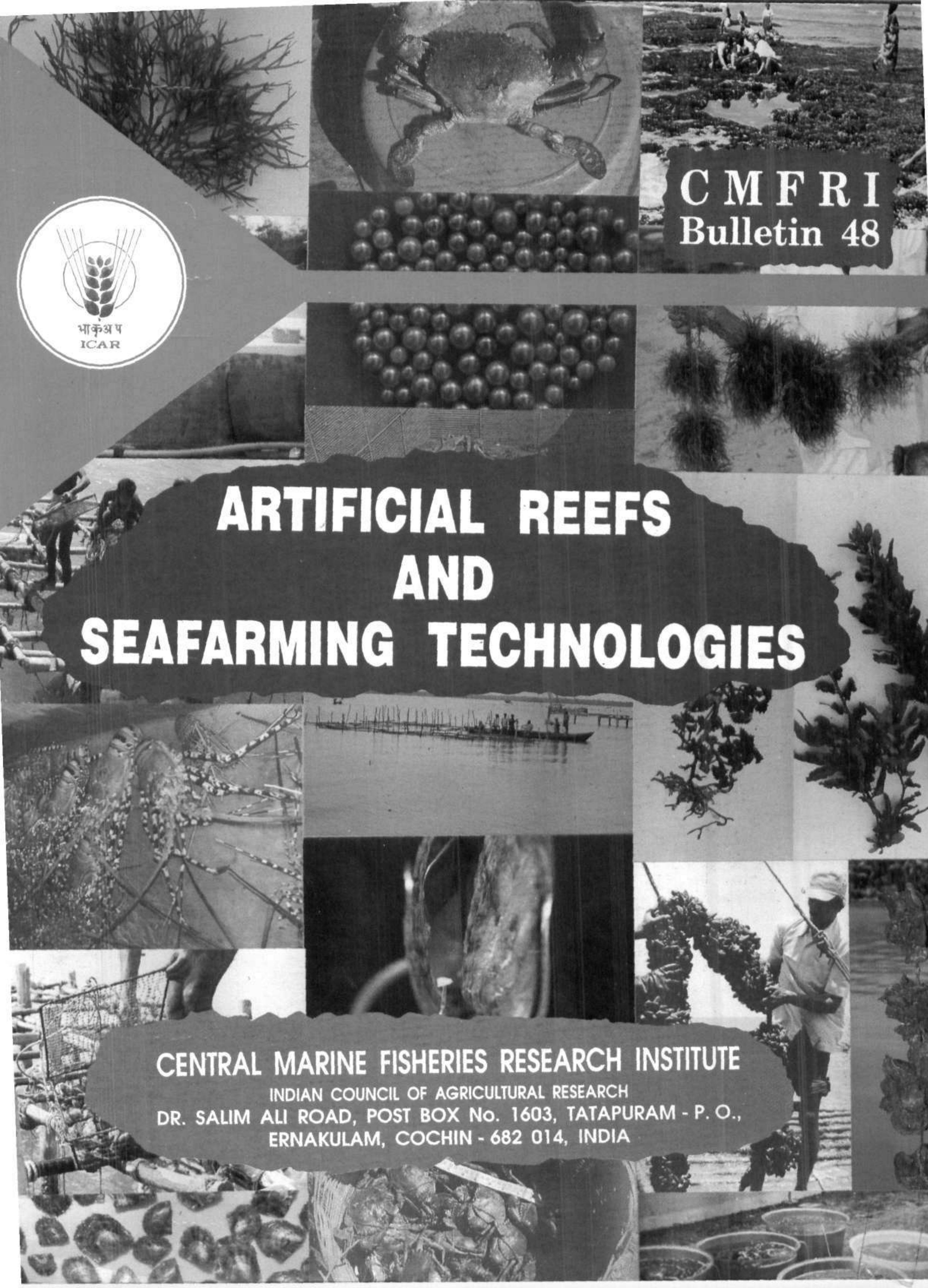

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ARTIFICIAL REEFS AND SEAFARMING TECHNOLOGIES

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
DR. SALIM ALI ROAD, POST BOX No. 1603, TATAPURAM - P. O.,
ERNAKULAM, COCHIN - 682 014, INDIA

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DR. K. RENGARAJAN

Editor

January 1996

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PREFACE

The nearshore waters of India along the 8060 km coastline support lucrative fisheries contributing about 90% of the total marine fish landings of the country. The brackishwater ecosystems also afford capture fisheries of some magnitude, besides traditional cultue fisheries in certain maritime States. We have an area of 9 million hectare of inshore waters of less than 18 m depth and 1.7 million hectare of brackishwaters in the adjoining coastal zone. Increasing interest is being evinced in the optimum utilization of these water resources by augmenting their productivity through artificial reefs and seafarming. The objective of developing artificial fish habitats is basically to improve 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 SE 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 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 Indian Federation of Fishermen, Thiruvananthapuram, (iii) The Waves, Madras and (iv) The Centre for Research on New International Economic Order, Madras. The ***Central Marine Fisheries Research Institute*** is at present setting up an artificial reef comprising of 100 concrete modules at a shallow area of 10 m depth off Chellanam in Ernakulam District.

The Institute has developed various marine fisheries and mariculture technologies over the past five decades since 1947. These technologies are popularised through onfarm trials, workshops, seminars and training programmes suited to managers, technicians, entrepreneurs, fishermen and farmers. The technologies of marine prawn hatchery, prawn farming, pearl oyster hatchery, pearl oyster culture, pearl culture, edible oyster hatchery, edible oyster farming, seaweed culture & utilization, sea-cucumber hatchery, sea-cucumber farming, crab hatchery, and crab farming have already become very popular. The Institute has established a total of seven seafarms one each at (1) Andhakaranazhy near Cochin for mussels 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, and (7) at Darmadam near Calicut for edible oyster and 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 state-of-the-art of these technologies and the commercial potential of these technologies are dealt with in this Bulletin for the benefit of the participants of this workshop on "Artificial Reefs and Seafarming Technologies" and other users.

I take this opportunity to thank Dr. Y. S. Yadava, Fisheries Development Commissioner, Ministry of Agriculture, Government of India for sponsoring the workshop on Artificial Reefs and Seafarming Technologies at the appropriate time and for entrusting the same with the CMFRI. I record my sincere thanks to the authors of the papers published in this Bulletin. I also record my special thanks to Dr. Robert V. Kemper, Editor of the *'Human Organisation'*, Journal of the Society for Applied Anthropology, for their kind permission to reprint an article by Dr. John Kurien. I record my appreciation to Dr. V. K. Pillai, Senior Scientist & Officer-in-charge, Trainers' Training Centre for organising the workshop in an excellent manner in all aspects. I wish to thank Dr. K. Rengarajan, Senior Scientist for editing this Bulletin and getting it ready in time.

Cochin 682 014,
6th January 1996.

M. DEVARAJ
Director

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ARTIFICIAL REEFS FOR A SUSTAINABLE COASTAL ECOSYSTEM IN INDIA INVOLVING FISHERFOLK PARTICIPATION

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Introduction

Forty countries on six continents, are using the artificial reef technology today. Artificial reefs are reported to increase fish catches by 20 to 4000%, prevent overfishing and "with greater awareness of the world's deteriorating marine environments, there is increasing reliance on artificial aquatic habitats in the world" (Grove and Sonu, 1991). When natural reefs like coral reefs and rocky reefs in tropical coastal waters are known for their high biological and fishery productivity and diversity, why not artificial reefs accomplish the same? Artificial fish habitats are of two types, benthic Artificial Reefs (ARs) to attract demersal fish and Fish Aggregating Devices (FADs) to attract column as well as pelagic fish.

Experiments with artificial reef technology

Traditional artificial fish habitats in India

Traditional artificial fish habitats on the Coromandel Coast were first described by Hornell (1924). Bergstrom (1983) reviewed the fish aggregating devices of India and the Southeast Asia. Some of these traditional practices are still in vogue even today. Branches of trees, weighted with rocks as anchors, are dumped into the sea by artisanal fishermen on the coast of Tamil Nadu. They serve as artificial reefs (ARs) called *Mullom* in Tamil and are fished with a hook and line. Similarly, coconut fronds, tied at 1 m intervals along a rope, like a bottle-brush, are suspended from a float and anchored to the seabed with a weight, are called *Kambi* in Tamil and they serve as a Fish Aggregating Devices (FADs). They are fished by four catamarans from four corners, using a square lift-net (bag net) *Mada valai* or *Ida valai* in Tamil.

Traditional knowledge and experience of fishermen is amazing concerning these artificial reefs and fish aggregating devices. Specified areas of the coastal waters are traditionally used, for installing artificial fish habitats, by specified fishing families of the nearest village, through a traditional system called *Seppaadu*, approved by the village panchayat. The species of tree preferred for its trunk or branches as reef material is the Tiger bean *Delonix elata* (Family Ceasalpinaceae) called *Konnu maram* or *Vaadanaaraayana maram* in Tamil. Fishermen believe empirically that the bark of this tree when it rots in seawater, emits a foul stench which acts as a fish-attractant. Chemical analysis of this bark yields the aminoacid L-asparagine, aspartic acid and sucrose acetate, which are known to be fish-attractants (Hariharan, 1969). Through long experience, fishermen know that rocky reefs called *Paarai* in Tamil, and slushy or muddy areas called *Cheru* in coaster waters are biologically and fisheries-wise more productive than barren sandy areas called *Tharai* in Tamil. They are also aware of the fact that these artificial fish habitats, using green vegetation are bio-degradable and hence eco-friendly, although they are short-lived, warranting recurring costs for the poor fishermen.

Modernising the traditional artificial reefs

In order to experiment with modernising these traditional artificial reefs, used extensively by the fishermen of the Periya Neelangarai Kuppam, a fishing village about 25 km south of Madras, on the Madras-Mahabalipuram Road, first of all, the author to obtain the unanimous consent of the village panchayat. Then the technology of the modern artificial reefs (*Naveena mullom*) as the fishermen call it, was explained to the fishermen, through the Participatory Rural Appraisal (PRA) technique.

Seventeen fishermen volunteered to experiment with the modern artificial reef technology. First the author worked with traditional reef technology itself, in order to obtain baseline data on the fishing potential and composition at a reef on the coast, as well as to gain a good rapport with these traditional fishermen. Seven different species of locally available trees or their branches were used as reef material, but found that their traditionally preferred one, namely the Tiger bean yields the best fish catches (Sanjeeva Raj, 1989).

Then it was got the volunteering team of fishermen, through the PRA technique to draw a map of the floor of the sea, against their village, upto 4.5 km (Sanjeeva Raj, 1990) to choose the right sites for installing artificial reefs on the seabed.

In order that these artificial reefs are rendered more durable and less destructive to green trees, as in the traditional technology, concrete well rings as reef materials were substituted. In February 1988, about 150 concrete well rings, each about 60 cm in diameter and 30 cm in height, were skillfully let down along two polythene ropes, as beads on strings, to a depth of about 20 to 25 m and about 2 km away from the shore. They formed a rough pyramid, with a circular base of about 4 m in diameter, and about 1.5 m in height at the apex (Sanjeeva Raj, 1989, 1991). This reef is surviving intact even to this day, seven years after its installation, yielding heavy catches, and proving that the older the reef the more productive it would be.

Ecological, economic and social benefits

Ecological benefits

Using hook and line, during the day time, with prawn as bait, 25 species of teleosts belonging to 18 families, were caught at this reef, during the first three years from March 1988 to February 1991 as per the data maintained by the participating fishermen themselves. At any one time, four to six species of fish could be fished at the reef. Species composition and dominant species varied according to the season. Catch per unit effort (CPUE) and income per unit effort were calculated. Ecological succession at the reef was studied. Species like *Alepes (Selar) mate* (Vari Paarai in Tamil) and *Carangoides malabaricus* (Kuzum Paarai) were dominant during the premonsoon months, but large (1 m long) *Rachycentron canadus* (Kadal Veraal) were dominant during the summer months. Today, after seven years of habituation, an amazing variety of large fishes such as the rabbitfish, parrotfish and large croakers, which were earlier available only at the submarine mountain (*Paniyur Malai*), opposite the fishing village Paniyur Kuppam, have now migrated to this artificial reef, having accepted it as a natural rocky reef. Six to eight of these 25 species recorded at this reef might be breeding right at the reef, as their fry and fingerlings were collected in large numbers from amidst the coconut fronds of the column and surface fish aggregating devices (FADs), supplemented at this reef.

Artificial reefs are eco-friendly technologies. Ecologically, a rich succession of marine life, not only as encrusting biofoulers on the concrete substratum takes place, but also a succession of fish fry, fingerlings and adult fish colonise this reef for shelter, feeding and breeding. New food-chains are formed at this reef. Cuttlefish and squids deposit voluminous egg-masses amidst these concrete modules, and crabs and lobsters crawl on their surfaces. Algae, bivalves and barnacles literally choke the hollow of these concrete rings, and from a catamaran, one can even hear the snapping of the valves of the Giant Barnacle *Balanus tintinabulum* so abundant characteristically on the Mahabalipuram Coast. Such is the rich biodiversity promoted by these artificial reefs. Indian coastal waters which are so much devastated by mechanised trawlers since the past four decades, can thus be revitalised through these artificial reefs.

Not only such recolonisation of the coastal waters at the artificial reefs, but also the breeding or reproductive potential of coastal organisms can be enhanced at the reef, and thus coastal fishery stocks can be restored to their original levels, through artificial reefs.

Economic benefits

Artificial reefs are low-cost or appropriate technologies, so that even the poorest of the poor artisanal fishermen who cannot afford a net, can easily afford a hook and line, to earn his daily bread. Artificial reefs of concrete modules are one-time investments, with no recurring costs for fishermen. Cost-benefit-wise, artificial reefs are incredibly remunerative.

Artisanal fishermen can be trained to contribute and share the cost of artificial reefs, for the village cooperative.

Social benefits

Artificial reefs are best operated only as common properties of the whole fishing village community. Since the whole community participates in installing them, the whole community has the right fish at the reefs. This incidentally helps to build up the solidarity of the fishing village community, without any disparity between the richer and poorer fishermen, within the village.

Artificial reefs may help to prevent the entry of mechanised trawlers into the coastal waters and would thus minimise the long-standing feuds between artisanal and trawler fishermen.

Constraints

Artificial reefs would work well only as common property resources of the whole fishing village, but not as individual or family properties, lest there are fights within the village itself, for fishing rights at the reef.

Fishing villages wherein some or all of the fishermen own mechanised trawlers, or villages in close proximity to a fleet of mechanised trawlers, will not opt for artificial reefs, as they would obstruct or damage the trawler nets.

Fishing villages with natural rocky or coral reefs within their fishing territories also may not opt for artificial reefs, as they would be superfluous and would not make much difference from natural reefs.

Close to fishing harbours or to passenger or cargo harbours, adjacent to coastal jetties, oil-rigs and pipe lines, intake sumps of power plants and along navigation routes, artificial reefs would not be allowed.

Future prospects

Lot of basic research still needs to be done at artificial reefs, through scuba-diving and underwater photography, to study the reef profile, ecological succession, biodiversity of the reef communities, carrying capacity for each species, breeding potentials and population structures, maximum sustainable yields, detoxification and cleaning of coastal waters from its pollutants and alternate reef material out of wastes, etc.

Fishing regulations to avoid over-fishing, and fishing of breeders during their breeding season, fishing within the norms of the Maximum Sustainable Yields (MSY) and periodic renovation and regular maintenance of the reef should be enforced among the participating fishermen, as their joint responsibility.

Artificial reefs could be developed as tourist centres also, for game-fishing with hook and line, scuba-diving, underwater photography and for other eco-friendly aquatic sports.

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ARTIFICIAL REEFS HABITAT ENHANCEMENT AND INCREASING FISHERIES POTENTIAL

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Introduction

Artificial reefs are used throughout the world to increase the fisheries potential of barren or relatively unproductive areas. Artificial reefs also act as effective fish attracting devices during certain times of the year. Reefs when properly located and structured not only concentrate fishes, but also increase the biological productivity of the area. Formation of rough rigid bottom habitat with artificial reefs of diverse materials increases the surface area necessary for fish food organisms. The reefs also often serve as spawning habitat and shelter for fishes and shellfishes.

Artificial reefs also act as an ideal tool of rehabilitation or enhancement of areas impacted by overfishing and bottom trawling. The artificial fish habitats established by the traditional fishermen of the Southwest coast of India, particularly off Trivandrum and Kanyakumari Districts, since the beginning of eighties, have been models of regenerative process of depleted fishery wealth in the coastal waters.

Artificial reefs

Artificial reefs are natural or man made external objects or stable structures placed in the sea to provide an artificial fish habitat and thereby to attract, aggregate and regenerate pelagic, demersal, migratory and residential fishes. An artificial reef develops into a fish habitat when barnacles, algae, oysters, mussels and other sessile organisms colonise the reef as they do any firm surface in shallow water. The process by which the organisms invade a previously uninhabited area, is known as Ecological Succession. It begins with an accumulation of bacterial slime. Benthic diatoms and protozoans appear next. They multiply rapidly. Hydroid and multicellular algae follow and then come the planktonic larvae of barnacls, mussels and snails. Eventually the ecosystem reaches a balanced state or climax community, inwhich no further colonisation occurs and ecological succession ceases unless a disturbance of the system causes the process to start afresh.

