillus cartilaginous*	Colonies thick, round & compact, and could be lifted from the agar entirely
6. *Bacillus idosus*	Colonies dry lustreless and laminated, finely wrinkled
7. *Bacillus intrieatus*	Colonies widespread, whitish, flat, mycelium -like ingrowth into the agar, containing filaments with numerous septa.

Colonies of spore-forms of *Bacillus* of probiotic value, most often observed in the aquatic environments, have been identified to be the 7 species shown in Table 7. All of them can be mass cultured and used as probiotics in their logarithmic phase when their enzyme potential is maximum. They exhibit antagonism towards other heterotrophs, and hence, could be successfully used as probiotics to control microbial diseases in aquaculture ponds. As they are highly proteolytic, they easily mineralise the faecal matter and left-over feed putrified by other heterotrophs. By active mineralisation the pond environment is made clear. *Bacillus* can act as a host defence barrier by making the target epithelial cells unavailable to pathogens through competitive exclusion. The antibiotics produced by these seven species are environment friendly. The *Bacillus* strains are biodegradable after their activity. The most effective mode of action of *Bacillus* is now known to be by immunostimulation.

The performance of *Bacillus* is influenced by the inoculum level, species of shrimp or other organisms tested, stage of maturity, level of stress and quality of the rearing pond environment. Because of this wide spectrum of variables, there is a broad range of response to probiotics and the plethora of positive responses span a wide range of experimental protocols.

According to Moriarty (1996), microbial ecology and biotechnologies have advanced to the point that commercial products and

Table 8. Commercial probiotic products and immunostimulants used by the aquaculture industry

Probiotics	Manufacturers/country	Price(Rs)	Quantity
1. DMS 1000 series	ARDA-TEK Australia	3,000	5 litres
2. Synerbac	-do-	-do-	-do-
3. Wunapuo-15	Team Aqua Corpo-ration, Thailand	6,000	25 kg
4. Biostart™ Bio-brews	USA	5,000	5 litres
5. Aqua bacta aid products	Water Quality Sciences International Inc., USA		–
6. Aquakalgon+	Wockhardt Ltd (India) in collaboration with Techniques et Biochimie Appliques (TBA), Paris.	–	–
7. Aqua buck up	Ecomax India	5,000	5 kg
8. Spec™ bac	Proposed by CMFRI	5,000	5 kg
9. Immustim (purified Beta 1,3-D-glucan)	Immu Dyne Inc. USA	–	–
10. Aquastim	College of Fisheries, Mangalore, India	–	–

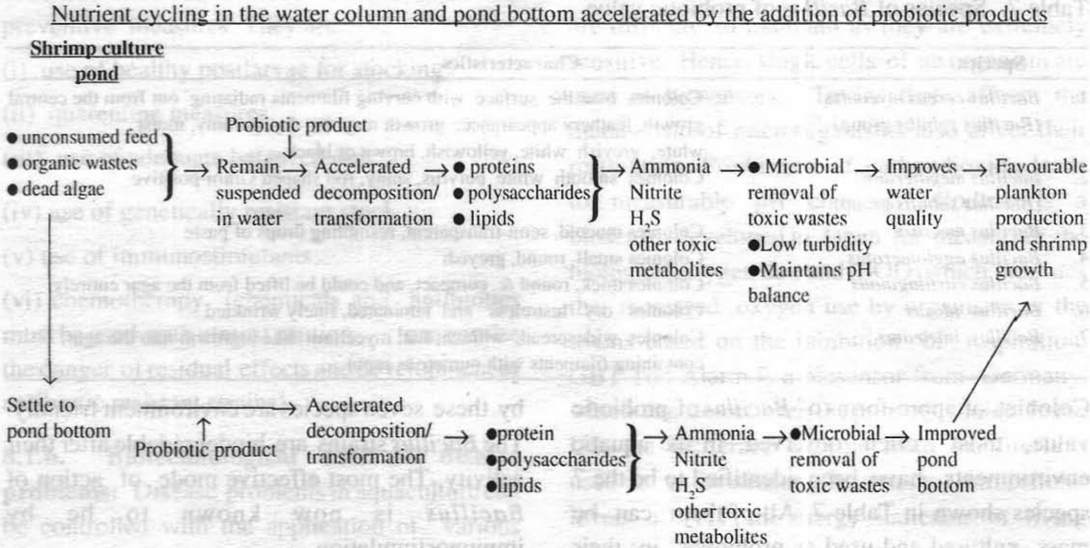

Fig. 6. Nutrient cycling in the water column and pond bottom accelerated by the addition of probiotic products

technologies are available for treating large areas of water and land to enhance population densities of particular microbial species or biochemical activites. The bacteria that are added must be selected for specific functions that are amenable to bioremediation and added at a high enough population density and under the right environmental conditions. The efficacy of bioremediation and probiotics depends on the nature of competition between species or strains of bacteria. A normal shrimp culture pond has many different types of microorganisms. The most numerous types are those that are very efficient at reproducing themselves. These types make use of the detritus that accumulate on the pond bottom and rapidly build up their biomass by growing and replicating themselves. But, what is desired is a major reduction in the detritus without the growth of biomass. In otherwords, the types of bacteria that we want in the system are those that are less efficient at reproducing themselves, but are highly efficient at reducing the amount of detritus in the pond (Fig. 6). A variety of probiotic products are commercially available and are used by the aquaculture industry for environmental management (Table 8).

(iii) Immunostimulants: Most of the immunostimulants used are of fungal or bacterial origin (viz., B1, 3-glucan derived from fungal or yeast cell wall; lipopolysaccharides and peptidoglycan derived from bacterial cell wall). These compounds stimulate the nonspecific defence system in the crustaceans by the activation of the prophenol oxidase system (resulting in the production of melanin at the site of infection which possesses antimicrobial properties), stimulation of phagocytosis and encapsulation. However, the efficacy of these immunostimulants against viral infections still needs further investigations.

Immustim is an immunostimulant developed by Immu Dyne Inc., USA, for shrimps and marketed worldwide. The College of Fisheries, Mangalore has developed a similar product called aquastim which has been successfully applied in commercial farms (Dr. I. Karunasagar, personal communication). As the immune system in shrimps is rather weak, weekly application of aquastim is necessary.

Table 9. Economic profile of trade in pearls in India and transfer of technology by CMFRI

- India's total pearl production	:	20 kg SPIC 13 kg TNFDC 2 kg Pancharatna 5 kg
- Country's imports annually	:	725 kg, worth Rs. 290 million
- Production target by pearl culture in India	:	1000 kg, worth Rs. 500 million
- Japan's pearl production	:	63,375 kg marine
- China's pearl production	:	199,500 kg freshwater
- USA's pearl production	:	9,375 kg marine
- World production	:	276.6 t (199.5 t freshwater; 77.1 t marine)

Table 10. Development of pearl culture technology in India by the CMFRI

		Year	Location & Results	
I. First pearl production in India	:	July, 1973	Tuticorin, Gulf of Mannar Tuticorin,	
II. First hatchery production of pearl oyster in India	:	August,1981	molluscanshellfishhatchery	
III. Development of land-based pearl culture technology	:	1995	Kakinada, Visakhapatnam, Madras & Mandapam	
IV. Successful location testing for site selection for pearl production	:	1976	Vizhinjam Bay, Kerala	
		1985	Mandapam, Tamilnadu	
		1986	Lakshadweep	
		1987	Gujarat	
		1994	Calicut, Andhakaranazhi (Cochin)	
V. Number of pearls produced by CMFRI through an investment of Rs. 8,10,500 at Tuticorin	:		No. of pearl oysters harvested	No. of pearls obtained
		1973-1978	605	428
		1978-1983	768	443
		1983-1988	3576	1390
		1988-1995	6365	2171
		1995 -1996	7583	2666
Number of pearls sold	:	1994 -1996	1173	
		(180.72 g) for	Rs. 1,28,668	
VI. Technology transfer experiments at Valinokkam, Gulf of Mannar	:	1-7- 1991 to 11-8-1992		
Total expenditure	:	Rs. 36,312		
Total pearls produced	:	1,849		
Pearls given to farmers as wages	:	250		
Balance pearls sold	:	1,599		
Revenue earned	:	Rs. 73,134		
VII. Establishment of Tamil Nadu Pearls Ltd.				
Duration	:	4 years		
Total expenditure	:	Rs. 6.9 million		
Pearls produced	:	13 kg		
Pearls sold	:	4 kg for Rs. 0.782 million		
VIII. Sponsored projects for pearl culture				
1. Donor	:	Department of Ocean Development		
Year of allocation	:	1995		
Amount	:	Rs. 2.5 million		
Location	:	Mandapam Camp		
2. Donor	:	ICAR		
Year of allocation	:	1996		
Amount	:	Rs. 3.0 million		
Period of operation	:	8 years		
Location	:	Mandapam Camp		
3. Donor	:	Dept. of Biotechnology		
Project	:	Tissue cultured marine pearls		
Period of operation	:	May, 1994 to May, 1997		
Amount	:	Rs. 2.207 million		

8.2 Pearl oyster farming and pearl production

The world production of marine pearls was 78 tonnes valued at US $ 1092 million during 1993. Japan still holds the monopoly in the production of marine pearls. Although India had the distinction of developing the cultured pearl technology in 1973, it could not commercially produce pearls for world trade. The country has ample scope to develop and expand the cultured pearl industry in different locations along both the west and east coasts and the Andaman & Lakshadweep waters (Tables 9 & 10).