Origin and development

It was known to the Japanese fishermen since the ancient past that alien objects placed in water cause aggregation of fish and prompt growth of seaweeds. The oldest written records shows that in 1650 reefs were constructed by placing rocks in the water. Later records show that this practice has been used in many areas of Japan. However in the post world war II period artificial reef programme was developed into a long range programme for fishing ground construction and it is reported that presently Japan spends nearly US $ 3 billion on this programme.

The artificial reef programme of United States dates back to 1860 and at present there are about 300 highly productive artificial reefs in US coastal waters supporting from sport fishing to commercial fishing. In most of the western countries Artificial Reef Programme attained significance in the post world war II period only, however, reef building technology gained so much attention these years and presently reefs are increasingly designed for specific resources.

As an age old practice, traditional fishermen of Trivandrum Coast operating shore seines used to dump rocks fastened with coconut fronds into sea bottom to attract fishes closer to the shore. Occurrence of large fish shoals in areas of sunken ships and boats were known to the traditional fishermen for many decades. The sunken ship, off Anjengo fishing village 45 km north of Trivandrum

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at 45 m depth matured into a rich Artificial fish habitat and is a very good fishing ground for perches, carrangids and a number of other fishes. The first recorded artificial fish habitat construction was off Puthiathura in 1953 and subsequently off Eraviputhenthura (Kanyakumari Dist.) in 1957. However, an organised effort to construct artificial fish habitats and artificial reefs was made only from 1980 onwards. The declining trend of the coastal resources and reduction in the catch per effort was the first catalyst to start this programme. The Government of Kerala recently implemented two artificial reefs off Parithiyoor and Kollamkode (Pozhiyoor) using ferro-cement triangular structures and was found to be highly effective in habitat enhancement and fish aggregation.

The recent developments in the Artificial Reef Programme across the world show the increased awareness for habitat regeneration. Purpose built Artificial Reefs are now fairly frequently placed either on damaged reefs or on the sea bed near the natural reefs. By creating additional habitats, they allow a greater number of larvae to settle, seek shelter and survive predation.

Design and construction of Artificial Reefs

The productivity of an Artificial Reef is found to be directly related to the size, shape and height of the reef. As the experience accumulated with time, it was realized that the concept of artificial reefs may be enlarged to a scale sufficient to create new fishing grounds in areas were none had existed.

The first generation reefs were installed utilizing locally available materials such as rocks fastened with coconut fronds, coconut stumps, bundles of coconut and screwpine leaves. These were randomly dumped by the fishermen at selected sites. It was found that coconut leaves, screw pine leaves and coconut stumps when decayed, help plankton and other organisms grow around and on them, which attracts large number of smaller and bigger fishes into the area. However, a basic drawback with this random dump and hope method was that the reef didn't have the desirable shape, size or height. According to fishermen, productivity was very low in these reefs. The next organised effort was at Shanghumugham where the reef was established at 10 m depth with 3 m height. The materials used were rocks fastened with coconut fronds, rocks placed in net bags, concrete well rings, old used tyres, old autoparts, etc. It was found that high structures like well rings provide shade and shelter for fishes and other organisms. This reef was found to be the most productive reef of traditional design. But two problems faced with all these were the sinking of the Artificial Reefs and the unsystematic distribution of the reef components. Another problem was the limited height of the reef structure. It was at this stage that the Intermediate Technology Development Group of London deputed one of their Engineering Consultants to India and after extensive consultation with the users, scientists and representatives of NGO's, a triangular module of 1.5 m size was designed, fabricated and placed underwater. Although a number of designs were experimented the triangular ferrocement modules were selected due to the following advantages.

1. The total weight of the module was only about 150 kg, hence handling and placement was very easy.
2. The width, height and length of the module was all 1.5 m and hence the structure was relatively stable and provided maximum surface area for epifaunal growth.
3. The design of the module helps to function as an effective unit in the Artificial Reef whichever position it reaches the bottom.
4. Because of the low cost, ferro-cement modules were highly economical.

Triangular structures were used exclusively for the Pozhiyoor reefs and the subsequent reefs at Valiathura and Shanghumugham. At Pozhiyoor 50 modules were used in the reef building. Experiments have shown that the size of the fish schools increases with the area and size of the Artificial Reefs. Hence the new reefs are being designed with 2.15 m height, also the number of the modules in the reef is also being increased. The ratio of structural height to water depth has been studied and it was found that a minimum ratio of 1:10 is required for good aggregation of pelagic fishes.

Placement of the reef modules

The placement of the reef modules were done with the active involvement of the local fishermen who have excellent knowledge of the sea bottom. Over the years they have built up a most detailed mental map of the sea bed. The technology for placement of the modules were also developed with the help of ITDG, London. A twin boat arrangement with a guadrupod in between the boats, connecting centrally, and a pulley and rope in the middle was the module handling, and placing structure. The Kattamarams ferried the modules from the shore to the reef site. The Kattamarams were placed underneath the quadrupod, in between the boats, and the modules were lifted off, and after the Kattamaram moved on, lowered to the sea bottom and placed. By adjusting the anchor lines placed at the four ends of the boats, the modules were placed one after the other and also in clusters. Bundles of coconut leaves were placed inside the modules for helping the units to attract fishes and cuttlefishes to the area.

Most of the reefs are established in the east-west direction cutting the water current along the coast, so as to provide shelter and maximum protection to the shelter seeking organisms.

Fish aggregation and fishery in the Artificial Reefs

The fundamental question as to what attracts the fish to the reef remains unanswered. Population dynamics associated with a reef involving intra-species, inter-species and oceanographic interactions also remain unresolved. Yet it may be generally stated that alien objects of virtually and kind placed in the water would cause some form of fish congregation.

Some fishes attracted to a reef throughout their entire life cycle, whereas others seem to exhibit the behaviour only during part of their life. Of the reef related species some may be called "upper fish" or "lower fish" as they respond vertically to a reef, whereas some may be called "migratory" or "residential" fish as the response of these fish is horizontal. Some fish species may only "drop by" or "visit" a reef, whereas others "settle down". Some species would live "off" the reef, some "by" the reef and others "within" the reef.

According to the behaviour pattern, reef attracted fishes can be generally categorised into the following groups.

1. Those species which prefer strong physical contact with their bodies against a hard object *e.g.* Moray eel.
2. Those species which like to remain in physical touch with an object, with pectoral fin or belly. Mostly sedentary fishes *e.g.* reef cods and rock cods.
3. Those species which like to remain in close proximity to a hard object without really touching it *e.g.* most reef dwellers such as parrot bass, snappers, breams and coral fishes.

Once attracted to a reef, the fish tends to assume a particular position relative to the reef depending upon the species. Their behaviour can be classified as follows.

a. Upper- and mid-layer swimmers which exhibit a tendency to congregate over the fishing reefs, remaining in the upper layer as a school. *e.g.* mackerel, big-eye scad, carangids, baracudas and smaller perches.

b. The bottom - layer swimmers which gather around a fishing reef, but without exhibiting a sedentary behaviour. *e.g.* apagonids, coral fishes, butterfly fishes, etc.

c. Sedentary fishes which inhabit crevices and holes in the reef. *e.g.* eels, lobsters, reef cods, etc.

Aggregation of fish in areas of newly established reefs was estimated by the fishermen in terms of the catch they were getting from the reefs. Many of the reefs along the Trivandrum Coast were established by small community groups and is opened to fishing only to the particular group.

Coconut leaves and screwpine leaves are dumped in the reefs mainly to attract cuttle-fishes. Decaying leaves attract large number of cuttlefishes to the areas and provide ideal environment for the females to lay their eggs and for the juveniles to spend thier early life. According to many fishermen, they start fishing only after the juveniles are sited in the reefs. Such reefs are locally called as "Kanavamada" meaning cuttlefish habitat. The presence of egg masses and juveniles clearly shows that reefs are not only aggregating cuttlefishes, but also provide excellent nursery grounds for the juveniles.

Most of the 31 Artificial Reefs are reported to be excellent fishing grounds for sepia, loligo, serranids, carangids, Big-eye scad, mackerel, goatfishes, white snappers, red snappers, etc. However, the predominant group caught from the reef is cuttlefish.

An underwater study of the reefs along the Trivandrum Coast by the Oceanography Department of Southampton University and Central Marine Fisheries Research Institute had proved that inspite of the smaller sizes of many of the reefs, they act as excellent habitat enhancement units and aggregates large number of fishes. The underwater video records and photographs showed the large-scale aggregation of ornamental fishes of the families *Apogonidae, Pomacentridae, Chaetodontidae, Caesionidae, Labridae, Callyodontidae, Zanclidae, Acanthuridae* and *Scorpionidae.* Crabs and lobsters are also noticed in the Artificial Reefs.

The epifauna collected from the reef modules revealed the presence of large number of pearl oyster *Pinctade fucata*, the chank *Zancus pyrum* and corals.

The biomass estimation of the Pozhiyoor reefs showed a unit biomass of 2.48 gms per cm^2 over a period of 9 months. Comparable studies showed that this is one of the highest productivity observed. From a study for one year it was found that the seasonal income of a fisherman from fishing in the reefs ranges from Rs. 2785 in Kollamcode to Rs. 4050 in Parithiyoor. On a percentage-wise analysis of the catch, it was found that the reef fishermen's catch was nearly 20% higher than that of non-reef fishermen.

Future prospects for the Artificial Reef Programme

Artificial Reefs are considered to play significant roles in revitalizing the aquatic environments which have been damaged by developmental projects and overfising. Such roles of the artificial reefs are particularly well appreciated by the artisanal fishermen who use traditional hooks and lines, long-lines, etc.

Artificial Reefs can also play a vital role in sea-ranching of groupers, perches, lobsters, etc. Releasing of juveniles of these fishes in reef complexes will help them to survive, flourish and reproduce better. Reefs also help to establish new fishing grounds where none had existed earlier and thereby increases the employment opportunity and income of the traditional fishermen.

Finally it may be noted that in the process of ecological destruction, it is in the tropics that the battle to preserve "Bio-diversity" will be won or lost. Artificial Reefs and Artificial Fish Habitats are great steps forward in the march for 'Eco-technology'.

Acknowledgement

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FISH AGGREGATION DEVICES AND ARTIFICIAL REEFS

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Introduction

The principle of fish aggregation is based on the tendency of fish to concentrate around floatsam and sunken structures for food, shade and shelter (hide-out from predators). The technology is quite popular in Japan, Philippines, United States of America and the Pacific Island countries, and has been in vogue for a long period. For the first time in India this technology was introduced through the pioneering efforts of Raja (1986) who designed and fabricated an indigenous Synthetic Fish Aggregating Device/Artificial Reef (FAD/AR) made from High Density Polyethelene (HDPE) - Patent Registration No. 650/MAS/87. The results of preliminary experiments were highly encouraging and were presented by Raja (1986). Subsequently, all aspects of the FADs/ARs were discussed in detail at the National Fishermen's Forum meeting held at Bangalore, and was well received and appreciated by the participants.

Structure

A single unit consists of a multisided 'hut' shaped frame made of HDPE pipe which were sealed at both ends by heat treatment (extrusion welding) and joined together with nuts and bolts.

Attractants/Appendages are comprised of HDPE pipe pieces, used automobile tyres and HDPE netlon cones. Plastic strips (black and green colour) are also attached to these attractants to increase their visual attraction.

Anchors are attached to the four corners of the structure. In addition, stones are also attached to provide the structure with maximum stability, so that it can neither drift away nor be shifted from the site of installation. The structures can be installed on the sea-bed ranging from 2 to 4 m in depth, 5-10 km from the shore.

Five such units, tied to form a pentagon, can be installed to form an artificial reef. To identify the location of the sunken structures, marker buoys are attached to them by means of varnished steel chains.

Benefits of FADs/ARs and other applications

Trials have shown that the installation of FADs enabled thousands of cephalopodes to colonise on these submerged objects and algae also proliferated over them. This provides an excellent environment for various types of marine organisms to grow and thrive, producing further link in the food chain. Moreover these structures in due course of time become good fish habitats enabling a variety of fishes to use it as a safe breeding ground. Observations have shown that about 18 species of fish which were not found in the inshore waters, have been attracted and captured around these structures. Most of them were predatory bigger fishes and commercially important varieties.

These devices can also be used as a mechanism to demarcate territorial waters for the artisanal fishermen. The day-to-day problems and conflicts of the traditional fishermen with the mechanised boat operators can be solved by forming a semicircular installation of these structures covering 3 to 5 coastal fishing villages.

A welcome bonanza from the FADs/ARs

During March, April and May 1992, the artisanal fishermen of the fishing villages of Injambakkam near Madras, were pleasantly surprised to find an increasing share of squids and cuttlefish in their catch, whenever they fished nearer to the FADs/ARs installed, about 8 km off the coast.

But, to the personnel of "THE WAVES", which had in the first place installed these FADs/ARs in Injambakkam this phenomenon came not as a surprise, but as vindication of the results of their earlier experiments with these structures.

During the initial experiments with FADs, various designs and attractants were tried out. One factor that caught the attention of the author, who conceived the idea, designed and conducted experiments with the FADs, even during the early trials, was the large amount of cephalopod eggs found in the netlon cones attached to the main frame. It was opined that these eggs would initially act as an additional attractant to various fishes and in the later stages contribute to the formation of an habitat for the cephalopods themselves. This is exactly what has taken place in Injambakkam.

It is now a proven fact that the FADs/ARs installed by "THE WAVES" are instrumental not only in aggregating the inshore fishes, but also in attracting various commercially important varieties of deepsea fishes to the nearshore waters, especially to the vicnity of these submergd structures.

The capture of cephalopods in appreciable quantities from the area surrounding these structures has yet again emphasised the capabilities of the FADs/ARs and has infact opened up new economically important vistas for the marine artisanal fishermen.

A detailed survey of the gear used, the method of operation and the season best suited for cephalopod fishing were conducted by the author's team in collaboration with the local fishermen.

Gear

The gear is locally known as the 'Manivala' and basically comes under the category of bottom net, trammel nets. A typical net of this type consists of three separate pieces or units that are joined together end to end at the time of operation.

Each unit is about 35 to 40 m in length and around 2 m in depth. It is made up of two outer walls of large mesh netting and a central wall of finer twine and much smaller mesh size. The outer walls (armours) are almost half the depth of the central wall (lint). The fishing principle is that the fish or squid while swimming, inadvertantly hits the lint (inner wall) which is then pushed through the armous (outerwalls) to form a pocket in which the animal is trapped.

The head rope is made of two polyethelene ropes of 3 mm diameter and are provided with a number of PVC floats (30 mm diameter and 10 mm thickness) and the meshes of the lint are equally distributed between them, the mounting being done in simple reaving method. The foot rope bears a number of lead weights as sinkers, at the rate of three sinkers for every float.

On the top and bottom, on the lint, there are selvedges of three meshes depth and made of thicker twine. The material used for the inner and the two outer walls are nylon. The armours (outer walls) are attached to the last row of meshes of the selvedges of the lint (inner wall).

Craft

The craft used is the traditional Kattumarans which are quite popular especially along the east coast. They are the best suited to negotiate the choppy waters of this region.

Operation

Two fishermen in each Kattumaran carries one full length of net consisting of three separate units, each of 35 to 40 m and joined together end to end. The fishermen paddle out to the vicinity of the FAD/AR at about 6 o'clock in the evening and on reaching the ground set their net about 50 m away from the FAD/AR. The net is simply payed out starting with one and with the craft kept moving in the opposite direction. To mark the nets each group employs thermocoel buoys, with different ensignia and colours, attached to either ends of the net. The net is then left in the sea and the fishermen return to the shore. The net is left overnight to fish and the hauling is done usually in the early hours of the day.

The catch are mostly found entangled in the pockets formed by the middle layer in the meshes of the outer layers on either side.

Catch

During the season the fishermen usually get around 20 to 25 kg per day per craft. During the beginning and ending of the season, the catch is low with 8 to 10 kg per day per craft. The cephalopod catch is sorted and sold in two size categories - those weighing less than half a kg and those weighing more than half a kg, fetching an average price of Rs. 22 and Rs. 26/kg respectively (as reported by the local fishermen). But in the open market the price is more than Rs. 40/kg. Other catches in the net are usually perches and prawns.

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4

ARTIFICIAL REEF RESEARCH IN MINICOY, LAKSHADWEEP*

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Artificial reefs are man-made underwater structures that provide habitat for many types of fishes. Fishes are attracted towards artificial reefs because the reefs shelter the fish from predators and make good feeding sites. The creation of man-made structures to enhance marine resources is the basis of a specialised branch of marine technology known as artificial reef development.

The dependence of pole and line tuna fishery on the availability of live-baits has been well documented. For successful tuna clipping, availability of desired species of live-baits in required quantity at correct time and space are prerequisites. At Minicoy, where CMFRI has been undertaking investigations on tunas and tuna live-baits, it was observed that the availability and abundance of live-baits evinced changing pattern in the recent past due mainly to the ecological stress such as environmental deterioration, fluctuations in the seasonality of migrant live-bait species and over-exploitation of the bait fish resources consequent to the introduction of mechanised vessels in tuna fishery.

The major habitats which harbour reef fishes including live-baits at Minicoy are the reef flat, reef front, inner lagoon shoals and sand flat. The association of major bait fish species with different types of corals *viz.*, corymbose, pedicillate, ramose and flabellate types in this ecosystem has been documented earlier. However, at present, the lagoon of Minicoy is a modified ecosystem compared to that of two decades ago. Large number of corals, especially the Acropora thickets were found to have suffered mass mortality during the late seventies. Excessive silation and sedimentation resulted from the deepening of the boat channels and subsequent influx of water coupled with greater degree of accretion were the major causative factors for the mass destruction of corals, and subsequent deterioration of baitfish habitats in the southern part of Minicoy Lagoon. It is in this context that CMFRI at Minicoy started experimental investigations with artificial reef structure (ARS) with the objectives of concentrating tuna live-baits in a limited area and thereby improving fishing opportunities, and providing improved habitats for these fishes by capitalizing on the relationship between available living space and the abundance of marine resources. This study forms one of the technical programmes under the Institutes' Research Project on investigations on tuna live-baits in Lakshadweep.

Fig. 1. Preparation of R.C.C. with rod holders.

Artificial reefs are man made underwater structures that provide habitat for many types of fishes. Fishes are attracted towards artificial reefs because the reefs shelter the fish from predators and make good feeding sites. Epizoic and epiphytic organisms, zooplankters, smaller fishes and many other members of aquatic food chain find a home within or around the reef. The creation of man made structures to enhance marine resources is the basis of a specialised branch of marine technology known as 'artificial reef development' through which fishes could be concentrated within a smaller area, by offering an

* Reproduced from the *CMFRI Newsletter*, 1988, 41 : 4 & 5, with the permission of the Director, CMFRI, Cochin 682 014.

increased food supply. The first artificial reef was built before 1790 in Japan by commercial fishermen and the Government there has granted subsidies for reef construction since 1930. In 1985, over 200 artificial reefs have been constructed along the U.S. coastline and recently, the U.S. National Fishery Enhancement Act mandated the development of the National Artificial Reef Plan in ocean fish fishery development and ocean resource management.

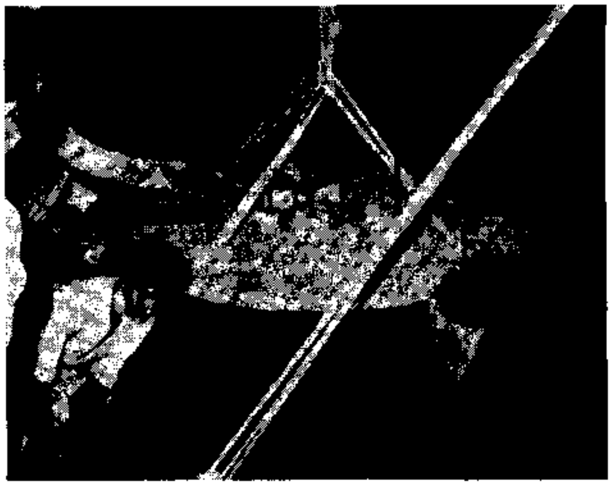

Fig. 2. R.C.C. base being installed.

The artificial reef structure employed for the investigation was designed by the author and fabricated with the assistance of the Lakshadweep PWD at Minicoy. It consists of a 2 m diameter, three-inch-thick RSS slab base on which twelve vertical M.S. rod holders of 10 mm thickness and 1.9 m length are fixed at regular intervals. Fourteen discarded car tyres, arranged in five rows and 6 x 4 inch size wooden block separators are interlocked by these vertical rods. A total number of sixtytwo 3 x 2 inch size wooden pieces are used to maintain the gap along the inner periphery of tyres. The M.S. rods are bent well above the tyres thus providing a locking device for the entire structure. The structure has a total height of 1.2 m. The ARS was instaled in the area between Tunda Point (southern end of Minicoy) and Viringili on 21st November 1988, where considerable damage to the accroporid corals was reported.

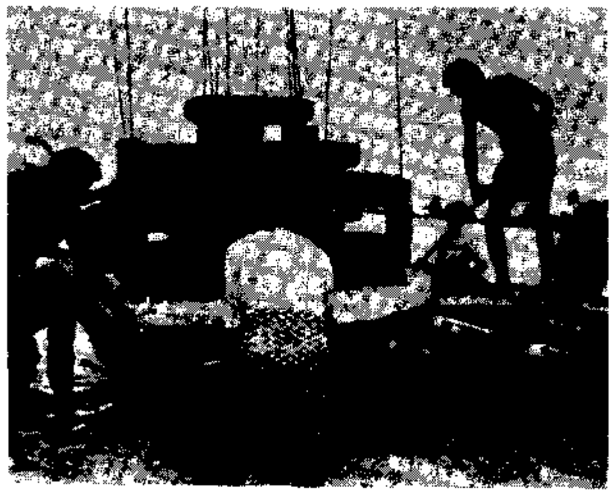

Fig. 3. The artificial reef structure.

Subsequent monitoring of the aggregating nature of the ARs with its age by the author and Shri T. M. Yohannan, Scientists at the Minicoy Research Centre of CMFRI revealed that within fifteen days of reef age, filamentous algae and zooplankters such as mysids and copepods started accumulating profusely on and around the reef structure. Colonisation of the reef structure, by fishes such as *Caesio pisang*, *Dascyllus aruanus*, *D. trimaculatus*, *Abudefduf semifasciatus*, *Chaetodon auriga* and *Thalassoma unbrostigma* have started from the 35th day of reef age. Recent introduction of *Chromis caeruleus*, a resident bait species to the ARS was found to be successful thereby proving the effectiveness of CMFRI's attempt in this line of technology. Encouraged by these results, the artificial reef development and deployment has been taken up as one of the priority programmes of the Institute at selected Centres.

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ARTIFICIAL REEF AND ITS ROLE IN MARINE FISHERIES DEVELOPMENT

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Introduction

Floating bamboo bundles and piles of stones kept on the sea bottom have long been used by traditional fishermen as fish gathering devices in various parts of the world. These objects provide living space, shelter for protection from the predators thus functioning as (i) a habitat for organisms. The attached algae and other sessile organisms serve as food especially for young ones. Thus the area where such objects are placed function as (ii) a feeding ground. These objects also act as a suitable substratum for attachment of eggs in some cases thus functioning as (iii) a spawning ground. Based on these principles artificial reefs are constructed in different parts of the world either to create a new fishing ground or to improve the production potential of the existing grounds. Although the construction of artificial reefs has been taken up as a Government sponsored programme in many countries, particularly in the Southeast Asian countries on a commercial scale, in India the work is still in a preliminary stage with only a few voluntary organisations and fishermen society taking some interest. In Japan for instance, annually $ 100 million is spent on artificial reef technology under Government's subsidiary project called the Coastal Fisheries Structure Improvement Project. Annually, about 60 million cubic feet of artificial reefs have been installed in recent years. According to the surveys taken since the beginning of the National Artificial Reef Programme, the productivity index in Japan has been estimated to be as high as 50 kg of fish per cubic metre of reef volume. India with a long coast line of over 6100 km can also significantly increase its marine fish production by constructing artificial reefs in certain selected places along the coast.

Types of Artificial Reefs

Artificial reefs may be broadly classified into two categories *viz.* (i) Artificial reefs set on the bottom and (ii) Artificial reefs floating on the surface or subsurface.

Artificial Reefs set on the bottom

Traditional fishermen have been constructing artificial reef on the floor of the sea by sinking boulders, discarded building materials, etc. in certain parts of the world and they have noticed an increase in fish catch. This is primitive method of artificial reef construction. Scientific method of artificial reef construction includes designing of suitable structures from materials such as steel and concrete, based on the results of the studies carried out on fish behaviour and oceanographic observations. Thus, the design, material and final dimension of the reef units are based on the species targeted, oceanographic characteristics of the area and other related considerations. The final structure of the artificial reef placed on the floor of the sea is thus a product of an interdisciplinary approach involving various branches of the science particularly engineering, oceanographic and biological.

Fish behaviour and reef design

Fishes respond to reef structures in different ways. The degree of such response has been termed as 'reefiness'. The behaviour pattern of certain species of fish allows one to design a suitable structure so as to attract that particular species. About 150 species of fishes have been recognized as showing clear response to reefs based on the behavioural studies carried out in Japan. Fishes orient their movements either through visual perception or through lateral line sensing of pressure variations in currents impinging upon the reef. The instinct called 'taxis', constitutes the fundamental linkage between the design of the reef structure and the fish. The various 'taxis' are (i) *geotaxis* - the fish tends to balance its body relative to the ground with the belly downside and the back to the light from above, (ii) *rheotaxis* - the fish tends to orient itself parallel to the current, (iii) *thigmotaxis* - the fish navigates relative to an object through physical contact or using its lateral line sensor, (iv) *phototaxis* - the fish responds to light and (v) *chemotaxis* - the fish responds to smell.

Fishes may be classified into five different categories depending upon their interaction with the bottom-set reefs.

Type I. Fish which always attaches a major portion of its body to solid objects *e.g.* eel.

Type II. Fish which attaches a part of its body *i.e.* pectoral fin or ventral surface to solid object *e.g.* rock trout, lionfish and grouper.

Type III. Fish which may not attach its body to solid objects, but needs to have solid objects close by all the times *e.g.* black seabream, parrot bass, opaleye ad coral-fish.

Type IV. Fish which does not necessarily need the presence of solid objects, but which will assume a steady position if some are there nearby *e.g.* horse mackeral, mackeral and yellow tail.

Type V. Fish which does not need the presence of solid objects at all, but it can assume a regular steady position in response to the stimulation of a floating object *e.g.* tuna, pike, salmon and trout.

Intensity of attraction of fish towards bottom-set artificial reef

The intensity of attraction of fish towards the artificial reef set on the bottom may be categorized as small, medium and large.

Small : Mackeral, mullet.

Medium : Seabream, surgeon-fish, filefish, parrot bass, grouper, yellow tail, cod.

Large : Eel, goby, flatfish, flounder, flathead, angler, lionfish, bullhead, rock trout, goatish.

Functions of Artificial Reefs in the life cycle of fishes

Artificial reefs play an important role in the lives of fish and have the following functions.

Artificial Reefs as habitat

It has been noticed during underwater observations that on seeing the diver the fish which were freely moving near the artificial reef structures, penetrated into the interior of the structures clearly indicating that the reef serves as a hiding place for such species. At times the fish remains at stationary position without even searching for food (*e.g.* rocky reef fish).

Artificial Reefs as feeding ground

The installation of artificial reefs creates a base for the attachment of algae and sessile organisms. These algae and sessile organisms serve as food especially for young fishes. In otherwords young fishes are attracted towards such places as food is available in plenty. Fishes like parrot bass and filefish feed on sessile organisms whereas grouper, flounder and eel confine themselves to the second higher level of the food chain by feeding on small fish. A close association between the seaweeds and fish larvae has been observed by many workers. Seaweeds have bountiful biota and have long been considered as an important nursery ground for fish and shellfish larvae. It has been reported that more than 150 species of fish appear in these seaweed beds. However, most of these species do not have any commercial value. Only about 30 species are commercially important. These species include seabass, wrasse, filefish, black rock fish, rock trout and greenling. Almost all these species spend a part of their larval stages in *Zostrea*. Some species like common horsemackerel, yellow-tail, amber jack, parrot bass, opal eye, rudderfish, rabbitfish, leatherfish, filefish, black rock fish, greenling and rock trout have been reported to occur in drifting seaweeds. However, most of these species leave the drifting seaweeds and move to a new habitat when they reach a particular size.

It has been reported that due to the formation of rip current in the vicinity of the artificial reefs the intensity of plankton distribution is very high which results in the attraction of plankton feeders in large numbers.

The density of sessile organisms in the reefs reaches its maximum after ten years of reef installation. It has been observed that the growth rate is faster initially at 60 m or deeper and after four or five years the areas at 30 - 60 m tend to have more rapid growth rate of the sessile organisms. Also, it has been reported that the growth rate of sessile organisms is faster in sandy bottom rather than in muddy bottom areas. Further the growth tends to be more rapid in open sea areas than in inner bay areas. It has been well established that the artificial reefs which have the highest growth density of sessile organisms, tend to be more effective in attracting fishes.

Diurnal changes in fish attraction

It has been reported that horsemackerel swarm in the bottom during day time, but disperse to the surface or midwater layers during night time. The swarming behaviour of larval yellow-tail and seabass in the artificial reefs is at its maximum during day time. Nocturnal fishes such as lionfish, remain in the crevices during day time, but become active in the evening and swarm around the reefs during night in search of food.

Underwater sound and its impact on fish behaviour

It has been observed that the lateral line sense organ of fish can detect a low sound of a few Hz, lower than 120 Hz. A low frequency sound will make the fish to position itself towards the direction of the origin of the sound and will make it to be alert to any subsequent changes of the sound's origin. When the speed of the sound is faster than the speed of the movement of an individual fish or schools of fish, many species react frantically and disperse. The range of the transmitted distance of the underwater sound varies according to the intensity of sound pressure at the origin of the sound. The lowest limit of auditory sense for fish is generally about -10 to -20 dB for bony fish. The maximum distance at which most can hear the sound of sessile organisms is generally a few hundred metres. Visual senses which must depend upon water clarity can never reach this distance.

Floating artificial reefs

It is well known that various species of fishes seek shelter among floating seaweeds especially during their early stages. Such behaviour of the fish is utilized in the exploitation of various fishery resources by providing suitable artificial floating shelters in the form of floating artificial reefs. While bottom-set artificial reefs are being extensively used in many parts of the world for exploitation of the coastal fishery resources, there has no such effort to exploit the offshore fishery resources. However, Japan has made a pioneering attempt in this direction by establishing a fish farm called "Tosa Kuroshio Fish Farm" in the form of a floating artificial reefs at a depth of 550 m approximately 40 km off Kochi city. The floating artificial reef has been designed and constructed by the engineers of Nippon Steel Corporation of Japan.

The reefs main hull is a steel disk 6 m in diameter with a weight of 12 tonnes and the floating hull with a overall height of 7.8 m. The reef is equipped with a water sprinkler system which is powered by a series of solar batteries mounted on the top of the reef. This sprinkler system has been designed to improved fish aggregation. The reefs mooring cable is a non-corrosive polyethylene-coated parallel wire cable with a diameter of 60 mm and a length of 485 m. The total length of the chain used is 830 m.

Experimental bottom-set Artificial Reefs constructed at Tuticorin

An experimental artificial reef was constructed at Tuticorin during July-August 1989 at a depth of 6 m using discarded Jeep tyres. Three designs of modules were fabricated on board M. V. *Cadalmin* IV (Fig. 1 & 2). Each module consisted of three tyres which were fastened together with polypropylene rope of 6 mm thickness. Design No. 1 was in the form of a tripod with the tyres standing vertically. Each module of this design was provided with maximum interspace between the blocks and the module occupied a floor area of approximately 2.3 m. A total number of 13 modules of this design was fabricated and released. Design No. 2 was fabricated in the form of a cylinder with no interspace between the blocks, but with provision for free flow of water from one end to the other. Design No. 3 was in the form of well with no inter-space between the blocks and the water in the module attaining more or less a stagnant condition. The bottom area covered by each module in Design No. 2 and 3 was less than 1 m^2. The height of the structure was about 1 m in the case of Design No. 1 and 2 and only 0.8 m in the case of Design No. 3. The modules were carefully released with the help of a winch of the Vessel and their position on the floor was set right by divers. The artificial reefs thus constructed covered an area of approximately 50 sq. m.

Fig. 1. Artificial reef module being fabricated with old tyres on board M. V. *Cadalmin IV.*

Within a period of one month from the time of construction of the artificial reefs good growth of algae was observed on the reef structures. The maximum length of the algal filament was 27 mm when observed after 15 days. This increased to 48 mm in 37 days. The algae belonged to Rhodophyceae and Phaeophyceae and were mainly represented by the genera namely *Acanthophora, Graciliaria* and *Padina.* The animal community was represented by various group of invertebrate organisms. However, the animals belonging to Porifera, Bryozoa, Polychaeta, Isopoda, Amphipoda and Cirripedia were found to have colonised the reef structures in large numbers. It was observed that the colonisation by polychaetes and cirripedes was very rapid. Initially, the composition of both the polychaetes and cirripedes was also almost in equal proportion. However, as the period advanced, the settlement of barnacles on the reef structures increased at a faster rate.