MOU's signed or proposed by CMFRI during 1996 for transfer of pearl culture technology

1) NCC Blue water, Chandanada, Andhra Pradesh
2) Gem Holiday Resorts Ltd., Madras, Tamil Nadu
3) Balaji Bio-tech Ltd., Nellore, Andhra Pradesh
4) M/s Sterling Shrimpex (P) Ltd., Chirala, Andhra Pradesh
5) Mr. Jagadeswara Rao, Visakhapatnam, Andhra Pradesh
6) Smt. V. Sarala, Visakhapatnam, Andhra Pradesh
7) M/s Aqua Prime International, Nellore, Andhra Pradesh

Six species of pearl oysters, namely, *Pinctada fucata* (Gould), *P. margaritifera* (Linnaeus), *P. chemnitzi* (Philippi), *P. sugillata* (Reeve) and P. atropurpurea (Dunker) have been recorded in the Indian waters. Among these, *P. fucata* is the most dominant species. It occurs in large numbers in pearl oyster banks known as 'paars' in the Gulf of Mannar and in the intertidal reefs known as 'khaddas' in the Gulf of Kutch. *P. fucata* is the only species which has contributed to the pearl fisheries in these two gulf regions. Along the southwest coast of India, particularly at Vizhinjam

Table 11. Expected economics of onshore marine pearl culture in the urban vicinity of Visakhapatnam (project started in late 1996)

(A) Nonrecurring (capital investment)		Rs.
Cost of land (1 ha)	:	10,00,000
Cost of 16 tanks of 4,000 m² total with hard bottom and roof (@ Rs. 250/m² per tank)	:	10,00,000
Cost of backyard hatchery	:	5,00,000
Cost of pumping, aeration and associated structures	:	3,00,000
Power installation and generator	:	2,00,000
Cost of algal production system (100 t/day)	:	2,00,000
Cost of oyster cages and suspending materials	:	10,00,000
Instruments for lab	:	2,00,000
Total	:	44,00,000
(B) Recurring (working capital)		
Wages	:	6,00,000
Nuclear beads	:	5,00,000
Instruments for implantation	:	50,000
Chemicals and glassware	:	1,50,000
Power charges	:	50,000
Repairs and replacement	:	50,000
Total	:	14,00,000
Repayment of term loan (A) with interest spread over 5 years	:	1,30,000
Grand total	:	27,00,000
(C) Revenue		
Total gross return from 1,25,000 pearls @ 25% yield and Rs. 40/pearl (total implanted oysters 5,00,000)	:	50,00,000
(D) Net profit (C - B)	:	23,00,000
Percentage of profit	:	85.2

and Calicut, large numbers of spat of *P. fucata* have been collected from mussel culture ropes in the 1980s. *P. margaritifera* is confined mostly to the Andaman Islands where it is common in some places, but it also occurs in the Vizhinjam bay in stray numbers. From the Lakshadweep, spat of *P. anomoides* has been recorded on the ridges of rocks and corals.

Raft culture, rack culture, onbottom culture and onshore culture are the 4 methods of rearing pearl oysters. Pearl oysters can be successfully reared in 50 t capacity concrete tanks filled with clean seawater. Mother oysters/seeded oysters numbering a minimum of 5 lakhs (maximum of 10 to 15 lakhs) can be successfully stocked and grown in tanks of 4000 m^2 each, with a depth of 1.5 to 2 m (Table 11). Besides the above four methods, longlines and underwater platforms are also used in some parts of the world.

The colour of the cultured pearls largely follows the colour of the nacre of the shell of the pearl oyster which produces the pearl and is genetically determined. Besides this, the nature of the culture site, depth, light penetration, feed, water quality, and the minerals and trace elements in the seawater also determine the pearl colour to some extent. Graft tissue preparation is also an important factor in determining the quality of pearls. Now a days in Japan, various chemicals and drugs are used to condition the oysters and make them grow healthy and produce good quality pearls. For obtaining good quality pearls in the seafarms, the oysters should be grown at depths of 5 to10 m. Strong sunlight on oysters must be avoided since sunlight can induce nacre secreting cells to produce calcite crystals to form prismatic layer over the nucleus resulting in poor quality of pearl. Alternatively, pearls could be grown in shallow depth of 1 to 2 m in onshore lands and seafarms by appropriately shutting off the natural light (Figs 7 to 10). There is very high potential for the culture of half pearls by implanting a number of half beads in holes made on the same shell; after implantation the oysters are released in the growouts, where the mantle secretes the nacre around the beads, resulting in pearls. The advantage in half pearl production is that it is equally costly or even costlier than full pearl, the technique is much less demanding in skill and upto 10 half pearls could be produced from a single oyster. Half pearl production will be part of the consultancy package proposed to be offered by the CMFRI since 1997.

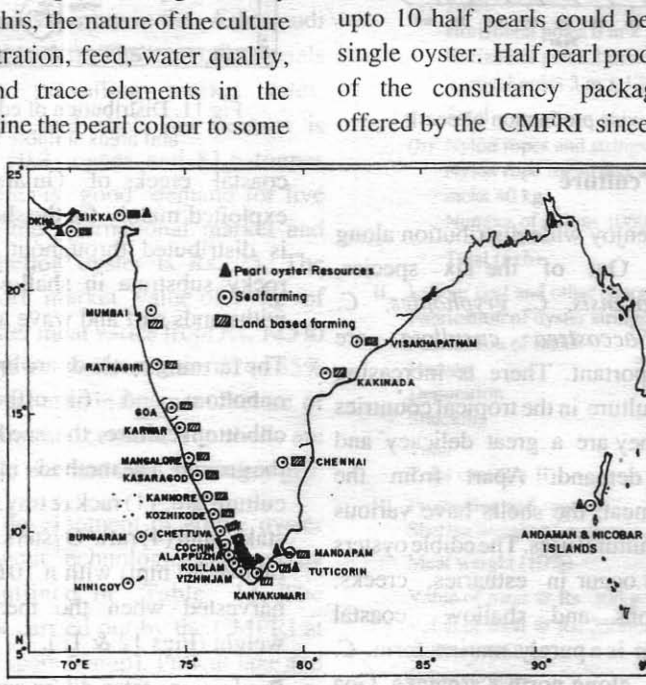

Fig. 7. Pearl culture prospects in India

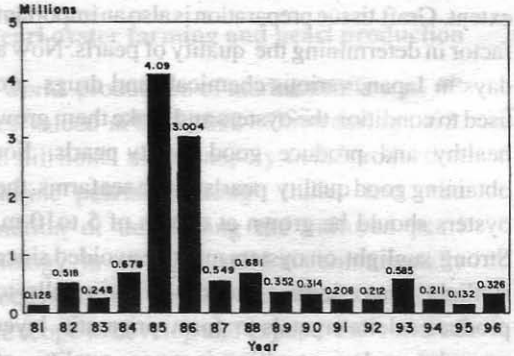

Fig.8. Pearl oyster spat produced at CMFRI hatchery

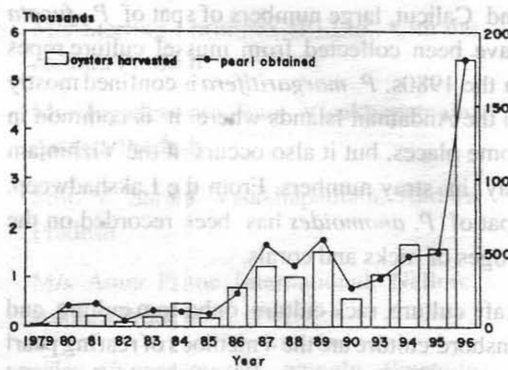

Fig.9. Pearl production in CMFRI farm at Turicorin

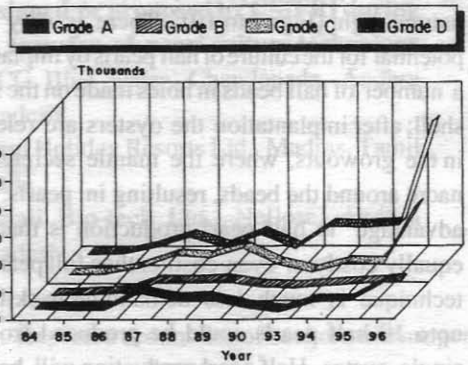

Fig.10. Grade-wise production of pearls

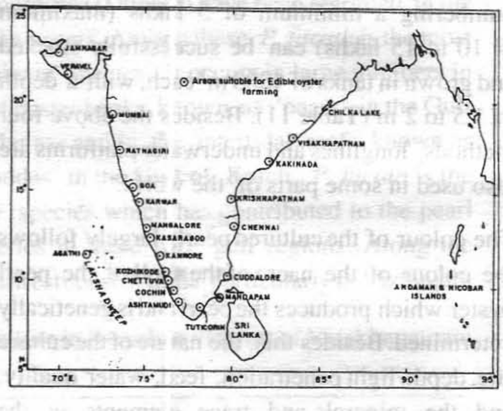

Fig.11. Distribution of edible oyster in India and areas suitable for oyster farming

8.3. Edible oyster culture

The edible oysters enjoy wide distribution along the Indian coast. Out of the six species, *Crassostrea madrasensis, C. gryphoides, C. rivularis* and *Saccostrea cucullata* are commercially important. There is increasing interest in oyster culture in the tropical countries in recent years as they are a great delicacy and there is growing demand. Apart from the edibility of the meat, the shells have various industrial and agricultural uses. The edible oysters are euryhaline and occur in estuaries, creeks, backwaters, lagoons and shallow coastal waters. *S. cucullata* is a purely marine form. *C. gryphoides* occurs along north Karnataka, Goa and Maharashtra. *C. rivularis* occurs along the coastal creeks of Gujarat where they are exploited mainly for the shells. *S. cucullata* is distributed throughout the Indian coast on rocky substrata in shallow intertidal areas and withstands surf and wave action (Fig. 11).

The farming methods are broadly divided into: (i) onbottom and, (ii) offbottom culture. In the onbottom culture, the seed oysters are sown on the ground. The methods involved in off-bottom culture are: (1) rack & tray, (2) rack & string, (3) stake, and (4) raft. Oysters reach harvestable size (above 80 mm) within 10 to 12 months. They are harvested when the meat attains fairly good weight (Figs 12 & 13).

Production rates differ according to the culture methods. Through the rack & tray method, the

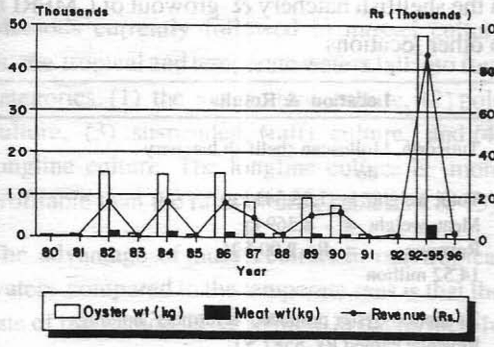

Fig.12 Oyster production and revenue earned by CMFRI at Turicorn (1979-95) and Dhalavapuram (1994-95)

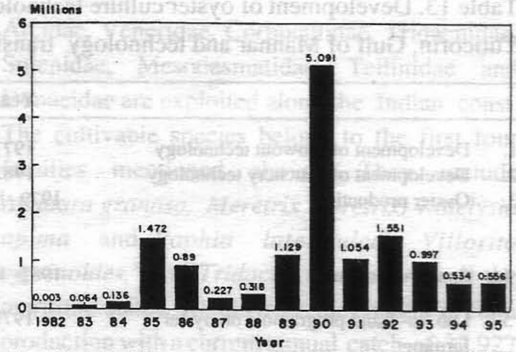

Fig.13 Edible oyster spat produced at the CMFRI Turicorn hatchery

estimated production was 120t/ha/yr at Tuticorin during 1980-86 and by the rack & string method, it was 80 to 105 t/ha/yr at Dhalavapuram in the Ashtamudi lake (Quilon) during 1994-95. The production rate through the stake method was 20 t/ha/yr at Tuticorin in 1980-86. In the rack & tray method the rate of return on investment was 30% and by the string method it was 44.8%. In an area of 1 ha, 24 units of 300 m^2 each can be accomodated as in the CMFRI's demonstration farms at Tuticorin and Dhalavapuram in the Ashtamudi lake (Quilon) (Table 12). The cost of materials depends on the prevailing market rates. Production of meat and shell per hectare is estimated to be 10.2 tonnes and 81.6 tonnes respectively. There is good demand for live shellon oysters in the international market and the cost of 100 shellon oyster is Rs. 25. The international export market value of 1 kg of chilled/frozen oyster meat varies from Rs. 125 to 300. The empty oyster shells contain 52 to 55% calcium oxide and are used in the manufacture of calcium carbide, lime and cement. The shells are crushed to suitable size and used as poultry grit.

The progressive development of edible oyster hatchery and growout technologies achieved by the CMFRI is outlined in Table 13. The experimental work carried out by the CMFRI at Athankarai (Mandapam Camp), Pulicat lake and Tuticorin in Tamil Nadu, Kakinada Bay and Bheemunipatnam in Andhra Pradesh, Goa, Mulky estuary in Karnataka and Ashtamudi lake and Dharmadam estuary in Kerala gave highly encouraging results, suggesting commercial feasibility of edible oyster culture along the east and west coasts of India.

Table 12. Production and economics of edible oyster farming by rack and ren method at Dalavapuram in a 300 m^2 area during 1995

		Amount in Rs.
I. Material cost		
(a) Poles		
Horizontal poles 6 m x 30	:	1,200
Horizontal poles 2 m x 9	:	120
Vertical poles 3 m x 126	:	2,520
Total	:	**3,840**
(b) Nylon ropes and strings		
Nylon rope for strings and racks 40 kg	:	2,800
Number of strings 1060	:	110
Total (a+b)	:	**6,750**
II. Labour cost and other charges		
Fabrication of oyster strings	:	480
Fabrication of racks	:	240
Harvest	:	640
Depuration	:	640
Shucking	:	880
Total		**2,880**
Total cost (I + II)		**9,630**
III. Production and revenue		
Shellon weight of oysters	:	4.25 tonnes
Meat weight (10%)	:	425 kg
Value of meat @ Rs. 30/kg	:	Rs. 12,750
Value of shell @ Rs. 350/tonne (80% of 4250 kg)	:	Rs. 1,190
Gross revenue	:	13,940
IV. Net profit (III - I + II)	:	4,310

Table 13. Development of oyster culture technology in the shellfish hatchery & growout of CMFRI at Tuticorin, Gulf of Mannar and technology transfer to other locations

		Year	Location & Results
1.	Development of growout technology	1977	Tuticorin, Molluscan shellfish hatchery
2.	Development of hatchery technology	1982	- do -
3.	Oyster production	1979- 1996	Total weight = 1,23,341 kg Meat weight = 8,369 kg Revenue = Rs. 2,00,504
4.	Spat production	1982- 1996	14.52 million
5.	Lab -to- Land programme on oyster farming	1979	2 t shellon oyster produced in farmers' holdings Revenue earned Rs. 8587.50
6.	Sponsored project by NABARD for Rs 8,58,200 for technology demonstration	1992-1995	Harvest = 47,756 kg (shellon) Meat weight = 2,946 kg Revenue earned = Rs. 95,339
7.	Areas found suitable for oyster farming based on site selection experiments (good growth rate and survival in all these places)	1993-1994	Ashtamudy estuary Kerala Munambam " Korapuzha Dharmadam " Karwar Karnataka
8.	Demonstration farms	1994-1996	1) Dalavapuram farm in Ashtamudi = 0.2 ha 2) Chetuvai farm = 0.03 ha 3) Narakkal farm = 0.02 ha 4) Dharmadam farm = 0.04 ha - good spat production from wild - yield in rack & string method = 80 t/ha - good growth rate and 8-10% meat yield within 6 to 7 months
9.	Private oyster farms adopting CMFRI farming technology	1995-96	7 farms at Dalavapuram = 0.03 to 0.2 ha each 1 farm at Munambam = 0.04 ha 1 farm at Padanne = 0.04 ha
10.	Mixed farming trials	1995-96	-oyster seed for farming obtained from the wild - seed from Dalavapuram transported to Munambam, Narakkal, Chettuvai, Dharmadam, Padanne and Lakshadweep. -good survival and growth of transplanted seed. At Dharmadam and Padanne -green mussel grown in edible oyster racks -good growth rates and survival from December to May 2.5 t of mussels harvested from Padanne, 1 t from Dharmadam in May, 1996 and sold @ of 14/- per kg shellon -About 20 new private farms supported by IRDP-TRYSEM established in the north Kerala estuarine waters in late 1996, expected to yield over 150 tonnes of mussels and about 200 tonnes of edible oyster in May 1997

8.4. Mussel culture

The green mussel *Perna viridis* and the brown mussel *P. indica* are the two species occurring along the Indian coasts. The green mussel enjoys a wider distribution along the east and west coasts of India including the Andaman Islands, whereas the brown mussel is restricted to the southwest coast of India. Along the east coast, the green mussel is found on small beds in the Chilka Lake, Kakinada, Madras, Pondicherry, Cuddalore and Porto Novo while along the west coast it forms extensive beds around Quilon, Alleppey, Cochin, Calicut to Kasargod, Mangalore, Karwar, Goa, Bhatia creek, Malwan and the Gulf of Kutch (Fig. 14).

Methods currently followed in mussel culture in the tropical and temperate waters fall into four categories: (1) the sea bottom culture, (2) pole culture, (3) suspended (raft) culture, and (4) longline culture. The longline culture is more profitable than the raft culture (Tables 14 & 15).

The advantage of mussel culture in our tropical waters compared to the temperate seas is that the rate of production is very high in the former. In European waters the seeds attain marketable size in a period of 12 to 36 months while it takes only 5 to 6 months in India because of the faster growth and high productivity in the tropical waters (Table 16).

8.5. Clam culture

A number of clam species belonging to the families Arcidae, Veneridae, Corbuculidae, Tridacnidae, Solenidae, Mesodesmatidae, Tellinidae and Donacidae are exploited along the Indian coast. The cultivable species belong to the first four families mentioned above. They include *Anadara granosa, Meretrix meretrix, Katelysia opima* and *Paphia laterisulca, Villorita cyprinoides,* and *Tridacna marina.* Of all the maritime states, Kerala leads the country in clam production with a current annual catch of 32,927 t which accounts for 72.5% of the total clam landings. The current annual clam landings in Karnataka is estimated at 6,592 t although considerable fluctuations in the landings have been recorded. The clam production in Goa has been estimated at 887 t/year and that of Maharashtra at 1,100 t/year. Along the east coast

Table 14. Production rates achieved in mussel culture by different methods in various centres

Species	Place	Production rate	Period	Raft	Long-line	Rack
Perna viridis	Calicut (opensea	4.4 to 12.3kg/m of rope	5 months	+	–	–
"	Karwar(bay)	7.6 to 10 kg/m of rope	5 to 6 months	+	–	–
"	Goa (NIO) (bay)	6 kg/m of rope	6 months	+	–	–
"	Ratnagiri (opensea)	7 kg/3 m of rope	6 months	+	–	–
Perna indica	Kovalam, Madras (opensea)	6.6 kg/m of rope	4 months	+	–	–
P. viridis	Vizhinjam (bay)	10 kg/m of rope	7 months	+	–	–
P. viridis/ P. indica	Andhakaranazhi (opensea)	10 kg/m of rope	6 months	–	+	–
P. viridis	Padanne	10 kg/m of rope	6 months	–	–	+
P. viridis	Dharmadam	10 kg/m of rope	5 months	–	–	+

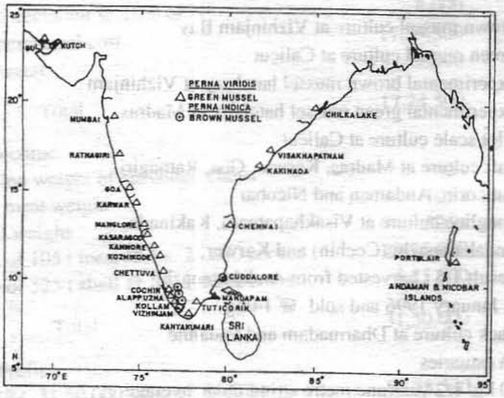

Fig.14. Distribution of green and brown mussel in India and areas suitable for farming.