Underwater observations on the biota of the artificial reef was carried out by diving with SCUBA and inhabitation and behaviour of fish and shellfish were studied. The inhabitation by fish was recorded for the first time during the third month after the installation of the reef structures. Four distinct groups of fishes were recognised based on the degree of their attraction to the reef structures. Group 1. *Serranus* sp. preferred to live within the crevices of the reef structures; Group 2. *Lutianus* spp. preferred to swim in the stagnant water body of the well-type module without touching the reef structures; Group 3. *Caranx* spp. were observed to hover in large numbers about 2 m above the reef structures and Group 4. The blennids *Dasson* sp. and *Petroscirtes lienardi* were observed in the subsurface and found to cling to the marker rope whereas baby crabs (*Portunus pelagicus*) were found to live on the marker float, hiding themselves under the seaweeds grown on the float.

Fig. 2. Reef modules are ready for lowering into the sea.

In addition to the underwater observations, experimental fishing also was carried out in the vicinity of the artificial reef periodically by perch traps (Fig. 3). *Lethrinus* spp. with a size range of 138-210 mm and *Lutianus* sp. with a size range of 122-172 mm dominated the catch during the first year. But during the subsequent samplings the number of these species gradually declined and during the third year after installation of the artificial reefs the samplings were dominated by *Serranus* sp.

It was noticed during the underwater observations that *Serranus* sp. was attaching a major part of its body to the reef structure. As the shape of the tyre module was curved, the fish was found bending its body. On seeing the diver the fish was moving to another module and attached to it. Thus it appears that large concrete structures with wide openings and cavities may provide a favourable habitat for serranids which prefer to have strong physical contact with the object unlike Lutianids which prefer to swim freely within the reef-created stagnant water. A knowledge of the behaviour patterns of certain species of fish will thus enable us to design a reef tailored to attract that particular species.

Fig. 3. Perch trap being released in artificial reef area for collecting fish.

Conclusion

Artificial reefs when constructed on a large scale covering a vast area with scientifically designed structures will increase fish production significantly by creating a fertile ecosystem in such areas. As stated earlier the structures used for the construction of the artificial reefs primarily function as a base for the growth of algae and settlement of sessile organisms. The organisms thus settled on the reef structures reproduce there resulting in higher density of zooplankton in such areas which ultimately leads to the formation of a good feeding ground for various marine organisms. Further, suitably designed concrete structures will provide favourable habitat for spiny lobsters and various species of demersal fishes resulting in the aggregation of such groups in artificial reefs. Thus artificial reefs play important roles in marine fisheries development by (i) creating nursery ground, (ii) providing favourable habitat for fishes and shellfishes and (iii) conserving the fish stocks from over-exploitation.

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Bull. Cent. Mar. Fish. Res. Inst., 1996, **48** : 18 - 23

6
ARTIFICIAL REEF FOR ARTISANAL FISHERIES ENHANCEMENT - AN ATTEMPT OFF TRIVANDRUM COAST *

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Introduction

Several demersal fishes are found to congregate in the vicinity of submerged objects such as reefs, logs, ship-wrecks and rock out-crops where plants and benthic animals flourish than in areas where the bottom is flat and barren. These communities serve as food for larger predators. Submerged objects may, at times, provide shelter and even spawning locations for many-a-fish. Underwater observations made by divers while retrieving portions of submerged vessels also report that such habitats harbour considerable concentration of fishes .

The use of artificial structures to attract fish and/ or enhance fisheries has long been practiced. Increasing impacts on nearshore fisheries from fishing pressure, habitat loss and pollution have caused fisheries authorities in coastal areas of the world to consider the potential for artificial reefs. Artificial reefs and fish aggregating devices are frequently and successfully used to create fishing areas near artisanal villages in several nations . Although utilization of artificial aquatic habitats has occurred for centuries, scientific description of their function and impact has been done only recently. In India, Bergstrom (*BOBP/WP* - **23**, 1983) reveiwed the traditional fish aggregating devices used in the Bay of Bengal. A modified artisanal artificial fish habitat on the Tamil Nadu coast of India has been described by Sanjeevaraj (*Bull. Mar. Sci.*, **44** (2) 1989). A synthetic fish aggregating device-cum-artificial reef has been developed by the Murugappa Chettiar Research Centre (The Hindu, 22 Feb., 1989). An artificial reef structure made of automobile tyre attached to R. C. C. base by M. S. rods is being installed at Minicoy by the Central Marine Fisheries Research Institute to study the aggregating behaviour of tuna live-baits (*CMFRI News Letter No.* **41**, 1988).

The benthic realm of the shelf area stretching between Cape Comorin and Vizhinjam in the south-west coast of India has plenty of rocky out-croppings which harbour rich and varied fauna of fish and the fishermen are immensely benefited by this favourable environment. Similarly, the ship-wreck found off Angengo at a distance of about 10 km from the shore at 40 - 50 m depth also harbours a variety of fish which are being exploited by the fishermen of the neighbouring villages. But, as the adjoining area found in between Panathura and Valia Veli (Fig. 1) being free from any such out-croppings, the fishermen are deprived of the benefits which their counterparts in the neighbouring areas enjoy. This has prompted them to develop artificial reefs, called *paars* in vernacular, in that area to make the fish to congregate there. An attempt is made here to study the impact of such artificial reefs on the local fisheries and the salient findings emerged during a study spread over a period of two years ie., from May. '87 to April, '89 are presented here.

The general information given regarding the first six artificial reefs was collected from the fishermen who were involved in the construction and management of the artificial reefs in the area in the recent past. Details pertaining to the 7th artificial reef were collected by making direct onboard and shore based observations. Out of the seven reefs, fishing was done only in three reefs (Valiyathura, Kochuthoppu-I and Kochuthoppu-II) and hence the data given here relate to these three reefs only. Among these the Kochuthoppu-II reef was in operation only for one year from April, 1988. As the landings were brought to Valiathura landing centre from the reef as well as from the neighbouring fishing areas, the centre was visited weekly once and the landings were recorded separately for the reef as well as for other areas and their total landings were estimated monthwise. On-the-spot observations were also made on the fishing in the reef. Fourteen sampling units, each consisting of a granite stone weighing 2 kg, (square) bits of tyre, plywood, asbestose and roof tile tied to a nylon rope (1cm thickness) at 25 cm interspace, were placed over the reef to study the benthic community. Underwater observations were made on the reef site by scuba diving.

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Artificial reef construction and managment

Reef construction

Reefs were constructed mostly in the sandy region at a depth varying from 5 to 27m. Granite stones of varying sizes were put first on the site selected for the reef construction so as to form a circular or rectangular ridge. Over these, concrete rings (Front cover photo) of 150 cm diameter into 45 cm height locally called 'urai' used for lining the inner side of commmunity wells, were placed. After this, any locally available unwanted/cheap materials like broken concrete slabs, worn-out rubber tyres, empty barrels, up-rooted coconut tree stumps and leaves, screw pine plants etc., were placed in an unorderly manner over this, so as to provide shade and shelter for the fish (Fig. 2). Coconut leaves were also used to tie 2 to 3 granite stones together at the time of loading the stones to the catamarans. Some reefs are even known after the material used such as 'ola paru' and 'kaitha paru' meaning, reef made of coconut leaves or of screw pine plants respcetively. The materials were transported to the reef site by catamarans (non-mechanised). Sometimes 2 or 3 loaded catamarans are towed to the reef site by mechanised boats if the distance to the site from the shore is considerable. After reaching the spot, the material are dumped by turning the catamaran upside-down. As given earlier, seven artificial reefs, as listed in Table 1, have been diveloped in this region. Of these the first six were constructed in 1988 by the Kochuthoppu fishermen by utilising SIFFS funds. Of the first six listed, two got submerged due to silting and 2 were abandoned due to objection from local fishermen; since they were built within the reach of shore seine operation. The first two in the list were renovated subsequently and they along with the 7th one, are of little use as fish congregating device now.

Fishing

Those who were involved in the construction of the reef only are allowed to fish from the artificial reef. There is no float or flag to locate the reef site for fear of poaching by other fishermen. Eventhough fishing was done throughout the year in the neighbouring areas, in the reef environment, it is done only during the calm season between November and April. The fishermen venture into the reef only during day time. Though a variety of gears are employed in the neighbouring areas, only hooks and line (non-mechanised) are operated in the artificial reefs. "Achil", a kind of hooks and line with hooks varying in size from No. 12 to 8, with artificial baits are used. On bright sunny days and in clear weather conditions the fishing operations are found more economical. A single unit goes thrice a day during the peak season. At a time about 15 to 20 such units are operated at a single reef site. Normally single manned catamarans of the size 5 m with 4 logs are used for fishing.

Fisheries

Trend in fisheries

Landings realised during the period 1987-'88 and 1988-'89 from the artificial reef environment and 'other region', ie., from Cheriyathura in the south to Shangumugam in the north are furnished in Table 2. A perusal of the above table indicates that the landing during 1987-'88 from the reef environment was only 59.0 tonnes as against 636.0 tonnes from the 'other region'. A drastic reduction in the landing from the reef environment could be noted during the subsequent year, ie., 1988-'89, with a total of 24.2 tonnes. In otherwords, the percentage contribution of fishes from the artificial reef environment dwindled to 3.6 from 8.5.

The fishing season in the reef environment lasted for about 6 months from November in 1987-'88, while in 1988-'89 it lasted only for 5 months from December. Peak landing was observed during February in 1987-'88 and in March during 1988-'89. The landing from the 'other region', on the contrary, was spread over the year with peak landing during February and March respectively for the above two years (Table 2).

Gear - wise contribution

As mentioned earlier, hooks and line operated from non-mechanised units were in vogue to exploit the fishes from the reef region. But in the 'other region', in additon to the above gear, hooks and line operated from mechanised craft, shore seine, boat seine and gill nets were also operated.

Species composition

Fishes like *Decapterus dayi, Carangoides plagiotaenia, Priacanthus hamrur, Sphyraena* sp. *Rastrelliger kanagurta* and *Nemipterus* spp. dominated the catch of the reef region, while in the 'other region' *Selar crumenophthalmus, D. dayi, Auxis rochei, Trichiurus lepturus, Rastrelliger kanagurta, Euthynnus affinis, Nemipterus* spp. *Sarda orientalis* and *Dussumieria* spp. dominated (Table 3). Among the dominant groups, fishes such as *D. dayi, R. kanagurta* and *Nemipterus* spp. were common in the catches of both the regions. The dominance of species like *Carangoides plagiotaenia, Priacanthus hamrur* and *Sphyraena* sp. in the reef region shows that the reefs attract both reef dwelling and demersal forms of fishes as expected. Fishes like *Carangoides plagiotaenia, Lethrinus harak, Selar*

TABLE 1. *Details of the artificial reefs constructed off Trivandrum coast*

Name of the reef	Location of the reef	Year of construction	Depth (m)	Distance from shore	Materials used for the construction	Remarks
Valiathura reef (*Kaitha Paru*)	On the south-western side of Valiathura pier	1983	20	Beyond the reach of shore seine operation	Coconut tree stumps, concrete rings, granite stones, empty barrels and screw pine trees	A local ex- service man and the village parish priest supported the fishermen. Renovated once. Slight fish aggregation
Kochuthoppu reef I (*Ola Paru*)	On the south-western side of Kochuthoppu	1984	18	Beyond the reach of shore seine operation	Granite stones concrete tub (4x4') used for salting fish, coconut tree stumps and plaited coconut leaves	Fishermen belonging to the Vanakkapura committee. Renovated once. Slight fish aggregation
Beemapally reef	In between of Beemapally and Poonthura	1984	10	With in the reach of shore seine operation	Granite stones and coconut tree stumps	Discontinued as the shore seines got entangled to the reef material
Vettukadu reef	North - west of Kannanthura	1984	5	Within the reach of shore seine operation	Concrete rings, coconut tree stumps and wooden logs	Discontinued as the shore seine fishermen objected to it
Cheriathura reef	In between of Cheriathura and Valiathura	1984	16	Beyond the reach of shore seine operation	Concrete rings and granite stones	Almost burried due to silting
Shanmugam reef	Off Shanmugam	1985	20	Beyond the reach of shore seine operation	Materials used for the construction of stage for the Papal Visit to Trivandrum	Almost buried due to silting
Kochuthoppu reef II	South - west of Kochuthoppu	1988	27	3 km beyond the reach of shore seine	Granite stones, coconut leaves and rubber tyres	Funded by SIFFS and managed by the local fishermen welfare society

kaila, Carangoides malabaricus and *Selaroides leptolepis* were found only in the reef region. It is interesting to note that these forms live normally in reef areas.

Underwater studies

Underwater observations were made on 26 - 10 - '88 and 10 - 1 - '89 by CMFRI scientists using Aqua lung in the Kochuthoppu reef II (Reef No. 7) constructed on 28 - 2 - '88. Due to poor visibility, the divers could not reach the reef bottom on 26 - 10 - '88. But during the second occasion they could reach upto the bottom and study the conditions there. The sea bottom at the reef site was found to be sandy and some of the reef materials were partly buried in sand due to heavy bottom current which was rushing from south to north. Even after one year of its construction the reef materials including the coconut tree trunks were found to be intact except the coconut leaf splinters used for binding the stones and the sampling units: It was found during diving that the layout of the reef was not properly made as to attract bigger fishes. However, the divers could observe large numbers of small fishes such as *Apogon novemfaciatus, Amphiprion* spp., *Chaetodon* sp. and *Dascyllus* spp. hovering over the reef materials. Fishes like *Epinephelus corallicola, Lutianus argentimaculatus, L. lineolatus, Petrois antennata, Spiloticthys pictus* and *Heniochus acuminiatus* were found in small numbers.

TABLE 2. *Monthly fish landings (kg) recorded at Valiathura landing centre during the years 1987 -'88 and 1988 - '89*

Month	From reef region				From 'other region'			
	1987 - '88	1988 - '89	Total	Average	1987 - '88	1988 - '89	Total	Average
May	-	-	-	-	33,384	18,600	51,984	25,992.0
Jun.	-	-	-	-	3,562	1,49,400	1,52,962	76,481.0
Jul.	-	-	-	-	33,534	12,710	46,244	23,122.0
Aug.	-	-	-	-	39,377	No data	39,377	19,688.5
Sep.	-	-	-	-	68,640	79,065	1,47,705	73,852.5
Oct.	-	-	-	-	18,792	56,460	75,252	37,626.0
Nov.	8,060	-	8,060	4,030.0	94,628	41,730	1,36,358	68,179.0
Dec.	465	372	837	418.5	81,237	45,203	1,26,672	63,336.0
Jan.	10,401	3,226	13,627	6,813.5	81,637	72,480	1,53,717	76,858.5
Feb.	28,304	7,392	35,696	17,848.0	61,637	67,620	1,29,257	64,628.5
Mar.	11,036	9,145	20,181	10,090.5	54,067	49,228	1,03,295	51,647.5
Apr.	687	4,050	4,737	2,368.5	65,646	51,690	1,17,336	58,668.0
Total	58,953	24,185	83,138	41,569.0	6,35,973	6,44,186	12,80,159	6,40,079.5

The general fish catch around that area on that day consisted of *Saurida* spp., *Priacanthus* sp., *Nemipterus* spp. *Decapterus dayi* and smaller carangids. The reef building poychaete, *Sabellaria spinulosa* was found plenty in the reef site.

Food preference

The gut contents of fish such as *Saurida undosquamis, S. tumbil, S. gracillis, Apogon novemfaciatus* and *Lutianus lineolatus* caught from the reef were dominated by the polychaete, *Sabellaria spinulosa.* However, the above species caught from the 'other region' and *Decapterus dayi* caught from the reef did not contain polychaete in their stomach.