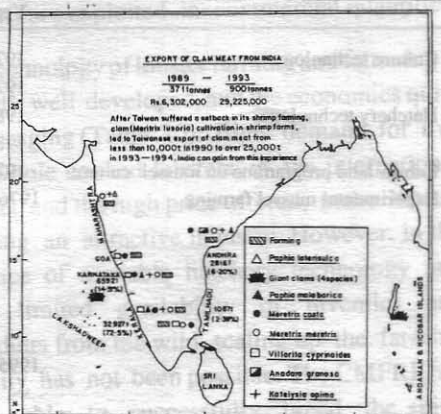

Fig.15. Distribution of clams in India and farming areas

Table 15. Economics of open sea mussel farming (0.36 ha area) (longline method)

I. Initital investment		Rs.
Cost of construction of a longline unit (floats, anchors, anchorline, horizontal & vertical lines)	:	1,28,000
Floating platform for watch & ward	:	25,000
FRP dinghi & OB engine	:	75,000
Spat collectors	:	10,000
Others	:	12,000
Total	:	2,50,000
II. Fixed cost (for one crop of 6 months only per year)		
Depreciation @ 33.3%	:	83,250
Interest @ 18%	:	45,000
III. Operational cost (per crop)		
Seed	:	30,000
Materials (cotton cloth, cement block, etc.)	:	15,000
Labour	:	1,33,000
Miscellaneous	:	22,000
Subtotal		2,00,000
IV. Total cost (annual) (II + III)	:	3.3 lakhs
V. Expected production	:	55 tonnes
VI. Gross revenue at Rs. 10/kg	:	5.5 lakhs
VII. Net profit (VI - IV)	:	2.2 lakhs

of India, the clam resources are of smaller magnitude. In Tamil Nadu, the Vellar estuary and the Pulicat Lake together contribute annually 1087 t, while in Andhra Pradesh, the annual clam production was estimated at 2816 t (Fig.15).

Since clams are cultured on the bottom, site selection depends on the substratum. The occurrence of natural clam populations is indicative of the suitability of the site with particular reference to the tide level, substratum and salinity. Clam farms are located in estuaries, bays and other sheltered areas close to the shore. Clams are rarely grown in ponds, but in recent years, due to the disease problems in shrimp farms, there is growing interest in many Southeast Asian countries to utilize the shrimp ponds for clam culture. In Taiwan, *Meretrix lusoria* is grown in ponds, formerly used for milkfish and shrimps and also in the outlet and inlet canals of these ponds. As a result, Taiwan's export of clam meat which was less than 10,000 tonnes during 1990 exceeded 25,000 tonnes during 1994. The results of hatchery production of clam seed (Fig.16), farming and ranching achieved by the CMFRI since 1978 (Table 17) suggest good scope for the expansion of clam farming in shrimp farms and in protected natural waters (Table 18).

India's export of clam meat has been increasing steadily over the past few years, particularly to Japan, Western Europe and USA. The export increased from a meagre 371 t in 1989 to 800 t in 1993 (Table 19). In terms of value, almost five fold increase has been recorded from Rs 63.02 lakhs in 1989 to Rs 292.25 lakhs in 1993.

Table 16. Progressive development of mussel culture technology in India by the CMFRI

	Year	Location & Results
I. Culture technology	1973	Brown mussel culture at Vizhinjam Bay
	1974	Green mussel culture at Calicut
II. Hatchery technology	1984	Experimental brown mussel hatchery at Vizhinjam
	1985	Experimental green mussel hatchery at Madras
III. Lab-to-land programme on mussel culture	1979	Pilot scale culture at Calicut
IV. Experimental mussel farming	1976-82	Raft culture at Madras, Karwar, Goa, Ratnagiri, Tuticorin, Andaman and Nicobar Longline culture at Visakhapatnam, Kakinada, Andakaranazhi (Cochin) and Karwar Result 1.5 t harvested from Andakaranazhi in January 1996 and sold @ 14/kg
	1995-96	Rack culture at Dharmadam and Padanne in estuaries
V. Production rate achieved		10 kg/ 1/2 year/one metre string on an average in all farms
VI. Sponsored projects for mussel hatchery	1994-97	Sponsored by the Dept. of Biotechnology

Table 17. Progressive development of clam culture technology in India by the CMFRI

	Year	Location & Results
1. Farming technology	1978	Farming of ***Anadara granosa*** at Kakinada: 0.39 t/100 m^2/5 months = 39 t/ha 2.6 t/625 m^2/5.5 months = 41.6 t/ha 6.1 t/0.16 ha/7 months = 38.1 t/ha Survival = 88.6%
2. Hatchery technology	1987	Developed at the Tuticorin shellfish hatchery for *Villorita cyprinoides* and *Meretrix casta*
3. Pilot scale seed production	1987	At Tuticorin shellfish hatchery for *Meretrix meretrix*
	1988	- do - for *Anadara granosa* and *Meretrix casta*
	1988-1996	- do - for *Paphia malabarica* (35,000 to 1.54 million seed per year)
4. Searanching of clam seed	1989-1996	At Ashtamudi, Madras, Tuticorin, Munambam & Pondicherry Production (P. malabarica) at Ashtamudi : 1.425 kg to 5.93 kg/m^2/3.5 months Survival 7.05 to 17.64%
5. Sponsored projects for clam hatchery and ranching	1993-1995	Donor : Marine Products Export Development Authority: Amount : Rs 0.362 million Total seed produced = 1.54 million Places where sea ranched = Ashtamudi, Munambam & Ayiramthengu
	1994-1997	Donor : Dept. of Biotechnology Amount : Rs. 0.8 million Seed produced = about 1 million

Table 18. Economics of clam culture

		Amount in Rs.
A. Capital expenditure		Amount in Rs.
1. FRP boat with outboard motor	:	80,000
B. Operational cost		
1. Casurina poles	:	2,500
2. Pen enclosure	:	10,000
3. Seed @ Rs 55/1000	:	16,50,000
4. Running cost of boat	:	6,000
5. Labour	:	6,000
6. Harvesting, depuration & shucking of meat	:	50,000
7. Contingencies	:	6,000
8. Salary to Manager @ Rs. 2,000 for 6 months	:	12,000
9. Watch and ward for 6 months	:	12,000
Total	:	17,54,500
C. Interest at 15% for A for one year	:	12,000
D. Cost of production		
1. Depreciation @ 10% of A	:	8,000
2. Operational cost	:	17,54,500
3. Interest	:	12,000
Total	:	17,74,500
E. Income		
Shellon weight of harvested clams	:	700 t
Wet meat weight	:	105 t
Shell weight	:	525 t
Sale of 105 t meat @ Rs. 25,000 per ton	:	26,25,000
Sale of 525 t shell @ Rs. 1,000 per ton	:	5,25,000
Total	:	31,50,000
F. Profit		
(Rs. 31,50,000 - Rs. 17,74,500)	:	13,75,500
Net profit on investment	:	77.5%.

8.6. Lobster farming

Spiny lobsters (rock lobsters) are low volume, but high value fisheries which support some of the most valuable marine fisheries resources worldwide. India earns approximately US $ 15 million each year through the export of lobsters (Fig.17). Though the lobsters are widely distributed along the Indian coast, the major fisheries are located along the northwest (Maharashtra & Gujarat), the southwest (Kerala & Tamil Nadu) and the southeast (Tamil Nadu) coasts. Among the six shallow water species, only *Panulirus polyphagus, P. homarus and P. ornatus* are exploited in commercial quantities.

The technology of lobster farming and fattening is already well developed, and the economics quite encouraging (Table 20). High demand for live and whole cooked lobsters in the international market and the high price offered, make lobster farming an attractive industry. However, in the absence of a viable hatchery technology and only limited availability of juveniles and subadults from the wild, scaling up the farming activity has not been possible. The CMFRI has been able to successfully breed the spiny lobsters and rear the phyllosoma upto the VIth

Table 19. Export of clam meat

Products		1989	1990	1991	1992	1993
Dehydrated Clam meat	Q:	42	107	164	129	124
	V:	933	2,546	4,789	3,855	5,669
Frozen Boiled Clams	Q:	329	414	1,232	940	776
	V:	5,369	7,558	37,392	31,028	23,541
Clam meat Pickle	Q:	–	–	–	37	NEG:
	V:	–	–	–	2,025	15

Q = Quantity in tonnes; V = Value in Thousand

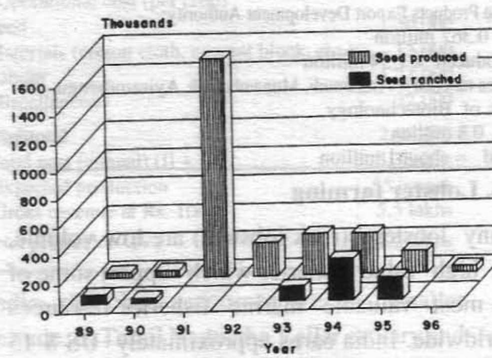

Fig.16. Production of *Paphia malabarica* seed in CMFRI hatchery

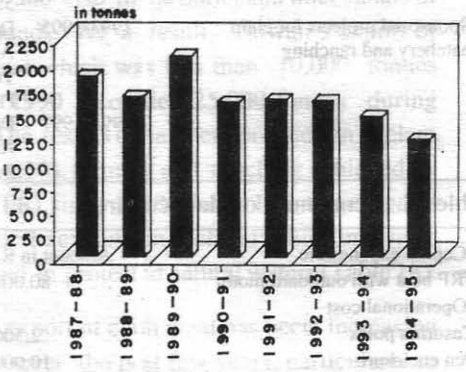

Fig.17. Export of lobster tail during 1987-88 to 1994-95

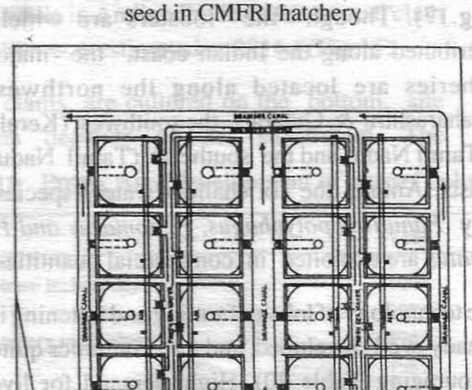

Fig.18. Layout of an indoor lobster culture facility developed for the industry by the CMFRI

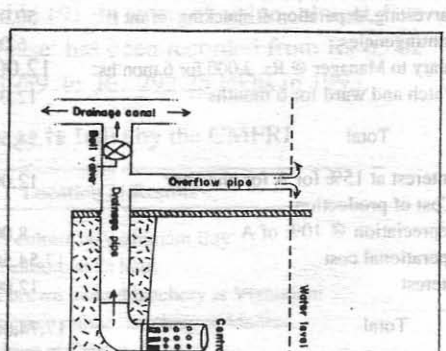

Fig.19. Schematic diagram of a lobster culture tank developed for the industry by the CMFRI.

Table 20. Economics of spiny lobster culture for producing one tonne lobster in indoor system

Assumptions: Species - *Panulirus ornatus*, duration of culture - 6 months, size at stocking - 150 g, size at harvest - 500 g, mortality - 10%

		Rupees in lakhs
A.	Capital cost Construction of tanks and overhead shed; pumps, air blowers and generator; erecting pump house and pumping system; PVC pipes and fittings for water and air distribution; construction of sump and filtration system, etc.	12.00
B.	Operating cost Juveniles, feed, electricity, chemicals & antibiotics and lobster shelters; wages to labourers and miscellaneous expenses	4.00
C.	Gross profit from selling 1000 kg lobsters @ Rs. 800 per kg	8.00
D.	Net profit (depreciation of capital, construction and equipments excluded)	4.00

stage as early as 1978. This work which was suspended after the cyclone devastation of the Institute's mariculture laboratory at Kovalam (near Madras) in 1980 is now being revived with a view to completing the life history successfully, paving the way for a viable hatchery system.

In the matter of growout, eyestalk ablation experiments have shown that a group of lobsters of 85 g average weight, after eyestalk ablation, increased to 432 g in 165 days as compared to the growth increment of only 57 g for the control group. A lobster growout system designed by the Institute for the Amalgam Seafood Exports Cochin consists of a series of circular or square cement tanks of 9 to 16 sq.m area each with either a flowthrough or a semiclosed recirculation system (Figs 18 & 19).

8.7. Crab culture

During the period 1989-94, India has exported live mud crabs to the tune of about 630 tonnes valued at Rs. 2.58 million on an average annually. Among the maritime states, Tamil Nadu, Andhra Pradesh and Kerala have already taken up crab farming as an alternative source of income generation in the coastal rural sector. Indo-Pacific in distribution, the mud crabs inhabit

Table 21. Economics of three systems of mudcrab farming under taken in the Mother crab farm at Tuticorin

Culture method	Production & income	Expenditure	Net profit/crop
Monoculture 0.5 ha	Crabs 780 kg Rs. 1,57,200	Cost of seed, feed fencing, power supply wages etc. Rs 43,860	Rs 1,13,340 (120 days)
Polyculture 0.5 ha	Crabs 1140 kg Rs 2,32,400 Milkfish 720 kg Rs 28,800	As above Rs 48,400	Rs 2,12,800 (138 days)
Fattening 0.3 ha	Crabs 560 kg Rs 1,22,850	As above Rs 56,200	Rs 66,650 (30 days)

Total production in all 14 ponds of 5.2 ha	=	6340 kg
Postharvest mortality 3.8%	=	240 kg
Total Income	=	Rs 12,20,000
Expenditure	=	Rs 3,05,000
Net profit	=	Rs 9,15,000
Period of culture	=	4 months
Average net income	=	Rs 1,75,961/ ha/4 months

Table 22. Achievements of CMFRI in breeding and seed production of crabs

Species	Year of work & Authors	Results
Mud crab *Scylla serrata*	1983 Marichamy & Rajapackiam (1984)	Incubation period, egg hatching and complete metamorphosis studied for the first time in India
- do -	1983-84 Marichamy & Rajapackiam (1992)	Egg hatching and early development upto crab stage studied under controlled conditions at Tuticorin. A maximum of 15% survival at crab stage obtained.
Scylla tranquebarica & S. serrata	1994-95 M.K. Anil (Personal communication)	Complete larval development of both species studied for the first time in India. Experimental seed production trials yielded 20 to 25% survival for both species.
Swimming crab *Portunus pelagicus*	1996 Josileen and others (1996)	Larval rearing and seed production successfully carried out at Mandapam with a survival rate of 80 to 85% upto zoea-V stage and lesser survival rates for successive stages.

the marine as well as brackishwater environments. In India, both the species (*Scylla serrata and S. tranquebarica*) coexist in the inshore sea, estuaries, backwaters, coastal lakes and mangrove swamps of all maritime States on the mainland and the creeks and bays of Andaman and Nicobar Islands. They prefer muddy or sandy bottom.

Mudcrab fattening experiments using *Scylla tranquebarica* were carried out at Narakkal in a pond of 1000 sq.m at a low stocking density of 300 water crabs, each of 500 to 550 g during 1996. They were fed daily with salted trash fish at 10% of body weight. Water exchange was facilitated by means of tidal flow. Selective harvesting of mud crabs was carried out at weekly intervals, after 21 days of the initiation of the experiment. A total of Rs 8500/- was spent towards the cost of crab and the feed. The harvested crabs were sold for a sum of Rs 9600/- in 40 days (Table 21). The experiment is being continued. Crab fattening has to be pursued for a minimum of 7 to 8 months with continuous harvesting and stocking to make it an economically viable

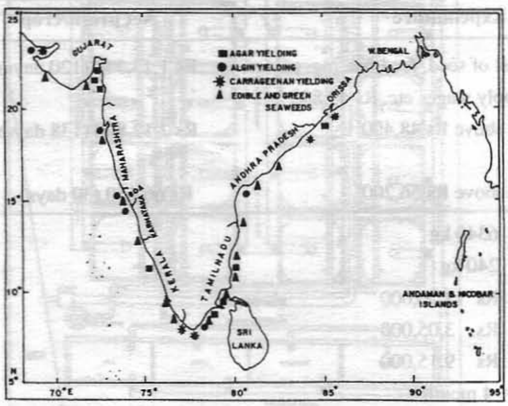

Fig.20. Distribution and abundance of various seaweed resources along the Indian coastline.

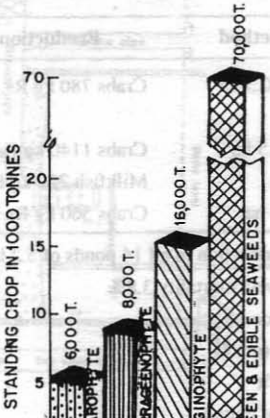

Fig.21. Standard crop of seaweed resources along the Indian coast

operation. Profitability can be further increased by polyculture with compatible species of fish and shellfish.

Experiments conducted at the CMFRI, Tuticorin during 1983- 85 on the mud crabs *Scylla serrata* and *S. tranquebarica* gave encouraging results. A survival of 15% was achieved from the egg to the first instar stage. The techniques have been further refined as a result of which a survival of 20% has been achieved recently. Similar experiments conducted in the CMFRI, Cochin on both these species also gave 20% survival rate. Experiments currently being carried out at Mandapam gave encouraging results and an economically viable hatchery technology is emerging from these efforts.

The CMFRI has carried out breeding of the marine crab *Portunus pelagicus* and succeeded in obtaining a survival of 8 to 10% from the egg to the first instar stage. Experiments are being continued to increase the survival rate and develop a viable hatchery technology for this species. Experiments on the broodstock development and farming revealed that this species has great potential for seafarming. Three generations of *P.pelagicus* have been produced successively and being successfully maintained in the CMFRI Mandapam marine hatchery (Table 22).

Studies on the farming of mud crabs have been initiated by the Institute as early as 1983 and being perfected over the years. Recently three types of farming have been undertaken, namely, monoculture, polyculture and fattening. Depending on the availability of seed, these technologies can be advantageously made use of by the entrepreneurs. Table 21 deals with the economics of these three methods of farming.

One of the major constraints being faced by the farmers is the inadequate supply of seed crabs, as the only source at present is the wild stock in most of the countries, where crab farming is attempted. It is, therefore, imperative that concerted effort is made to develop commercial hatcheries for adequate and sustained supply of baby crabs to make mud crab farming an organised industry. The first commercial mud crab hatchery established by Indo Marine Aquaculture (located at Marthanpattinam, Thennampattinam - 609 115, Sirkali Taluk, Nagapattinam district, Tamil Nadu) has come into production and sale of seed in January, 1996.

8.8 Seaweed culture

About 700 species of marine algae have been recorded from different parts of the Indian coast. Of these, nearly 60 species are commercially important, belonging to green, brown and red algae which occur along the southeast coast, Tamil Nadu, Gujarat, Lakshadweep and Andaman & Nicobar Islands. Fairly rich seaweed beds are

Table 23. Important Indian seaweeds and their standing crop

Agarophytes	Alginophytes	Carrageenophytes	Edible & green seaweeds
Gracilaria edulis	*Sargassum* spp.	*Hypnea valentiae*	*Ulva* sp.
G. corticata	*Turbinaria* spp.	*H. musciforms*	*Enteromorpha*
G. crassa	*Hormophysa* sp.	*Eucheuma* sp.	*Caulerpa* spp.
G. follifera	*Cystosiera* sp.		*Codium* spp.
G. verrucosa			*Laurencia* spp.
Gelidiella acerosa			*Acanthophora*
Gelidium sp.			
Standing crop (in tonnes)			
6,000	16,000	8,000	70,000
			Total 100,000

Table 24. Methods of seaweed cultivation

Fragment Culture Methods	Spore Culture Methods
1. Coir rope longline	1. Settling spores on coral stones
2. Coir rope net	2. On gastropod shells
3. Nylon rope	3. Nylon rope
4. Broadcasting in ponds	4. Coir rope
5. Tying in plastic bags	5. Nylon twine
6. Tying on floating rafts	6. Circular cement blocks
7. Tying the fragments to rocks	

Current Production of Phycocolloids from Seaweed (in tonnes)

Colloids	Global	India	No. of Indian Factories
1. Agar	5000 (from 30,000t dry wt)	130 (from 750t dry wt)	30
2. Algin	–	500 (from 3000t dry wt)	28
3. Carrageenan	–	Nil	Nil

present in the vicinity of Bombay, Karwar, Ratnagiri, Goa, Varkala, Kadalundi, Vizhinjam, Visakhapatnam and in the coastal lakes of Ashtamudi, Pulicat and Chilka (Fig. 20).