General remarks

Recent studies (Artificial reefs and fish aggregating device, National Academic Press, Washington, 1988) on artificial reefs suggest that the reef site is more important than the design of the reef. The general guidelines for the placement of artificial reefs suggested are: (1) The site should be nearer to fishing villages to simplify the logistics of installation and to minimise travel time and fuel consumption before the fish can be processsed on land. (2) An artificial reef should not be placed in commercial fishing areas unless it is specially intended to close an area to these operations. (3) The artificial reef should be located 1 km from natural reefs, otherwise, the fish will tend to swim from one to the other. (4) Sites with strong tidal currents should also be avoided because these currents will cause erosion around the reef, unless the bottom is hard. (5) Mouths of rivers where siltation may bury the reef should also be avoided. (6) The long axis of the reef should be perpendicular to the prevailing current and along fish migratory patterns. A constant current is quite acceptable and is favourable to benthic filter feeders inhabiting the structures. (7) The depth of the reef must be approporiate for the target species. (8) A firm sand or shell bottom is most suitable for an artificial reef to prevent subsidence. (9) The bottom profile should be flat or gently sloping. (10) Soft clay,

TABLE 3. *Species constituting the catch (%) at Valiathura landing centre during the years 1987 - '88 and 1988 - '89 combined*

Species	Reef region	'Other region'
Rastrelliger kanagurta	7.46	8.96
Euthynnus affinis	0.22	7.70
Sarda orientalis	-	4.27
Auxis rochei	-	10.24
Auxis thazard	-	0.99
Istiophorus sp.	-	0.82
Cybium sp.	-	0.30
Nemipterus spp.	5.71	4.68
Epinephelus spp.	2.05	0.36
Lutjanus malabaricus	0.76	0.36
Lethrinus nebulosus	0.90	0.17
Lethrinus harak	0.75	-
Pristipomoides typus	-	0.30
Priacanthus hamrur	17.15	0.93
Therapon sp.	-	0.34
Leiognathus spp.	-	0.82
Decapterus dayi	30.60	14.36
Selar crumenophthalmus	1.34	16.38
S. mate -	0.34	
S. kalla 0.17	-	
Carangoides malabaricus	0.01	-
Selaroides leptolepis	0.01	-
Carangoides plagiotaenia	17.28	-
Other carangids	3.30	5.76
Coryphaena sp.	-	1.06
Trichiurus lepturus	-	5.94
Lesser sardines	-	1.11
Stolephorus spp.	-	0.53
Dussumieria sp.	-	5.11
Sphyraena spp.	11.58	1.15
Saurida spp.	0.70	1.04
Balistids	-	0.26
Tylosurus sp.	-	0.45
Triacanthus sp.	0.01	0.04
Chorinemus sp.	-	0.32
Rays	-	0.02
Sepia spp.	-	2.47
Crab	-	0.04
Miscellaneous	-	2.38

silt sediments and areas that are already productive should be avoided. (11) High wave energy locations and areas with seasonally shifting sands should not be considered. The Japanese National Programme suggests that artificial reefs should have a hierarchial arrangement where modules form 'sets', 10-20 sets form a 'group' and several groups form a 'complex'. They advocate minimum effective sizes of 400m^3 for a set and 50,000 m^3 for a group, with at least a 1 km seperation between each group.

Though the reef sites selected at the Trivandrum coast have many of the favourable aspects mentioned in the guidelines, they lack certain important aspects such as a suitable depth to attract many of the reef fishes, a suitable bottom to increase the durability of the reefs and an area free from wave action to avoid silting. The bottom of the area in which the present reefs are built is sandy with high rate of silting due to high wave action. Because of high wave action and silting, the water becomes turbid especially during the monsoon months thereby making the fishing in the reef regions impossible for a major period. So it is suggested that the reefs should be constructed at a deeper area having sandy or some hard substrtatum so as to avoid turbidity of the water as well as sinking of the reefs. Already two out of six reefs are buried due to wave action and silting within a period of 2 - 3 years. Other two artificial reefs (Nos. 3 and 4 of the list given in Table 3) had to be abandoned subsequently since they were located within the zone of shore seine operation. This point requires special consideration in the present context since there is a marked delimitation in the operation of various gears along the coastal water. However, it seems that this point has not been considered while constructing the above said two artificial reefs. If the reefs are constructed at a deeper area, there is possibility of getting more varieties of fish especially perches and other economically important reef fishes. This needs careful monitoring of the area scientifically before fixing up the site. However, this has not been done in any of the present cases.

The material used for the construction of reef in the different parts of the world also vary considerably. The actual choice of the material shall be based on what is readily available and economically feasible. Bundles of brush wood are tied to lines to capture crabs, shrimps and small fishes in Japn, Philippines, Indonesia and Vietnam. In Central Africa, boxes full of leaves are placed at the bottom of lakes and estuaries. Ivory Coast fishermen place coconut palm fronds in shallow waters to attract shrimps. In the protected areas inside the bays on the south coast of Cuba, fishermen are still using "mangrove fisheries". Lobster shelters are also

Fig. 1. Concrete rings kept ready for transporting to reef building site.

made by constructing reef with mangrove branches. In the Philippines, "brush parks" have been developed to provide shelter and spawning grounds for fish. The traditional Japanses artificial reef involved simply placing shore or quarry rocks at shallow depths as a way to enhance fishing grounds. In North Japan, rocks are placed to enhance kelp production. In Virginia and New York (USA), slit tyres have been imbeded in a 10 cm concrete base for use as a reef module. A steel rod or cable is passed through the tyres for additional reinforcement. Automobile tyres are also used in Thailand for reef construction. An experimental artificial reef constructed of old tyres has been placed near Haifa, Israel. The Japanese have developed hundreds of types of concrete modules to increase fishing grounds. Damaged concrete pipes have been used for artificial reef construction in Hawaii. In Taiwan, concrete blocks have been used on sandy bottoms for over 10 years. In Thailand, artificial reefs have been made with concrete modules to enhance fishing grounds for artisanal fishermen. The trawler exclusion modules are also being combined with groups of artificial reefs to make the area free from trawling. In the United States, ribbons of fiberglass reinforced plastic (FRP) have been bonded into openmesh cylindrical shapes and then joined in arrays of 2 - 10. Cement ballast is used to anchor the units. In the United States obsolate oil and gas drilling rigs and its steel towers have been used to serve as artificial reefs. Here in Trivandrum, granite stones, empty barrels, cocrete rings, coconut tree stumps and leaves and worn-out automobile tyres are used in the construction of reefs.

For a country like India, two approaches are suggested for an artificial reef programme, depending on the available resources. According to the first, commonly available materials withstanding extreme weather conditions such as granite stones can be used for reef construction where funding is limited. The second approach is to fabricate specially designed permanent structure. This requires well-funded programmes, steel and concrete for construction, and larger vessels for their installation.

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7

COLLECTIVE ACTION FOR COMMON PROPERTY RESOURCE REJUVENATION : THE CASE OF PEOPLE'S ARTIFICIAL REEFS IN KERALA STATE, INDIA*

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This paper is about the efforts being made by communities of coastal fisherfolk in South India to build artificial reefs as a means of rejuvenating the ecosystem of their coastal waters damaged by indiscriminate trawling. These initiatives provide the basis for questioning the now influential opinions that in the case of resources in the realm of the commons, precious little will be done to save them from ruin, particularly by those individuals who enjoy access to them. It hopes to add to the accumulating evidence that collective action by the laboring masses in the developing world - peasants, fisherfolk and forest dwellers, to mention a few - to revive and rejuvenate their common pool resources calls to question the undiscriminating policy prescriptions which continue to see only "market or state" interventions to solve issues relating to environmental degradation.

There is now an impressive body of literature which documents the role played by community-level collective action in the management of common prosperity resources. To cite a few examples we have the successful anti-soil erosion and afforestation measures by the farmers of Sukhomajri in the lower Shivalik range of the Himalayas in India (Chopra *et al.*, 1990); the peasants of Trobel, Switzerland, who have for over seven centuries managed their community-owned grazing lands (Netting, 1981); The communally-managed irrigation systems of Illocos Norte, Philippines (Siy, 1982); the innovative self-regulation of the coastal waters by the fishermen of Alanya and Aristofersen in Turkey (Berkes, 1986); and those in Lofoten, Norway (Jentoff and Kristofersen, 1989). Some of this collection action has been endogenously structured by those who use the common property resource. Som others have taken root after appropriate intervention from "outside" led the participants to perceive some gains from collective action within the realm of their use of common property.

The resulting social institutions - some of which have existed over centuries - have evolved sets of rules which the participants understand, agree upon, and are willing to follow. It is the evolving nature of relationships between the participants, within the context of their common property resource, that creates new values and fresh norms, revives cultural knowledge and trust, and facilitates action towards such a desired end. James Coleman refers to such intangible institutional design as a form of social capital (Coleman, 1988).

The impressive evidence of creation of such social capital by community participation in common property resource management from around the world does not seem to have influenced mainstream policy prescription in the developed or developing countries : large sections of the academy and many in the business of state craft still emphasize "state" or "private" hegemony as the best means of governing the natural resources used in common.

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Such policy prescriptions, particularly the intervention of the state, are also premised on the contention that the victims of a ruined common property resource are the least capable of initiating action to conserve it. An eloquent critique of the foundations of such policy prescriptions together with empirical examples of collective action in governing and conserving the commons has been provided recently by Ostrom (1990).

This article proposes to take the discussion a step further. It provides a case study of "appropriators of common property resource" - artisanal fishermen of India, fishing in the coastal marine waters - who have taken collective action not only to conserve their fishery resource, but also to rejuvenate it. Using the medium of artificial reefs, they not only evolved new material designs, but also crafted new institutional forms in the process of their cooperative initiatives to resuscitate the coastal marine ecosystem damaged by the use of state-sponsored and market-oriented use of inappropriate technology.

The fishery and the fishing community

India has an illustrious maritime and fishery history and features today among the world's top ten fishing nations. It has a marine coastline length of over 6,000 kms and a vast network of rivers, lakes and backwaters that yield a fish catch of over 3.6 million tonnes (Metric tonne = 1000 kgs or approx 2200 lbs). Two-thirds of this harvest is from the marine coastal waters and is netted by the half million active fishermen who belong to specific, traditional caste-bound, artisanal fishing communities who live on the geographic, economic, and social fringes of Indian socieity.

The most productive coastal marine fishery zone of India is its lower southwest coast region, comprising Kerala State and Kanyakumari District of Tamil Nadu (hereinafter referred to as "the region") (Fig. 1). It is also one of the world's most important sources of marine prawns. The annual sustainable fish yield from one km^2 of these coastal waters is estimated at 35 tonnes compared to the all-India average of 13 tonnes. On this basis the maximum sustainable yield (MSY) for this region is estimated to be 380,000 tonnes per annum. The major economic species are oil sardines, mackerels and prawns.

This resource plenitude has led to the larger carrying capacity of this coastal zone and accounts for greater concentration of traditional fishing communities along this coast than else-where in India. Though the region constitutes only a little over one-tenth of the country's coastline, it is home to about a third of the active marine fishermen in India.

The 130 km long coastline of the Trivandrum District of Kerala State and the Kanyakumari District of Tamil Nadu is considered to be the most densely populated tract of the southwest coast both with regard to the population of fishermen and number of fishing craft. About 52,000 active fishermen reside in 90 villages along this stretch, and operate about 24,000 small traditional crafts - the majority *kattumarams* - made by tyng four logs of soft wood together (Fig. 1).

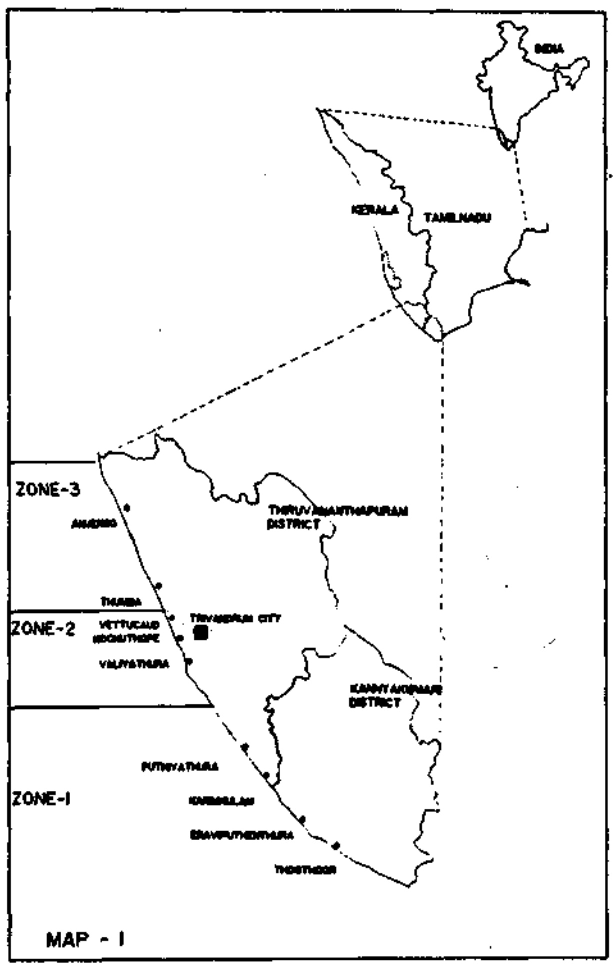

Fig. 1. Map of the study area.

This area is not only famous for its dense settlement pattern, but also for the immense diversity of fish resources in its coastal waters. The assortment of passive and selective fishing gear used by the fishermen to harvest these resources is remarkable : specialized small-meshed gill nets; large multi-meshed drift nets; trammel nets; bottom-set nets and traps; boat seines; shore seines and also a variety of hook and line sets.

The fishermen of the area migrate seasonally to other fishing centers in India, with or without their fishing equipment. They have thus come to be known for their skill and daring, their intricate knowledge of the coastal waters, their navigational acumen, and their ability to fish even at the margins of the continental shelf with relatively simple technology. Their knowledge is based on a long cultural continuum of habituated practice stored in the memory and passed on by those who work. It is practical knowledge conditioned into cultural practices. At its core is an elaborate understanding of the nuances of the aquatic milieu and the behaviour patterns of living marine organisms.

Early origins of the artificial reef idea

The idea that certain types of objects when dropped in the coastal waters tend to attract fish has undergone considerable evolution among the fishermen of the region. They refer to all such sunken objects as *kritrima paar* (artificial reefs).

Artificial reefs are man-made or natural objects specifically placed in the coastal waters to attract fish, provide or improve fish or shellfish habitat, and increase fish biomass locally. Their design can range from haphazardly lowered local scrap materials to modern Japanese-style structures in the form of highly sophisticated modules built of concrete, fibreglass, or steel[1].

Reconstructing from the oral tradition of the older fishermen we provide a brief history of the artificial reefs in the area. It is said that there was an age old practice, among the fishermen of the area who operated the shore-seine, of dumping rocks fastened with coconut fronds into the near shore sea within depths of 5 to 10 metres. Fish tended to aggregate over and around these rocks and were more easily netted by the shore-seines.

Large sunken structures also proved useful in serving the same purpose. It was known that a ship had sunk off the village of Anjengo during the Second World War because the local fishermen had rescued some of its crew. In 1949 a hook fisherman discovered the wreck at a depth of 50 metres. He was amazed by the high hooking rate over the limited area[2]. News of this new fishing spot spread quickly by word of mouth. Expert hook fishermen from the more densely populated southern villages of the area swamped the area and achieved greater success in fishing over the wreck by using artificial bait. The use of artificial bait was new to the fishermen of Anjengo and initially they opposed it[3]. But within a brief period the southerners settled down in Anjengo by marrying into the community[4]. Soon, the use of artificial bait to fish over the *kappal paar* (ship reef) gained wide-spread acceptance in the village.

During the early forties, a ship berthed at the Valiyathura Pier near Trivandrum city lost its anchors in a storm. Only one was immediately recovered from the sea bottom. The other anchor was found only a decade later when a hook fisherman got his line entangled in it. His loss was temporary because it was compensated by his simultaneous discovery of a rich fishing spot around the *nanguram paar* (anchor reef).

The early practice of dumping rocks with coconut fronds in the shore-seine fishing grounds and the discovery of the rich fishing spots atop sunken structures in deeper waters provided the basis for conscious attempts to erect artificial reefs in deeper waters.

The first examples of such artificial reefs date back to the early 1950s in the villages where natural reefs existed and where there was a tradition of hook and line fishing. The best example of such a reef was the one erected in 1955 in Puthiyathura. The hook and line fishermen of Puthiyathura had been fishing over the natural reefs found close to the shore (2.5 km away) at a depth of 40 m. Over time they observed that fishermen from the neighbouring village of Karimkulam - also fishing off a natural reef at about the same depth - got better harvests. The only difference that they observed between the reefs was that the one off Karimkulam was higher than theirs. This led them to try ways and means of raising the height of their own reef. They dumped granite stones piled on the beach to form anti-erosion sea-walls on the existing natural reef thus raising its height by about a metre. The fishermen observed that six months later their efforts paid off in the form of higher hooking rates.

Another early attempt in 1957 was made in Eraviputhenthura. The hook fishermen of this village and a favourite fishing spot about 1.5 km off the coast at a depth of 22 m. The sea bottom here had a clay substratum and the larger concentration of fish observed there was attributed mainly to this. In their village the panchayat (local administration) authorities had used large concrete rings (3 m in diameter and 0.5 m high) to build a community well. One of the unused concrete rings remained on the beach. The fishermen got together, transported this ring on their *kattumarams* to their favourite fishing spot and dropped it there. This was the first known example of an external pre-fabricated structure being used in a known fishing spot as an artificial reef. The new reef was christened *Vatta paar* (ring reef).

Decline of artificial reef construction

For almost a quarter of a century after the late 1950s little was heard of more attempts to create reefs. Several reefs however, were formed by accident and these continued to provide occasional fishing spots[5]. For a while, they generally provided to be good fishing grounds, but then ceased to be productive.

The sudden loss of interest in reefs can be largely attributed to the new fishery development strategies of the 1960s. The importance given to the fishery sector changed rather dramatically. India was facing an acute foreign exchange crisis in the 1960s and every effort had to be made to increase exports. New harvesting technologies like bottom trawling were promoted in a big way by the government to cash in on the prawn boom following the marked increase in prawn prices in the international markets[6]. The coastal waters - once the eclusive preserve of traditional fishing communities who viewed the sea as their community asset - became a virtual open access resource to anyone who could afford to make the necessary investments in craft and gear.