As per the current estimate, the total standing crop of all seaweeds in the Indian waters is more than one hundred thousand tonnes (wet wt) consisting of 6,000 tonnes of agar yielding red seaweeds, 16,000 tonnes of algin yielding seaweeds and the remaining quantity is of edible and carrageenan yielding seaweeds (Fig. 21). The important species are listed in Table 23. Seaweeds are cultured either by vegetative propagation using fragments of seaweeds collected from the natural beds or by spores such as tetraspores or carpospores. The fragments are also cultured by broadcasting them in outdoor ponds and tanks (Table 24).

Seaweed farming along the coast of peninsular India has the potential to fetch a return of Rs. 9,000/- per ha per year for an investment of Rs. 36,000/-, assuming the production rate to be 3 fold in each of the two crops/harvests. A production target of 2 million metric tonnes of cultivated seaweeds is proposed to be achieved by 2020 (Figs 22 & 23). The hike in the production from the current 0.2 million tonnes through wild harvest to 2 million tonnes by farming by 2020 is possible through the following activities:

1) enlargement of the farming areas including the brackishwater lakes
2) upgradation of culture technology into intensive culture and multispecies culture systems
3) onshore culture in tanks, ponds and raceways
4) introduction of high yielding, exotic species and development of high yielding varieties through genetic manipulations

8.9. Seacucumber culture

There are more than 200 species of seacucumber in the seas around India, of which 75 species are distributed in the shallow water. They occur mainly in the Gulf of Mannar and Palk Bay, the Andaman and Nicobar Islands and the Lakshadweep. In the Gulf of Mannar and Palk Bay *Holothuria scabra* is the most important species for processing in to beche-de-mer. In recent years Actinopyga echinites and *A. miliaris* are also exploited in good quantities. *Holothuria spinifera* and *Bohadschia marmorata* are available in smaller quantities only. Although *Holothuria scabra* and *H. spinifera* are not found in the Lakshadweep, Holothuria nobilis and *Thelenta ananas* are quite important in this island, where *Bohadschia marmorata, Actinopyga mauritiana, A. echinites, A. miliaris, Stichopus variegatus, S. chloronotus* and *Holothuria atra* are also available to some extent. While the most important species in the Andaman and Nicobar Islands is *H. scabra, smaller quantities of Holothuria atra, A. mauritiana, A. echinites, A. miliaris, H. nobilis, Stichopus variegatus* and

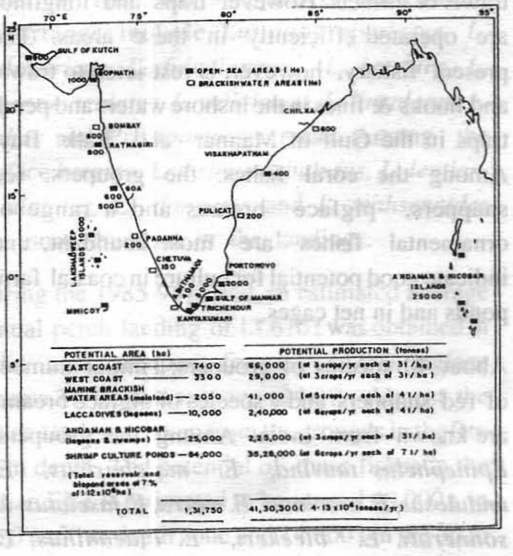

Fig.22. Potential areas of seaweed aquaculture along the Indian EEZ

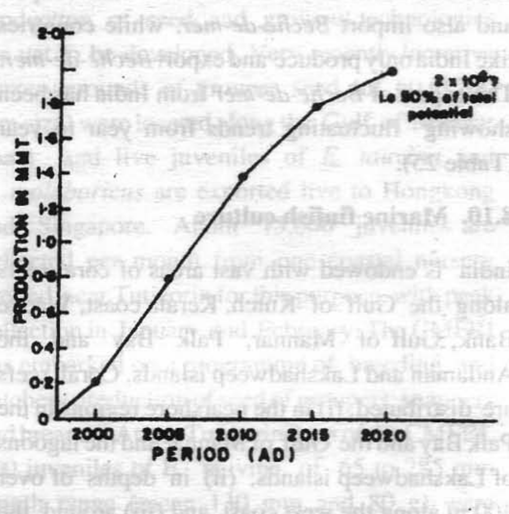

Fig.23. Projected Indian mariculture production of seaweeds

S. chloronotus also occur, but *H. spinifera* is absent in this island. The record of *Thelenota ananas* from the Andamans needs to be checked. Sea- cucumbers are distributed in the Gulf of Kutch and in certain other locations along the coast of the mainland of India, but they are not of commercial value.

The CMFRI succeeded in the production seed of *H.scabra* for the first time in 1988 by induced breeding through thermal stimulation at the Tuticorin field mariculture laboratory. (James *et al.,* 1989). Since then *H. scabra* seed is being produced in this hatchery on a regular basis.

Beche-de-mer production is a very ancient industry in India. The Chinese had constant trade with southern India for more than thousand years. Customs records on the export of *Beche-de-mer* from the Madras Presidency are available from 1898 onwards. Since the middle of the last century a good *Beche-de-mer* processing industry was functioning in the Lakshadweep, but it ceased in recent times. In the Andamans also there was good processing activity since the mid seventies around Port Blair, but it stopped recently due to the ban imposed by the Andaman and Nicobar Administration.

Table 25. Annual export of beche-de-mer from India (Q = Quantity in kg V = Value in Rs.)

Country		1990	1991	1992	1993	1994
Taiwan	Q	-	-	255	-	-
	V	-	-	3,19,038	-	-
Hongkong	Q	-	984	20,520	13,020	37,562
	V	-	1,32,645	18,02,625	10,96,992	65,18,207
Singapore	Q	37,338	27,962	18,566	6,657	8,254
	V	50,90,987	85,02,083	54,68,454	25,76,362	25,86,972
Total	Q	37,388	28,946	39,341	19,677	45,816
	V	50,90,987	86,34,728	75,90,117	36,73,354	91,05,179

All countries which produce *Beche-de-mer* do not consume. Some of the countries consume, export and also import *Beche-de-mer,* while countries like India only produce and export *Beche-de-mer.* The export of *Beche-de-mer* from India has been showing fluctuating trends from year to year (Table 25).

8.10. Marine finfish culture

India is endowed with vast areas of coral reefs along the Gulf of Kutch, Kerala coast, Wadge Bank, Gulf of Mannar, Palk Bay and the Andaman and Lakshadweep islands. Coral reefs are distributed: (i) in the nearshore regions in the Palk Bay and the Gulf of Mannar and the lagoons of Lakshadweep islands, (ii) in depths of over 400 m along the west coast, and (iii) around the islands in the Andaman and Lakshadweep. Most of these areas are not suitable for fishing with trawls or gillnets. However traps and longlines are operated efficiently in these areas. The present fishery, however, is restricted to trawls and hooks & lines in the inshore waters and perch traps in the Gulf of Mannar and Palk Bay. Among the coral fishes, the groupers, red snappers, pigface breams and a range of ornamental fishes are most abundant, and indicate good potential for culture in coastal farm ponds and in net cages.

About 40 species of groupers, similar number of red snappers and 9 species of pigface breams are known from India. Among the groupers, *Epinephelus tauvina, E. malabaricus, E. undulosus, E. areolatus, E. merra, E. fasciatus, E. sonnerati, E. bleekeri, E. diacanthus, E. chlorostigma, E. caeruleopunctatus and Promicrops lanceolatus* constitute important

Table 26. Marine fish culture experiments carried out in India

Place	Culture System	Methods	Species	Growth rate(mm)	Survival (%)	Production (Kg/ha/yr)	Authors
Krusadi	Monoculture	Pond	*C. chanos*	230-240/yr	–	–	Chacko and Mahadevan (1956)
	Monoculture	Pond	*C. chanos*	240-250/yr	–	–	Menon (1959)
Mandapam	Monoculture	Pond	*C. chanos*	300 /yr	9-11	212-455	Tampi (1960)
Veppalodai	Polyculture	Pond	*C. chanos*	333 /yr	50	192	Marichamy and Rajapackiam (1982)
Tuticorin	Polyculture	Pond	*C. chanos*	300-378/yr	5	324	Marichamy (1980)
			L. macrolepis	211-240/yr	67	630	
			S. serrata	130-175/yr	26	690	
Mandapam	Monoculture	Tank	*A. bicolor bicolor*	23/month	98	2.2 kg/sqm / 5 months	Dorairaj *et.al* (1985)
Mandapam	Monoculture	Cage	*S.canaliculatus*	8.5/month		-	James *et.al* (1985b)
			S. javus	6.2/month	60	-	
			E. tauvina	19/month	73		
			S. sihama	10/month	-	-	
Mandapam	Polyculture	Pond	*V. seheli*	15.8-24.6/month	-	-	James *et .al* (1985a)
			L.macrolepis	13/month	-	-	
			C. chanos	16.8-30/month		-	-
			P. indicus	9.4/month	-		
			S. sihama	11.4/month	-	-	
Mandapam	Polyculture	Pen	*Mugil sp.*	18/month	-	-	Venkataraman *et.al* (1985)
			C. chanos	50/month			
Tuticorin	Polyculture	Pen	*C. chanos*	27/month	5-48	damaged	Shanmugam and Bensam (1982)
Tuticorin	Monoculture	Pond	*C. chanos*	44/month		318-857	Bensam and Marichamy (1982)
Mandapam	Monoculture	Cage	*E. tauvina*	16.3mm/month	-	-	Hamsa and Kasim (1992)

fisheries. The red snappers of commercial importance include *Lutjanus rivulatus, L. malabaricus, L. fulviflamma, L. kasmira, L. argentimaculatus, L. waigiensis, L. lineolatus, L. gibbus* and *Pristipomoides typus.* Among the pigface breams, *Lethrinus nebulosus, L. lentjan, L. miniatus, L. elongatus* and *L. mahsenoides* are most abundant in the landings.

During the 1985-94 period, an estimated average annual perch landing of 13,616 t was obtained in India with groupers forming 44.9%, pigface breams 31.1% and snappers 24.0%. Almost the entire catch was taken from the grounds in the 0 to 50 m depth. The potential of these fishes in the Indian EEZ is estimated to be around 40,000 t in the 0 to 50 m depth zone and 14,600 t in the 50 to 300 m depth zone. The wide difference between the potential and the landings is due to the grounds not being accessible to trawlers and setnets. Therefore, fishing by traps and longlines needs to be introduced for the effective exploitation of these resources.

The coral reefs constitute an important habitat for a vast range of ornamental fishes of about 300 species. Of these, fishes of the families Acanthuridae, Pomacentridae, Labridae, Scaridae, Chaetodontidae, Siganidae, Holocentridae, Syngnathidae and Balistidae are important. These fishes are known to be abundant mainly in the lagoons of the Lakshadweep islands, followed by the Andamans, Gulf of Mannar, Palk Bay and Vizhinjam Bay. Currently, there is no exploitation of these fishes for aquarium purpose. The CMFRI has initiated a detailed survey and assessment of the ornamental fishes of the Lakshadweep.

In the area of marine fish culture, India is still in the experimental phase. Experiments on several species : *Chanos chanos, Mugil cephalus, Liza macrolepis, Valamugil seheli, Siganus canaliculatus, S. javus, Sillago sihama, Epinephelus tauvina, Anguilla bicolor bicolor, Lates calcarifer* and *Etroplus suratensis* were conducted (Table 26). Breeding and hatchery production of seed and growout technologies are yet to be developed. Very recently lucrative nursery grounds of grouper seed (of 60 to 260 mm size) were located along the Gulf of Mannar coast and live juveniles of *E. tauvina* and *E. malabaricus* are exported live to Hongkong and Singapore. About 15,000 juveniles are collected per month from one coastal nursery ground near Tuticorin for this purpose, with peak collection in January and February. The CMFRI has embarked on a programme of breeding and hatchery production of seed of groupers, snappers and breams. At the Tuticorin farm of the CMFRI, 300 juveniles of E. tauvina of 65 to 285 mm length range (mean 130 mm and 80 g) were stocked during June-July 1996. By the end of September 1996 (75 days) the groupers at Tuticorin attained an average size of 225 mm and 110 g. At the Mandapam centre of the CMFRI *E. tauvina* of the length range of 92 to 245 mm and weight range of 10 to 200 g were stocked in outdoor cement tanks and fed sardines at the rate of 10% body weight. In six months, they attained 180 to 360 mm and 160 to 630 g. Eyeball swelling, tailrot and infection by *Caligus* resulted in some mortality. Recently ovaprim was injected to *E. tauvina* at the rate of 0.5 ml per kg body weight; in six days, spawning took place in fish of 2.0 to 2.5 kg wt. A private company (Sannet Aqua) is currently operating a net cage at Tuticorin in the Gulf of Mannar at a depth of 4m for captive holding and fattening of groupers (fed on sardines) for live export in ships to Hongkong. The comnpany has exported in 1996 about 20 tonnes of live groupers.

9. Stock enhancement programme

9.1. Searanching

Searanching is termed as production and release of aquatic organisms into their natural habitats to augment their stock. It was in the United States that the idea of searanching originated as back as

Table 27. Some searanching results: global & Indian experience

Country	Location	Species	No.of seed ranched	Year	Results
1. Japan	Komance-Ko-Lagoon	Kuruma shrimp	700 million	-	2.4 times increase in the production of kuruma shrimp
	-do-	Seabream Flounder	16 million 19 million	-	Substantial increase in the wild stock
	16 national and 43 local aqua-culture centres	80 coastal species	-	-	
2. U.S.A.	Hawaii	Striped mullets	Pilot scale	1970s	100% increase in the wild stock
	Texas	Red drum	Pilot scale	1970s	Significant increase
	Hawaii	Threadfin	Pilot scale	1970s	Significant increase
3. -	Bohai sea Yellow sea	Penaeid shrimps	Large scale	1980s	Recapture rate4 to 13.6%: searanched seed account for > 90% of catch
4. India (CMFRI)	Palk Bay	*Penaeus semisulcatus*	6 million	1990-94	Augmentated yield
	Gulf of Mannar (Pearl banks)	*Pinctada fucata*	10 million	1985 & 1990	Significant increase in adult pearl oyster in the natural beds
	Ashtamudi estuarine lake in Kerala	Clams	0.486 million	1993-96	Fairly good increase in production

1870. Since then many countries have been practising this for enhancing the resources as fishing pressure is evidently felt on many of the resources. Searanching also helps in conserving the resources. The idea of searanching in India started with pearl oyster which appeared to diminish in number since the Gulf of Mannar pearl fishery of 1961 due to many factors. To overcome the erratic natural population of pearl oysters, it was felt that searanching would be the correct step. With the establishment of a molluscan hatchery at Tuticorin and large scale production of seed, searanching became a reality. Ranching of shrimp seed has become relevant in the context of diminishing returns from the natural resources. The spiny lobsters, clams and seacucumbers offer immense scope for searanching because of the increasing demand in the export trade, decreasing production from the fishery, and the success in hatchery production of their seed (Table 27).

Japan is the pioneer in the searanching of a variety of marine organisms including shellfishes and finfishes. They embarked on a stock enhancement programme (SEP) in a big way involving 16 national and 43 local aquaculture centres, focussing on the problems of 80 coastal species including the kuruma prawn *(Penaeus japonicus)*, blue crab, red seabream (*Pagrus major)*, abalone and flatfish. By releasing about 700 million seed of *P. japonicus* in the Komance-Ko-lagoon, they have increased the production by 2.4 times. In the case of finfishes, ranching of 16 million seabreams and 19 million flounders resulted in substantially supplementing the natural stock.

In Hawaii, stock enhancement programme was undertaken for the depleted coastal fisheries, of which the two highest ranked species, the Pacific threadfin *(Polydactylus sexfilis)* and the striped mullet (*Mugil cephalus*) were taken up in the first phase as test species. Pilot hatchery release experiments resulted in 100% increase in mullet abundance in the nursery habitat. In Texas, consequent on the decline of the red drum

Table 28. Proposed pilot scale searanching programme by CMFRI under the 9th Five Year Plan

Commodity	Location	Quantity (million)	Species
Shrimps	Veraval	10.0	*Penaeus penicillatus, Penaeus merguiensis*
	Karwar	5.0	*P. merguiensis, Parapenaeopsis stylifera*
	Calicut	10.0	*Metapenaeus dobsoni, P.indicus P. stylifera*
	Vizhinjam	15.0	*P.indicus, Metapenaeus dobsoni P. stylifera*
	Mandapam	10.0	*P. semisulcatus*
	Madras	10.0	*P. indicus, P. monodon*
	Visakhapatnam	10.0	*P. indicus, P. monodon*
Lobsters	Veraval	0.2	*Panulirus polyphagus, Thenus orientalis*
	Calicut	0.2	*P. homarus*
	Vizhinjam	0.2	*P. homarus, T. orientalis*
	Mandapam	0.2	*P. homarus, P. ornatus*
	Madras	0.2	*P. homarus, T. orientalis*
Pearl	Veraval	12.0	*Pinctada fucata oyster*
	Vizhinjam	6.0	*P. fucata*
	Mandapam	12.0	*P. fucata*
Cephalopod	Veraval	1.0	*Sepia pharaonis, Loligo duvaucelli*
	Calicut	1.0	*S. pharaonis, L. duvaucelli*

(Sciaenops ocellatus) fishery during the 1970s, a stock enhancement programme was started to recover the resource by the Texas Parks and Wild Life Department. Studies so far conducted revealed that the stocked fish survived in significant numbers and thereby enhanced the natural populations. Stocking hatchery fish along with stringent fishery and habitat protection measures could revive the red bream population substantially.

Stock enhancement programmes on penaeid shrimps began in the mid '80s along the coasts of the Bohai Sea and the central and northern Yellow Sea to build up the collapsed stocks in the traditional fishing grounds. A remarkable recapture rate ranging from 4.0 to 13.6% was observed under these programmes. At present the released shrimp accounts for more than 90% of the total catch.

In India, the CMFRI carried out preliminary ranching experiments on *Penaeus semisulcatus* in the Palk Bay at Mandapam, clams in the Ashtamudi lake and pearl oysters and seacucumber in the Gulf of Mannar with encouraging results. 6 million postlarvae (PL- 15 to 32) of *P.semisulcatus* produced in the pilot prawn hatchery at Mandapam, Tamil Nadu were searanched in the Palk Bay from 1990 onwards. This programme helped in augmenting the production of *P.semisulcatus* in the coastal waters of Palk Bay. The PL - 15 were reared to a size of over 60 mm in length. A total of 2964 laboratory reared and farm grown *P. semisulcatus* of 60 to 110 mm size were tagged and released into the Palk Bay. One percent of these shrimps were obtained from the commercial trawl catches landed in two nearby landing centres within a period of 53 days. During this period, the tagged prawns have migrated to a distance of 30 to 35 km. The above experiments show that the searanched postlarvae of P. semisulcatus survive, migrate, grow and get recruited into the fishery in Palk Bay (Pillai, et al., 1991). A total of 10 million pearl oyster spat (0.9 to 11.3 mm size; average 1.53 to 5.7 mm) was searanched in the Gulf of Mannar in 3 pearl oyster beds (paars) in 17 batches during 1985 and 1990 and 0.486 million clam spat ranched in Ashtamudi lake, Kerala State in 7 batches during 1993-96 as detailed here. The first batch of 64,000 seed of *Paphia malabarica* measuring 12.4 mm average length were ranched in Ashtamudi lake (Dalavapuram) on 18.2.93 in a 25 m^2 area in 1 m depth and the site was fenced with 3.0 mm netlon screen. On 19.3.93 they measured 20.4 mm and by 3.5.93 they grew to 30.3 mm. In the same area a total of 30,000 seed of *P.malabarica* measuring 4.9 mm length were reared in cages as their size was small for planting in the field. By 3.5.93 they attained 12.2 mm and were ranched in the same area. These seed were covered with 1 cm mesh synthetic net to protect them from predators. At Munambam *P.malabarica* occurs rarely. Hence a consignment of 8500 seed was ranched in a 10 m^2 area on 19.2.93 in 0.5 m depth. The clam seed measured 12.4 mm and they were covered with 1 cm mesh synthetic net. By the end of April they attained 23.4 mm length.