The new harvesting technologies and the prawn export processing industry became the domain of a new class of capitalist entrepreneurs. They employed a small section of male workers from traditional fishing communities on the trawlers and women workers in the processing plants. The vast majority of the active fishermen continued their artisanal pursuits with the only major changes being the use of nylon for fabricating their nets and higher price for their fish.

Fishing effort and fish harvests increased substantially. In Kerala State, from a level of 286,000 tonnes in 1961, the fish harvest increased to 337,000 in 1965 and peaked at 445,000 tonnes (significantly above MSY) in 1971. Since prawns were mainly found in the inshore coastal waters there was virtually no increase in the fishing area following the introduction of the trawlers. A greater and more powerful fishing fleet was continuously harvesting the same stock of fish in a small area of the coastal sea. This resulted in a conflict over space and product with the large number of artisanal fishermen. From 1975, despite rising investments (or rather because of it) the harvests began to fall below the MSY level indicating that the resource system as a whole was adversely affected. The significant drop in productivity (in physical and value terms) resulted in lower income levels despite rising fish prices. A crisis was in the making (Table 1).

TABLE 1. *Select data on Kerala State's marine fishery sector*

	1961	1965	1971	1975	1981
Fish Harvest (000 tonnes)	286	339	445	420	274
Harvest as % of MSY (MSY = 380,000 t)	7	89	117	110	72
Price of fish (Rs/t)	120	200	660	1760	2000
Value of harvest (Rs. mn)					
Current Prices	35	68	293	740	548
Constant Prices (60-61)	35	48	138	197	144
Active Fishermen (000) 3	80.7	88.6	101.9	111.6	127.9
Fishing Crafts					
Non-Mechanized	20667	209200	21718	25100	26271
Mechanized	152	501	1780	2105	3038
Productivity per annum					
Physical (kg/worker)	3540	3820	4370	3760	2140
Value (Rs/wkr-current)	430	770	2900	6600	4300
(Rs/wkr-const)	430	550	1370	1760	1134

Source: Kurien, 1987

The year 1979 witnessed the beginning of a socio-ecological movement spearheaded by the artisanal fishermen of the region, with the assistance of several social activists, formed a trade union. The union presented three major demands to the state authorities: (a) a total ban of trawl fishing during the monsoon period of June, July and August which was the breeding season for many species of fish; (b) reinstating the in-shore coastal commons to the artisanal fishermen in which trawlers would be totally prohibited; and (c) a greater share of assistance to the artisanal fishermen in the fishery development budget of the State (Kurien, 1992).

By 1983, this movement had attained the dimensions of a major political force in the region. In a preliminary democracy with numerous coastal constituencies, a restive fishing community was no solace for politicians, irrespective of their political color. Regardless of whether they were in or out of power, they began to take the fishermen's demands seriously.

In 1984, the second and third demands of the fishermen were conceded by the government. Legislation to demarcate and regulate the coastal waters was enacted and a police force to enforce these measures was set up. The emphasis on promoting prawn exports using State finances was relegated and the funds were earmarked for investment which would directly benefit the artisanal fishermen. A big push was given to upgrading their harvesting technology through the supply of outboard engines, beach landing crafts and new fishing gear. Welfare measures for artisanal fishermen and their families were also increased significantly.

The demand for a total monsoon trawl ban was conceded only in 1989 after three scientific commissions had studied the matter following the fishermen's refusal to compromise on this issue.

The importance of this socio-ecological movement was that it was the fishermen's first collective macro-initiative to re-establish their historical rights of exclusive access to the inshore coastal waters. In the words of an artisanal fishermen's union leader, on his sixth day of an indefinite fast before the government secretariat demanding greater regulation of the coastal waters: "Our struggle is to ensure a future - for us and the fish".

Resurgence of the artificial reef idea

The conflicts and impasse in the current pattern of fisheries development, the ecological crisis and the macro-level political mobilization around it, brougt renewed vigor to the search for alternatives.

The gains of the fishermen's movement in pressuring the State to legally recognize their traditional rights over the coastal commons was no small achievement. However, neither the State nor the unions had the enforcement structure necessary to protect the claims to the coastal commons. The costs of such an enterprise would have been prohibitive. An important and practical way to overcome this on, the part of the fishermen, was to initiate steps to define and protect the coastal zone within limits of individual fishing communities. The village-level measures taken by artisanal fishermen to achieve this, led to violent clashes with the trawlers, litigation by the trawler lobby, and accusations from the State that the fishermen were taking the law into their own hands.

The search for alternatives to rejuvenate their coastal commons was, however, on a different plane. At the village level, one important manifestation of this search was in the form of *gramakuttoms* (village gatherings) at which fishermen and social activists discussed the need to revive, strengthen, and enhance their cultural beliefs and knowledge about fish and the nature-processes in the sea.

These discussions highlighted the fishermen had a strong conservationist ethic towards the fishery resource. They had a keen awareness and knowledge of the totality of the aquatic ecosystem and viewed *Kadalamma* (mother ocean) as their community asset and a life-giving system rather than a hunting ground. Bringing ruin to her, individually or collectively, was something they could not comprehend.

Hook and line fishermen from the Trivandrum District were in the forefront of the village movement to help *Kadalamma* rejuvenate herself. Their success in fishing had depended exclusively on their encyclopedic knowledge of the natural reefs, sand banks in the sea and other fishing spots. They were the first to be affected by the damage to the demersal ecosystem caused by incessant trawling. Though they were victims of a tragedy of the coastal commons, they did not become strait-jacketed prisoners when faced with this dilemma.

Fishermen's knowledge about reefs : Discussions with the younger fishermen illustrated very clearly that although two decades had elapsed since artificial reefs were constructed, knowledge about the reef-sea-fish interactions had been passed down to them from the older generation and kept alive by their own practice of fishing over them. There was a holism about their understanding which stemmed from their concern with the whole resource system rather than just the fish in it.

Fishermen consider reefs as an important basis for ecosystem rejuvenation. This association is premised on their understanding that underwater structures in the sea cater to the *adisthana avasyangal* (basic needs) of fish; their need to feed; their strong desire for protection, rest, and shade; and their urge to breed.

Consequently, for an artificial reef to be a source of food to fish, the kind of materials used to build it gained importance. The materials used should be those on which benthic vegetation would aggregate quickly thereby ensuring adequate food supplies. The artificial reef needs to be erected in areas where the sea bottom is naturally productive.

To serve the needs of protection, rest and shade for fish, the structure and the position of the artificial reef are determining factors. Only an artificial reef of sufficient height will provide shade. Solid structures are not conducive for protection and rest as they do not provide hiding places from predators. If fish are to make artificial reefs their breeding grounds, then the prerequisites of food and protection become imperative.

For fishermen to be able to catch the fish which use the artificial reefs in such a wide variety of ways, the reefs should be aligned on the seabed in the east-west direction. Given the north-south direction of littoral current in the region, this is the best alignment to ensure that the maximum number of fishermen can fish over an artificial reef at any given time without getting their hooks entangled. They have also learned that artificial reefs shoud be located in the "fish channel" - a path which was identified as being between 25 and 50 m depth in the inshore sea. Referring to the way this total understanding of fish behaviour helped to induce fish into the artificial reefs, one fisherman remarked : "The fish teaches us and then we teach the fish (a lesson!)".

Sharing knowledge : The process of sharing the knowledge which they had accumulated over the years was achieved by creating unique possibilities for inter-village discussions. The forum for this was provided by the Program for Community Organization (PCO), a voluntary organization - initiated by this author and a few other social activists - which had been in close contact with these fishing communities for over two decades since the early 1960s.

In the initial years, the work of the PCO was based on its association with groups of fishermen and their families in individual villages in the area. Land based issues like cooperative marketing of fish as well as employment and training for the youth were the focus of activities.

The crisis in the fishery in the late 1970s changed all this. The village specific "land-based" approach gave way to a more generalized "sea-based" strategy for mobilization and awareness creation among the active fishermen of the area as a whole. The focus shifted towards analyzing the various facets of the relationships between fishworkers and the sea, the ways and means by which these bonds were disrupted as a result of state-sponsored fisheries development, and the manner in which the links could be strengthened.

The first important outcome of this change of orientation was the cadre-formation training and movement-oriented research backup provided to the newly formed fishermen's union referred to above. The second, close on the heels of the first, was the support in the search for micro-level alternatives for "greening" the coastal commons.

The exchange of information regarding natural and artificial reefs was part of the second strategy. The initial attempt by the PCO was to encourage fishermen to articulate the slowly disappearing oral traditions of their knowledge systems so that it could be documented, and, where possible, refined and complemented with the knowledge of modern science.

The pedagogy used for this process included arranging for the older and more experienced fishermen from villages with pre- 1960 experience of fishing over reefs to share their knowledge with others. One revelation during these sharing sessions was the difficulty of fishermen in expressing physical reality on a two-dimensional scale using the blackboard. This difficulty was overcome by their own suggestion that it would be easier for them to explain the science of reef building using a small glass fish-tank or pond using stones and leaves.

These animated sessions, attended by fishermen from several villages in the area, laid the bare foundations for a people's science movement. It also served to foster a new group of leaders vastly different from those who spearheaded the unions. Charisma, public-speaking talents, and political acumen got low priority; fishing skills and a hands-on grasp of technical details and community organization skills became more important.

The need for a better understanding of natural processes that take place underwater around an artificial reef highlighted the scope for a far greater degree of collaboration between coastal fishermen, marine biologists, oceanographers, and other scientific personnel. It revealed the exciting possibilities of undertaking what Norgaard referred to as a "coevolutionary development process" of the two knowledge systems. (Norgaard, 1984, Kurien, 1987).

Such discussions, arranged by the PCO, gave a big impetus to the learning process. They also revealed the sharp differences in the approach of scientists and experienced fishermen towards the marine ecosystem. While the former were preoccupied with their ability to make precise descriptions about fish behaviour and the nature of the sea, the latter were more adept at isolating the crucial interrelations which aided their ability to catch fish.

Promoting true dialogue was a slow and not too successful venture. For the fishermen, these sessions provided an opportunity to widen their horizons and provided the opportunity of getting to know what went on around them and also in other parts of the world vis-á-vis artificial reefs.

Towards People's Artificial Reefs (PARs)

The renewed initiatives among fishermen to erect artificial reefs needs to be situated against this background. Several groups of fishermen from as many as 22 villages in the area decided to take creative, collective action to erect reefs in the coastal waters off their villages. These actions needed to be viewed as the micro-level expression of their historic macro-level socio-ecological movement. We have termed the reefs erected in this process as "people's artificial reefs" or PARs.

During the years 1979-1989, the pace at which PARs were erected increased substantially (Table 2). The stretch of coastline where PARs have been erected can be further divided into three zones with the city of Trivandrum, the capital of Kerala State, as the reference point (Fig. 1 and Table 3).

TABLE 2. *People's Artificial Reefs erected in Trivandrum and Kanyakumari*

	Before 1960	1979-83	1984-1989
No. of PARs erected	2	9	21

Source: Adopted from Kadappuram, 1989

TABLE 3. *Percentage distribution of PARs along the coast*

Area		Pre-1960	Post-1979
Zone 1	Villages south of Trivandrum City	100	40
Zone 2	Villages around Trivandrum City	-	50
Zone 3	Villages north of Trivandrum City	-	10

Source: Adapted from Kadappura, 1989

The PARs erected during this period witnessed changes both in relation to the materials used and the institutional processes associated with the erection of and access to the PARs.

Changing materials : The "first generation" reefs erected before 1960 used materials available at the village which the fishermen could obtain without money. This "whatever-you-can-get" approach to collecting materials to erect reefs continued until the 1980s. The fishermen of Eraviputhenthura who were the first to use a pre-fabricated structure (cement well ring) in 1957 erected their first PAR in 1980 with the large unused iron wheel of a damaged road roller that was abandoned in the village. In Valiyathura an unused telephone post was used in 1983. However, with more organized and widespread efforts to build PARs, it was unlikely that such an approach could continue for long.

In the "second generation" PARs erected between 1984-86, it was noticed that while granite stones wrapped in coconut fronds remained the main component, three more important additional items were widely used: large rocks packed in monofilament net bags; the screw-pine plant: and cement well rings. All these items had to be specially ordered or collected specifically for the purpose and paid.

After 1986 there was a further spurt of changes. The use of old automobile tires tied to cement rings was tried out by the fishermen in Valiyathura. In Thoothoor, the granite stones were painted red before they were transported to the sea. Along with this came the measures taken to protect the PARs from being covered by fishing nets. Rings with built-in-hooks, anchors and concrete pillars placed at the four corners of the PAR structure were examples of the measures taken by the fishermen.

Changing Institutional Forms : The discussions about materials and designs was accompanied by the concerns about the micro-level institutional processes and forms to be adopted in erecting reefs and having access to them.

The information which we have of the pre-1960 reefs (in Zone 1) indicates that the erection was the result of the initiative of a small group of fishermen in the villages community. There were no perceived "private costs" to the group : the materials used were obtained free of cost and the labor involved in erecting the reef considered shramadan (voluntary labor). As a result the "promoters" of the reef were not overtly preoccupied with questions about property rights or private returns.

In the post- 1980 period we observe a quiet accretion of social capital in the form of institutional designs associated with the PARs. For a more analytical appreciation of these changes it may be useful to consider two fecets of the activity: (1) the initiatives for erecting PARs and (2) the claims for access to the PARs.

Initiatives for erecting reefs came from four quarters : individuals in the village, groups of fishermen within a village, the whole village community, and external agencies. These were not mutually exclusive type of initiatives. For example, certain leading individuals may play crucial role in the initiatives taken by a specific group of fishermen to erect a PAR. Alternatively, an external agency - *e.g.* an NGO, the church/ temple, - may financially or otherwise assist the whole village community in erecting a reef. By and large, these efforts were motivated by the concern to rejuvenate the "resource system" of the damaged coastal commons and thus rejuvenate the fish stocks.

The claims for access to the PARs came from two sources : a group in the village community or the whole village community. These access claims were motivated by differing understandings about the rights of appropriating "resource units" of fish from the PARs.

We shall enumerate below five "erection-access" combinations which have been observed in the post- 1980 period. At present, some combinations co-exist and some of them are likely to emerge as dominant forms.

Individual Erection - Group Access. One of the first post- 1980 reefs was erected in 1983 by an ex-serviceman from the fishing community in the village Valiyathura (Zone 2). He organized the erection of a reef partly using material freely available on the beach (stumps of coconuts, etc.) and also by arranging for the purchase of granite, cement rings, etc. This reef came to be known after him as *Ouseph Paar* (Ouseph's reef). The total cash investment was estimated to be about Rs. 1000/- which Ouseph claims to have raised by pledging his wife's gold ornaments. He hoped to recover this investment by collecting a rent from the fishermen who were accorded access to the reef by him. The reef became productive in about three months and became known as a good fishing spot. Due to the difficulty of monitoring and preventing free access to the reef, Ouseph's hopes of profit were only partially realized.

Group Erection - Group Access. Ouseph Paar became the inspiration for fishermen to consider taking their own collective initiatives to erect reefs as the means of rejuvenating the coastal commons and enhancing their fish harvests. Small groups in the villages joined together, collected equal shares, and erected reefs.

Initially, these small group initiatives were restricted to the villages around Trivandrum City (Zone 2), where hook fishermen were in a minority (Fig. 1). In 1984 the fishermen of Kochuthope, a village just north of Valiyathura erected a PAR which cost them Rs. 6000. Initially only the 100 hook and line fishermen who contributed to the erection had access rights to the PAR. Subsequently, when the PAR was built-up again, the membership was raised to 300. Their collective experience of restricting the use of the PAR to the members who contributed funds for its erection was fairly successful.

There was a spurt in the number of such "group erection - group access" PARs in the Zone 2 villages during the years 1984-85. The PARs were located just outside range of the shore-seine operations (at about 15 m depth) which was about 1.5 to 2.0 kms from the shore and just within keen eye-shot.

The fishermen of Zone 2 enumerated five distinct advantages of this location : (a) it prevented conflict with shore-seine operators; (b) it allowed easier monitoring of the PAR for "poachers," mainly from the neighboring villages; (c) it was within rowing distance, thus dispensing with the need for mechanical propulsion to reach the PAR and thereby reducing the costs of fishing; (d) proximity also made the PAR accessible to the older and the very young fishermen; and (e) since the reef fish were fresh and brought quicker to the shore they fetched a higher shore price.

At no stage during these years (1984-87) were PARs considered to be providing a major source of the fish harvests. However, the positive experience surrounding the erection of and access to PARs resulted in a favorable disposition towards enhancing the scope and dimensions of such group initiatives.