Taking into account the declining status of some of our prime fisheries, their high economic value and the prospects of overexploitation of the wild stocks, the following species are proposed for pilot-scale searanching for stock enhancement at different centres along the Indian coast by the CMFRI under the 9th Five Year Plan (Table 28). Besides, under the Indian-Australian Cooperation in S&T, searanching has been proposed for stock enhancement in the Vizhinjam bay and the contiguous waters (Table 29).

Table 29. Proposed searanching programme for the Vizhinjam bay and the contiguous Gulf of Mannar- Wadge Bank -Minicoy lagoon - Cochin coast under the New Horizon India - Australia cooperation in Science & Technology

Location	Species	No. of seed to be ranched in 5 years (in million)
1. Vizhinjam	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	8
	(ii) Pearl oyster (*P.fucata*)	160
	(iii)Grouper (*E.tauvina*)	16
2. Mandapam	(i) Shrimp (*P.indicus, P.semisulcatus*)	24
	(ii) Pearl oyster (*P.fucata*)	160
	(iii) Seacucumber (*H.scabra*)	10
	(iv) Grouper (*E.tauvina*)	18
3. Tuticorin	(i) Shrimp (*P.indicus, P.semisulcatus*)	36
	(ii) Pearl oyster (*P.fucata*)	180
	(iii)Seacucumber (*H.scabra*)	8
	(iv) Grouper (*E.tauvina*)	16
4. Quilon	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	330
5.Alleppey	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	172
6. Cochin	(i) Shrimp (*P.stylifera, M.dobsoni, P.indicus*)	330
7. Minicoy	(i) Pearl oyster (*P.fucata*)	20
	(ii) Seacucumber (*H.scabra*)	2

Total: Shrimp = 900 ; Pearl oyster = 520 ; Sea cucumber = 20 ; Grouper = 50

All Total = 1490

9.2 Artificial fish habitats

A significant number of maritime nations are showing increasing interest in artificial aquatic habitat enhancement programmes and about 40 countries in six continents have established such habitats to promote capture fisheries productivity and production (Robert and Choule, 1983).

The major objective of developing artificial reef habitats is basically to improve the conventional, commercial and recreational fishing and to sustain marine productivity. A variety of structures are used to attract various species of marine organisms. They range from improvement to the indigenous structures spread in extensive areas to very sophisticated concrete structures. Artificial fish habitats are being used at present to increase tuna catches in the tropical Pacific, to augment demersal fish catches in the Southeast Asian waters, to provide recreational fishing in the USA and to culture shellfish in European waters. Artificial reefs are in use over the last decade close to artisanal fishing villages along the districts of Thiruvananthapuram in Kerala and Kanyakumari and Chengalput districts in Tamil Nadu. Work on efficient design and fabrication of artificial reefs has been carried out by (i) the Fisheries Cell of the Programme for Community Development, Thiruvananthapuram, (ii) the South

Table 30. Species composition in artificial reefs in the Thiruvananthapuram and Kanyakumari district coasts

Local Name	Species	Qty in % in the total number of fish
Uralupara	***Atule mate***	41.20%
Kannan Pola/ Perumkanny	***Priacanthus cruentatus*** ***Priacanthus haamrur***	12.80%
Ayala	***Rastrelliger kanagurta***	10.30%
Clathy	***Abalistes stellatus*** ***Odonus niger***	6.50%
Vala Mural	***Ablennes hians***	3.00%
Kurali	***Lethrinus nebulosus***	2.70%
Kozhiyala	***Decapterus russelli***	2.50%
Kozhuva Para	***Carangoides*** **sp.**	2.40%
Chakani Para	***Carangoides*** **sp.**	2.40%
Pola	*Lutjanus lutjanus*	2.10%
Para	***Carangoides*** **sp.**	1.80%
Kozhuva	***Carangoides gymnostethus***	1.40%
Vela Para	***Carangoides*** **sp.**	1.20%
Kottan Para	***Carangoides*** **sp.**	1.10%
Vangada	***Megalaspis cordyla***	1.00%
Komali Para	***Carangoides*** **sp.**	1.00%
Kallu Kanava	***Sepia pharaonis***	0.60%
Others		6.00%
Total number of fish		2,632

(Species less than 1% in numbers are included under 'others' except cuttlefish)

Source: Artificial fish habitats, D'Cruz (1995).

Indian Federation of Fishermen, Thiruvananthapuram, (iii) The Waves, Madras and (iv) the Centre for Research on New International Economic Order, Madras.

D'Cruz (1995) observed that the setting up of artificial habitats for fisheries in the vicinity of the villages along the Kanyakumari-Thiruvananthapuram coasts enabled the fishermen to establish local fisheries for the low skilled and aged fishermen on regular basis and for the skilled fishermen on occasional basis during the better catching season of AFH's. It indicates that the prime objective of the construction of AFH's is to create convenient and rewarding fishing grounds by establishing local fisheries, especially during the lean fishing season (December to March). He further showed that the rainy season (southwest monsoon) and the fair weather season (December to February) are the two lean seasons creating difficulties to the fishermen of Thiruvananthapuram coast. According to the fishermen, though there is better availability of fish in the sea during the monsoon, the heavy rains and the surf during this season result in lower catches. In the fair weather season, little or no fish is available in the shallow waters due to the crystal clear nonturbid seawater. He also observed that in the FAD's half of the total species was contributed by Priacanthus sp. (49.72%) and about a quarter was contributed by *Sepia pharaonis.* Eventhough *Priacanthus* sp. dominated in terms of number, a *Sepia sp.* contributed much higher share in terms of weight. Compared to the AR's, FAD's gave better daily income due to the dominance of the high

Table 31. Species composition in fish aggregating devices in the Thiruvananthapuram and Kanyakumari district coasts

Local Name	**Species**	**Qty in % in the total number of fish**
Kannan Pola	*Priacanthus cruentatus* *Priacanthus hamrur*	49.70%
Kallu Kanava	*Sepia pharaonis*	23.40%
Uralupara	*Atule mate*	8.30%
Ayala	*Rastrelliger kanagurta*	4.40%
Clathy	*Abalistes stellatus* *Odonus niger*	2.80%
Mural	*Dussumieria acuta*	1.80%
Vangada	*Megalaspis cordyla*	1.20%
Kozhiyala	*Decapterus russelli* *Decapterus macrosoma*	1.10%
Others	—	7.30%
Total number of fish		15,419

(Species less than 1% in numbers are included as others)

Source: Artificial fish habitats, D'Cruz (1995).

value cuttlefish and squids (Tables 30 & 31).

It has been observed that since the AFH's have a significant impact on the fisheries of the artisanal fishing communities, they should be encouraged on a large scale with the participation of the community in selected villages for the benefit of the nonmotorised fishermen who possess only limited access to the resources.

10. Conclusion

Mariculture provides good opportunities for : (1) seafarming and associated activities of stock enhancement through searanching and artificial fish habitats, (2) land-based saline aquaculture in coastal zones using pump-fed or tide-fed seawater or brackishwater, and (3) hinterland aquaculture in saline soil and saline aquifer ecosystems. While coastal land-based shrimp aquaculture has grown rapidly in the current decade, the 1994-95 crop failures due to diseases have forced the industry to adopt ecofriendly systems of farming. The new approach is essentially of: (1) closed systems of farming coupled with the application of biotechnological, bacterial products; and (2) integration of compatible candidate species of bivalves, fishes, seacucumbers and seaweeds in the farming systems. The current practices have the potential to make coastal aquaculture more sustainable from the biological, ecological, legal, social and economic points of view. As a result of the adoption of these packages of practices the industry is set to quickly revive and yield over one lakh tonnes of shrimps during 1996 as against about 75,000 tonnes during 1995. There is, however, considerable fear of the outcome of the Supreme Court case against coastal aquaculture, which depends critically on access to the seafront. Seafarming in the opensea and the contiguous more protected bays, coves, gulfs, lakes, backwaters, lagoons and estuaries, inspite of the good potential, remain dormant in India mainly because of lack of awareness, issues of ownership of sites, opposition from traditional fishermen and risks from natural calamities. However, considerable R & D efforts have been initiated and private farms are being established in the Kerala backwaters (for bivalves and seaweeds) and also in the opensea in Tamil Nadu (for groupers and bivalves) and Kerala (for bivalves). Artificial fish habitat construction and operation by the small scale fishermen in the inshore fishing grounds has become a success in parts of Kerala and Tamil Nadu and is set to take off in Maharashtra, Andhra Pradesh and Orissa. There is considerable scope for the expansion of the artificial fish habitat programme in all the maritime states where it has substantial potential to become an industry as in Korea. The Indian experience of one percent of searanched banana shrimp entering the commercial catch from Palk Bay from a mere ranching of 10 million seed over a period of 5 years and the Bohoi Sea & Yellow Sea experience of about 96% of searanched shrimp entering the commercial catch from a massive stocking programme suggest that the shrimp stocks in the Indian seas, particularly the gulfs (Gulf of Kutch, Cambay and Mannar), bays (Bays of Vizhinjam, Palk, Kakinada and Waltair) the open Sandheads off West Bengal and the mudbanks of Kerala could be fast revived and made very productive by searanching. With an annual 8 billion shrimp seed capacity in about 170 hatcheries located along the coasts of the maritime states and with only less than half this quantity required for current farming, the surplus seed could be used for searanching. The resource for this purpose could be drawn from a portion of the present one percent cess on marine products export. The government of India may consider this question and issue the necessary guidelines for the implementation of this programme. Purchase of seed at a prefixed rate by the government may also serve as a support price in times of slump in price. Simultaneously, finfish, bivalves, abalones and seacucumbers also need to be taken up for searanching.

The hinterland saline soil aquifer ecosystems are now known to have the potential to produce at the rate of 2 to 3 tonnes of shrimps or marine fish per hectare in single crops of about 6 months. With about 8.5 million ha of inland saline ecosystem, the country has vast scope for progressively expanding this activity to commerical scales. There is need to accelerate the R & D in this regard by involving the State Departments of fisheries and agriculture, universities, NGO's, cooperatives, farmers' association and entrepreuners.

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