Group and External Agency Erection - Group Access. In early 1988, the fishermen of Valiyathura, who were members of a village-level cooperative part of the apex organization called the South Indian Federation of Fishermen Societies (SIFFS), decided to erect a reef. They formed a group of 100 members with each one contributing Rs. 100 towards the cost of reef material. They approached SIFFS for a grant of Rs. 10,000. The amount was granted and the SIFFS also took the initiative to arrange for fishery scientists to be associated with the erection as well as the monitoring of the biological aspects of this PAR.

The nature of access rights did not materially affect the activities of the scientists who were monitoring the biological changes that were taking place underwater. However, to assess the economic viability of PARs - a task which SIFFS intended to do - restricted access rights would make the task much easier. The concept of "group erection-group access" was therefore supported by SIFFS on the grounds that it was easier to monitor such reefs to establish their economic viability since the fish harvest is restricted to a well defined group.

Group Erection - Community Access. Our inquiries reveal that at about the same time as the fishermen in the villages around Trivandrum City were erecting their "group erection - group access" PARs, fishermen in the villages south of Trivandrum (Zone 1) where hook fishing predominated and where natural reefs were once in abundance, were erecting PARs adopting what they termed the *utsava shylee* (festival approach).

The erection of and access to these PARs was analogous to the funding and celebration of a village festival. For village festivals, funds are collected from all the households in the village on the basis of a "whatever-each-one-can-give-happily" approach. Contributions could be in cash or kind. The actual initiative and hard work of organizing the festival is undertaken by a core group (a festival committee) whose primary gain is social recognition. Any number of volunteers are accommodated. While the grandeur of the festival is proportionate to the total funds raised, access to the fun of the festival day is open to all in the community irrespective of their contribution.

The analogy can be fully extended to the PARs erected by fishermen in Zone 1. These PARs are assets financed by voluntary contributions of the entire households in the village; erected by a group of able-bodied, young fishermen, with the access to the PAR being open to the whole village community.

Community Erection - Community Access. It was during discussions at the PCO that fishermen from the southern villages (Zone 1) heard about the system of "group access claims" to PARs erected by groups of fishermen in the villages around Trivandrum (Zone 2). They were astonished and remarked : "You don't show your narrowness at a village festival or at sea. Both are for all." A very animated discussion followed in which the implications of the philosophy of stewardship of natural resources was raised. They were of the opinion, that as children of the sea and as those who know the secrets of the sea, such a narrow and partisan approach was not warranted *among themselves.*

The fishermen from the southern villages (Zone 1) suggested that while access to the PARs should be open to all, certain community agreements need to be evolved to restrict fishing effort by individuals. For example, a limit should be placed on the number and size of hooks. The use of lights to fish over the reef at night should be prohibited. Only one member of a household should fish at the PAR. These would ensure a more equitable distribution of the catch. Community sanctions for those who violated these norms were appropriated.

These inter village discussions resulted in a self-critical review of the other approaches. Despite some initial resistance and skepticism - backed also by reservations to this approach from SIFFS - the fishermen in Zone 2 made a quiet transition of community access to PARs. The discussions transformed the situation from one where village communities took isolated decisions to one where the pros and cons of seemingly appropriate decisions could be tested against the merits of the more rewarding experiences of others.

The most recent initiative (1991) to create a PAR by the fishermen of the village of Thumba (for the first time in Zone 3) bears witness to the effectiveness of committed information exchange about meaningful experiences. In true festival style the whole community of Thumba was motivated to raise funds to erect a PAR which they claimed would help to rejuvenate a natural reef which was recently destroyed by the indiscriminate fishing of a large fleet of trawlers. They formed a *sahodara samajan* (brotherhood fraternity) in which one member from each of the fishermen households in the village was given membership. This was a means of formalizing total community participation in the complete ventue. The *sahodara samajam* elected a "works committee" which would be responsible for erecting the PAR, deciding on the norms/restrictions on access, and for settling conflicts should they arise. Every household made a financial contribution. This fund was matched by an equal grant from their church[7]. Some technical assistance was obtained from the PCO on the appropriate shapes of the specially designed concrete structures to be used.

From the above description of the changing institutional forms we can discern a concerted movement towards greater community involvement in the erection and access to PARs. Sharing of experiences through a committed exchange of information facilitated largely by an NGO led to a steady process of accretion of institutional social capital. Implicit in this has been both a collective learning and self transformation process for large sections of the community of fishermen. The result has been the growing support for an institutional-choice which spreads both the costs and the benefits more evenly within the community.

These changing institutional forms challenge the influential predictions that only state or market solutions can allocate and protect common resources. They also call to question the assumption that those who are caught in a "commons dilemma" would rarely invest time and money in the design and supply of institutions to conserve it.

The initiatives of the fishermen of the region also illustrate that people who have a very intimate association with natural resources as a source of livelihood, given the appropriate circumstances, can empower themselves to go beyond macro-level collective action aimed at conserving resources to micro-level initiatives for improving and rejuvenating them.

Enter the state

Policy makers, government bureaucrats, and scientists were unaware of the growing importance and members of PARs until this fact was brought to their notice by the Program for Community Organization in 1987. When first appraised of the matter, they viewed these initiatives as quaint since they did not fit into the usual pattern of development and management strategies initiated to meet the crisis of overfishing of the coastal commons.

Having been in the past decade preoccupied with ways and means of getting the maximum amount of fish out of the sea with a minimum of social conflict and law and order problems, it was not surprising that they initially considered the "throwing of granite into the sea" to be a waste of time, materials, and money. Measures such as providing outboard engines or better craft to artisanal fishermen to fish in deeper waters and putting into action a marine police force to regulate fishing in the coastal waters were more in line with their concerns.

With the spread of the idea of PARs among the fishermen and the scientists, policy makers have begun to take cognizance of the matter. Initiatives of the fishermen along the lower east coast of India (Tamil Nadu) to build reefs and the role of NGOs specializing in rural technology in assisting their efforts has prompted the Department of Science and Technology of the Government of India to initiate a national program on artificial reefs. The purview of the program has now been extended to include the lower southwest coast region.

As a pilot project of this national program a prefabricated reef was placed in the coastal waters of the district of Alleppey in Kerala State. This was done with much official fanfare, but no participation from the local fishing community. The initiative was publicized as a resource conservation measure. There were to be no restrictions on access to the reef.

Unfortunately, the last one heard of the reef was also on the day of the official function. Fishermen of this district who have for decades used encircling nets to harvest large shoals of pelagic fish (which have no need for a reef habitat) have never known the use of reefs. Consequently the estimated Rs. 50,000 invested in this State-sponsored project was really a misplaced investment in every sense of the term.

The future of PARs: New meanings, new directions

The changes in materials, designs, and institutional forms have resulted in PARs attaining a wide range of "meanings" to the artisanal fishermen.

PARs are no longer just the collective effort of "throwing granite into the sea". They have become a symbol of the joint efforts for "greening the sea". They have become a symbol of the joint efforts for greening the sea". They have become the artifact around which fishermen can make creative use of their accumulated, transgenerational knowledge about the aquatic milieu and the behavior of fish.

PARs are also seen as the appropriate physical structures for a fencing of their exclusive fishing zone against the incursion of trawlers. PARs are the rallying point for collective action in evolving institutional processes and institutional forms for coastal resource rejuvenation.

While our description of the changing institutional forms highlights a noticeable convergence towards community access to PARs, the initiatives to erect the PARs are likely to receive the support of external agencies in the future. If the present level of investments can be maintained (on average, about Rs. 10000-15000 per PAR), community initiatives to erect PARs are likely to continue. Since community erection is closely associated with community access, an open question still remains : Will the coastal commons in the long run become "privatized" by village communities with differing economic endowments and fishing skills?

On the other hand, the success of PARs is creating a growing appreciation among the fishermen of the need for bigger and better designed physical structures for PARs - *e.g.* specially designed concrete structures. This is creating a latent demand for a greater level of financial investment in artificial reefs beyond the capacity of local village communities. The opportunity for more organized state involvement becomes an imminent possibility.

State investment will foster the negation of community access and favour *open access* for all active fishermen. It will also tend to "standardize" artificial reef construction taking out from if the "people's science" element and the popular, decentralized participation in creating this social asset. People would lose their autonomy and become passive recipients of the benevolence of a central authority. The values associated with PARs as concrete expressions of the people's will and resolve to nature a damaged ecosystem will tend to get lost in the euphoria of reefs as a means of enhancing fish harvests and quick profits[1].

This likely divergence in the future intiatives in erection of and access to PARs point to "higher order" dilemmas and choices of the future (Ostrom, 1990). The course that emerges will depend on a multiplicity of factors. Most important in this will be the manner in which these micro-level initiatives mesh into the larger macro-level actions which attempt at pressuring the State to redefine its power equations with the fishing community.

Lessons in collective action

The actions of the fishermen of the area in erecting PARs questions the conclusion that people confronted with a "Hardinian tragedy" of a ruined commons, will in accordance to Olson, *not* join hands for collective action unless coerced to do so. It also raises the issue about the assumption of the prisoner's dilemma game : that there cannot be any change in the structure of the game.

By examining the brief history of PARs we see that once those caught in a dilemma meet, discuss, exchange views, and learn from each other, it is unlikely that they will retain the status quo structures. They evolve new learning, new institutions and new trust among themselves - attributes which contemporary theories of collective action are only beginning to address.

We have observed how the resurgence of reef building, in the wake of the marine resource crisis, has also brought with it the reaffirmation of the community's responsibility to nurture the resource-system which is the basis of their survival. It has also provided a new, collective motivation for them to articulate, sharpen, and expand their knowledge base by greater interaction between themselves and with scientists and social activists. The resolve to build PARs has also provided fresh foundations for the spontaneous growth of new village leadership and widespread community participation. All of these are essential ingredients for sustainable collective action.

There is no claim that PAR building will make any substantial contribution to healing the wounds inflicted on the coastal ecosystem of the area. Nor can it be said that the future of these small-scale fishing communities and the common property resource which they consider to be their inheritance depend overwhelmingly on the success or failure of PARs as technological artifacts.

If an alternative development paradigm is to emerge, with sustainability of the coastal resource system at its heart, then the key to the future will be cultural, socio-economic and political empowerment, and even more importantly the social capital of institutions crafted during the collective action.

Notes

[1] The extent to which artificial reefs increase fish biomass or redistribute existing stocks of fish is not clear. However, even if they do not substantially increase fish production, they can be used as effective fisheries management tools. The increased standing fish crop around artificial reefs reduces fishing effort and, therefore, saves time and fuel. Fishermen in developing countries often must limit their efforts because of high fuel costs. Furthermore, artificial reefs can be used to create fishing grounds for artisanal fishermen who use traps and hook and line gear (Bostid, 1988).

[2]Using their depth gauging plumb-lines the fishermen have estimated the wreck to measure 50 metres in length and 45 metres in width. The top of the wreck was just 15 metres below the surface. This spot was until recently (until 1985) considered to be one of the major fishing grounds of the region. Fishermen say that too many drift and gill-nets which got entangled to it have wrapped around the top of the wreck and reduced its productivity.

[3]In the oral tradition of the village there is a couplet which eludes to this discovery and the use of artificial bait: "Sukkuruppan kandupidicha kappal paar/Irayillathe meen pidichu thekken maar" (*Translation*): Sukkuruppan discovered the shipwreck/(But the) Southerners fished over it without live bait.

[4]Fishing communities of this region follow a matrilocal tradition.

[5]The most interesting examples are that of the spent rocket heads (fired from the equatorial rocket launching station, Trivandrum) that dropped into the sea. Initially the authorities provided a compensation to fishermen who "discovered" these - when their nets got entangled on them and partially destroyed in the process. Soon the fishermen observed that the rocket heads became good fish aggregating devices.

[6]International prawn prices began to increase with the stoppage of Chinese exports after 1949 and the rising per capita incomes in Japan. Prawns were not a preferred seafood in this region. It commanded a price much lower than that of other species of fish until this export boom.

[7]The funds at the command of the church are completely raised by contributions from the daily earnings of the fishermen of the community. Such funds are controlled by the priest and a committee comprised largely of non-fishermen from the community. Church funds are normally utilized for building/extending church structures and for religious festivities. Against this background, the contribution for an occupational purpose attains great significance became of its potential demonstration effect along the coast.

[8]This is likely to be an imminent possibility given the keen observation by fishermen that cuttlefish (*Sepia pharonis*) which has a big export demand, spawn in the PARs. Whether fish other than specific "reef fishes" breed on artificial reefs still seems an unsettled issue among American and Japanese scientists. The former continue to debate whether artificial reefs actually increase productivity or merely attract and concentrate organisms from surrounding area. Japanese scientists generally have little doubt that artificial reefs, when properly designed, sited and placed can be used to increase the productivity of desired species. (Sheeby, 1982).

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8

ARTIFICIAL FISH HABITATS IN TRADITIONAL FISHERIES OF SOUTHWEST COAST OF INDIA*

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Abstract

Artisanal fishermen of Trivandrum area in South India are showing keen interest to put up artificial reefs to enhance fish production. Non-governmental organisations working for the welfare of coastal fishermen are giving financial and moral support to these fishermen to deploy more and more artificial reefs. The results of a study made on such reefs are presented in this paper.

Granite stones, truck tyres, coconut tree stumps, concrete well rings and concrete slabs are used for the construction of artificial reefs in this area. A gradual increase in the annual fish catch was noticed at Valiathura (Trivandrum) fish landing centre after the establishment of artificial reefs in this area. It rose from 669.0 tonnes in the year 1988 to 857.5 tonnes in 1989 and to 1442.8 tonnes in 1990. *Sepia pharaonis* was the major component in the catches from these reefs. *Carangoides plagiotaenia, C. malabaricus, Lethrinus harak, Selar kalla* and *Selaroides leptolepis* were caught only from the artificial reef region at a point of time. Underwater studies revealed the congregation of large shoals of small reef-dwelling fishes and other bottom living animals around the reefs.

Introduction

Creation of fishing grounds, which is a human endeavour, is of particular significance to coastal waters in the world. Development of coastal fishing grounds will no doubt increase fish catch and raise the level of living of coastal fishermen. Making artificial fish habitats (AFHs) and utilising them for regular fishing is not a new technique for the artisanal fishermen of southwest coast of India. Since there were plenty of natural reefs in this area, and regular supply of fish from these reefs, the fishermen never felt the need for going in for large scale reef constructions in the past. The introduction of otter-trawling in this area in the sixties have made tremendous havoc to the fishery environment by destroying the natural reefs which used to be an abode for bottom dwelling forms. The impact of bottom trawling on benthic resources and the marine ecosystem began to be felt severley towards the end of nineteen seventies. The reduction in fish production of the traditional sector around this time forced them to adopt new small scale technologies such as use of artificial baits and monofilament nets, motorisation of their country crafts and formation of artificial fish habitats. Since there is rapid increase (1) in the number of artificial reefs in the Trivandrum Coast since 1987 and non-governmental organisations like Programme for Community Organisation (PCO) and South Indian Federation of Fishermen Societies (SIFFS), working for the welfare of coastal fishermen are giving very good support to the reef projects (2 & 3) a study was made during the period 1988 to 1990 and the results are presented here.

Material and methods

As Trivandrum happens to be the centre of activity for artificial reef fishing, the fish landing at Valiathura was observed for three years from 1988 to 1990. Estimates were made separately for the units operated on the reefs as well as in the non-reef areas. The species constituted the catch of both the areas were also identified and listed separately. Underwater surveys using SCUBA were made to assess the fish congregation in the reefs and also to collect samples of benthic communities settled on the reef modules. Onboard observations

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* This work was done at Central Marine Fisheries Research Institute, Vizhinjam, Trivandrum when the author was a Senior Scientist there.

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were made to evaluate the fishing by fishermen in the reef and non-reef areas. Environmental data were also collected from both the area periodically.

Distribution of Artificial Reefs

The coastal area (Fig. 1), stretching from Anjengo in Kerala to Enayam in Tamil Nadu, has about 25 artificial reefs. Some of these are privately owned. Some sunken ships at the bottom also serve as artificial reefs. A shipwreck off Anjengo during World War II proved to be a blessing in disguise for traditional hooks and line fishermen. The site became an important fishing ground with rich catches assured in almost all seasons. The hundreds of test rocket covers that fell into the sea off Thumba on the Trivandrum Coast are also turning into fish shelters.

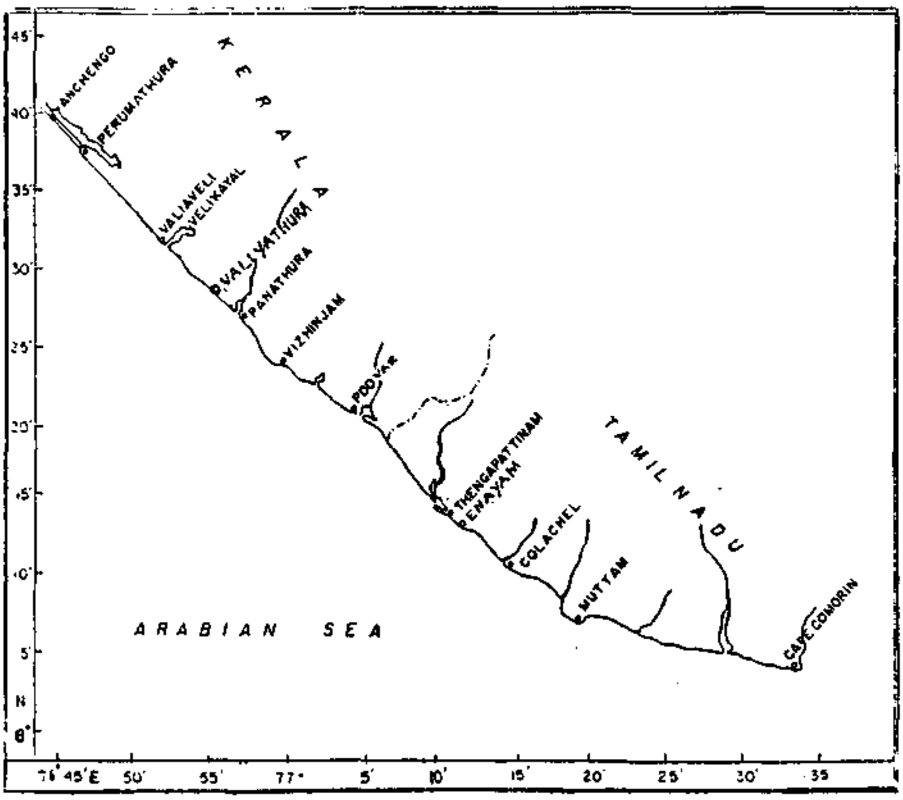


Fig. 1. Map of the study area.

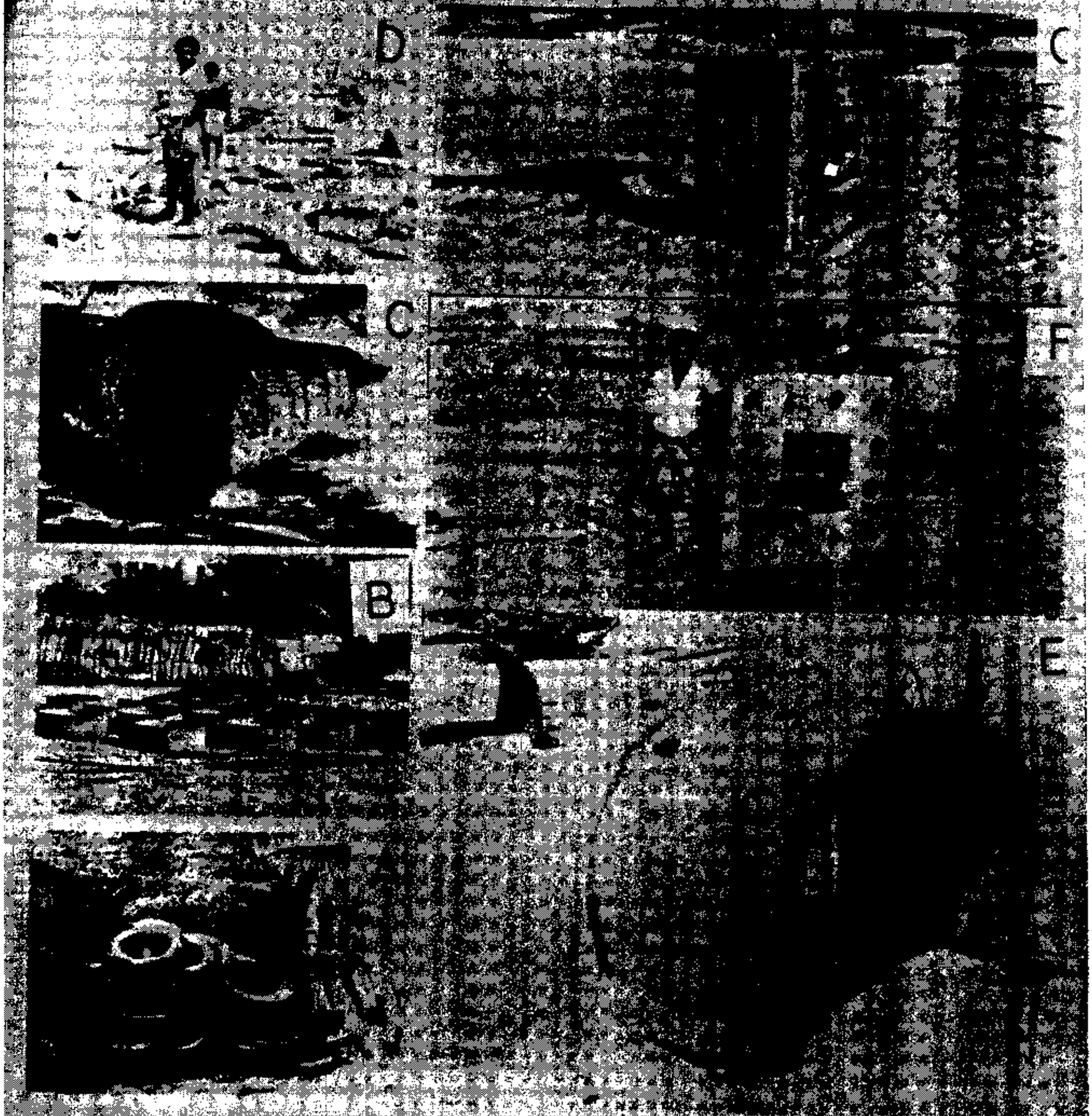
Materials used for the reef construction

Initially, all available materials like granite stones, worn-out tyres, wood stumps (bamboo and coconut), oil drums and pottery waste were used as reef material. Innovation were later introduced and concrete-filled worn-out tyres, concrete well rings and a variety of structures made out of concrete were used (Pl. 1). Notable among them are : the three dimensional chamber-type concrete module and the semicircular concrete module. In some places, a hut-type module made out of bamboo poles was also used.

Site selection and reef building

The selection of the sites for the reef depends on the traditional fishermen's knowledge of the place. They are manually built around 30 m depth covering an area of 150 square metre at a distance of 2-3 kilometre away from the shore, *i.e.* beyond the limit of shore seine operation. The fishermen bring granites in their catamarans and drop them at the site by over turning the catamarans. Then the concrete rings unloaded over them using ropes operated from the catamarans. The automobile tyres, which are stabilised with concrete inside, are placed over this by ropes. Broken pottery which are abundantly available on the coastal area are dropped from the catamarans. Branches of

Plate I. Materials used for the [illegible]



A. Worn-out car tyres, B. Concrete well rings, C. [illegible] stumps, D. Granite stones, E. Semi-circ[illegible] side of a three-dimensional cha[illegible] three-dimensional chamber-type module.

"Konna" trees and coconut fronts, which are believed to attract fishes, are also dropped to the bottoms. A visual triangular method is used by the fishermen to locate the site once the materials are dumped.

Results

1. The materials such as truck and car tyres, granite stones, concrete rings and slabs and coconut trees stumps were found to be cheap and suitable as reef material.

2. Even after one year of their laying these materials were found to be in tact. This shows the suitability of the site (Trivandrum-Enayam Coast) for reef construction.

3. The low productivity of some of the ARs was attributed to the wrong lay-out of the reef and inadequate reef materials.

4. *Sepia pharaonis* used to dominate the catch from the reefs during February and March months and the cuttlefish caught from the reef area during December-March period were mostly in their spawning condition. Fishing experiments conducted in the vicinity of the ARs during the above period brought large quantities of cuttlefish egg masses. Hence, it may be presumed that the cuttlefish congregate around the reef area for attaching their egg masses.

5. Underwater studies revealed the congregation of large shoals of small fishes such as *Apogon novemfaciatus*, *Amphiprion* spp., *Chaetodon* spp. and *Dascyllus* spp. Big fishes like *Epinephelus corallicola*, *Lutjanus argentimaculatus*, *L. lineolatus*, *Pterois antennata*, *Spilotichthys pictus* and *Heniochus acuminiatus* were found in small numbers.

6. Fishes like *Carangoides plagiotaenia*, *Lethrinus harak*, *Selar kalla*, *Carangoides malabaricus* and *Selaroides leptolepis* were found only in the reef region at a point of time. It is interesting to note that these forms live normally in reef areas.

7. A slight increase was noticed in the fish landings of the Valiathura landing centre after the construction of artificial reefs in this area. From 669.0 tonnes in the year 1988 it rose to 857.5 tonnes during 1989 and to 1442.8 tonnes during 1990.

8. Out of two types, tubular and well-type, arrangements of the concrete rings for the construction of ARs the first one seems to be more efficient.

9. Three types of modules were used as FADs in this area. They are the hut-type structure made of bamboo, the three-dimensional-chamber-type module and semi-circular module made of concrete. Out of these, the first two types were found to be effective.

10. The age of the reef also has a bearing on the productivity of the artificial reef. In the first year of its construction there is always good production. If the reef is not renovated at the end of the first year a decline in the catch is noticed normally.

11. Hooks and line units are found to be the suitable gear for the exploitation of fish from the ARs in this area. But, at the sametime, light fishing in the vicinity of ARs by large number of hooks and line units affecting the congregation of fish in the ARs was also noticed.

12. Intensive fishing was done during the sunny days of November-April months in the reef environment.

13. Good encrustation was found on the reef modules within a short period of their launching. They include barnacles (*Balanus* spp.), pearl oyster (*Pinctada fucata*), edible oyster (*Crossostrea* spp.), gartropods (*Turitella* spp.), bivalves (*Cardia* spp.), button crabs and solitary corals. The reef building polychaetes *Sabellaria spinulosa* Leuckart and *S. spinulosa* var *gravieri* Fauval, were found in plenty in the reef site.

Conclusion

A gradual increase in the annual fish landings has been noticed at Valiathura after the establishment of artificial reefs in this area. The cuttlefish *Sepia pharaonis*, was one of the major components in the catches from ARs and because of its good export market the artisanal fishermen were showing keen interest to put up more and more reef structures in this area. With the limited fund which they get from voluntary organisations they were able to put up small reef structures only. The small size of the reef necessitates renovation every year so as to keep them productive. If steps were taken to avoid this problem by putting up bigger reefs on a larger scale, the ARs will play an important role in this area for the development of artisanal sector. So far, no attempt has been made on floating reefs. Floating reefs are known to attract pelagic shoaling fishes like the tunas. So it is better to start some studies on floating FADs in this region so as to transfer the technology to the local fishermen.

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9

ARTIFICIAL FISH HABITATS*

A COMMUNITY PROGRAMME FOR BIO-DIVERSITY CONSERVATION

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Introduction

It has been generally recognised in India that artisanal fishermen are still the masters in traditional gear technology. Artisanal fishermen are continuously involved in innovating new fishing technologies and adapting them to their local marine environment. Technical capability of artisanal fishermen was kept in low profile and was confined and known mostly to regions of origin. The statements given in the note on the National Workshop on Technology for Small Scale Fishworkers are highly relevant in respect of technology developments in artisanal sector.

Technical changes in the small scale marine and inland fisheries sectors of India have always been fairly localised and rarely taken on a high profile. There are two important reasons for that:

i. the vast diversity of these sectors necessarily restricted a technical change to a particular region.

ii. the fact that in recent history most of the changes have been largely fishing gear related tended to keep them outside public vision.

Through continuous interaction with the ocean and fish, the artisanal fishermen accumulated trans-generationally a treasure of scientific knowledge on diverse marine ecosystems and fish behaviour. The technical capability of artisanal fishermen is based on this knowledge, the application of which has proven their worth by enduring for thousands of years like the *"Ayurveda"*, the indigenous form of medicine and health systems. Rejecting this as traditional and primitive, modern fishing technologies developed in the temperate waters like trawling, purse-seining and mechanised fishing were introduced in the mid 60's. The end results of these are overfishing, destruction of marine ecosystems and fall of fish production, particularly the share of the traditional fishermen.

The formal R&D institutions neglected almost totally the traditional sector. It was the commercial interests and profit motive together with government support that made them concentrate on the newly imported modern technologies especially for shrimps for a quarter of a century.

The dawn of 1980 witnessed explosive social unrest among fishing communities. It was a turning point for both the traditional fishermen and the state government. The state was forced to rethink its earlier policy on fisheries and the traditional fisherworkers turned to more dynamic alternative technologies. Since 1980, fishermen took active interest in constructing AFHs as a means of fish aggregating and regenerating and sustaining natural marine habitat greatly damaged by bottom trawling and overfishing.

AFHs construction is one of the methods developed by traditional fishermen to fight for the sustenance of marine life. In the process of ecological destruction, it is in the tropics that the battle to preserve *"bio-diversity"* will be won or lost. AFHs is a great step forward in the march for 'eco-technology'.

This book is based on the study on the innovation, adaptation and diffusion of artificial fish habitats technologies developed by artisanal fishermen of Kanyakumari and Trivandrum districts of the south-west coast of India. The study aimed to highlight (a) the technological capability of artisanal fishermen (b) the science and technology of artisanal fishermen and to show it is not at all inferior to modern science and technology but based on their intricate knowledge of the oceanography and fish behaviour (c) the need for formal R&D to study thoroughly and recognise the artifacts of artisanal fisheries sector in order to develop technologies appropriate to tropical waters.

Sources of information

i. Author's learning and experience as a community organiser with artisanal fishing community in Trivandrum district of Kerala State.

ii. Author's continuous interaction with artisanal fishermen during the information sharing sessions of "Dissemination of Scientific and technical information to fishworkers in Kerala", a three year fishermen's training programme by PCO sponsored and financed by Council for Advancement of People's Action and Rural Technology (CAPART, New Delhi).

iii. Participation in the artificial fish habitats building process from planning to execution and evaluation. Observation of fishing in the artificial fish habitats and discussion with fishermen while fishing in the artificial fish habitats and in the 'Gramakoottom' meetings.

iv. Artisanal fishermen involved in the construction of the 22 artificial fish habitats (49 artificial fish habitats fishermen were interviewed) and fishermen participated at various stages of the development of artificial baits (48 hook and line fishermen were interviewed)

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"Preview of the study" held at PCO on 9th April 1989. Respondents (artificial fish habitats builders and bait innovators) were fed back all information collected from them and others and checked the facts with them. A few fisheries and social scientists were also present.

Evolution of Artificial Fish Habitats

1. Background

India is the seventh largest fish producing country in the world. It has a coastline of 7517 km. Gujarat, Maharashtra, Goa, Karnataka and Kerala on the West Coast and Tamil Nadu, Andhra Pradesh, Orissa and West Bengal on the East Coast are the maritime states of India. The union territory of Pondicherry and Islands (Andaman & Nichobar in the Bay of Bengal and Lakshwadweep in the Arabian Sea) also covered in the coast line in India. The major share of marine production in India is still being contributed by the small-scale fishermen, using mostly traditional fishing craft and gear. In the small-scale fisheries, hook & line fishing is the oldest sustaining fishing method. Trivandrum and Kanyakumari districts of Kerala and Tamil Nadu respectively have the largest concentration of hook & line fishermen in India.

2. Fishery Situation in Trivandrum & Kanyakumari

Kerala and Tamil Nadu lie in the humid tropical zone (See Map I). The coastal fish habitats in this tropical waters are among the biologically richest and most diverse eco-systems of earth. Kerala has the highest pressure of fishing in the inshore waters, having only 10 ha per fisherman in 1980 as against 37 ha per fisherman for India as a whole[1]. Among the marine fishermen in India, 27% are in Kerala. Even though Kerala's land area is small comparatively, it enjoys 8% of India's coastline. Sixty five percent of the marine production of Kerala is still landed by traditional crafts. Kerala had 26,271 traditional fishing crafts in 1980, of which 11,480 were kattumarams[2]. In 1990 there were 30,459 traditional fishing crafts, of which kattumarams accounting for 15,090[3].

The state of Tamil Nadu with a coastline of 1,000 KM and continental shelf of 61,200 sqkm upto 200 m depth accounts for 13% of the coastline and 14% of the shelf region of India[4]. It varies from 40-60 KM, and more than 63% of this is no deeper than 50m. The fishing fleet consists of about 46,000 craft of which over 80% are traditional crafts. Traditional crafts are responsible for about 70% of the marine landings. The majority of the crafts are kattumarams. Propelled by oar and sail, kattumarams are still the predominant fishing craft in the state.

Fishing is the sole economic activity of the coastal people of Trivandrum in Kerala and Kanyakumari in Tamilnadu. Hook & line fishing from kattumarams at sea is one of the predominant fishing methods. Constructed entirely of wood and made with the simplest of tools the kattumaram represents the longest sustaining sea-going craft. The advantages are many: unsinkability, easy construction, low cost, relative stability, maneuverability and best suited for beach launching and landing in the surf-ridden sandy beaches of the region.

The continental shelf of the South West coast is as wide as 68 KM in North Kerala and as narrow as 40 KM in Kanyakumari. The narrowest continental shelf in Kanyakumari gets wider as it goes towards the North. The continental shelf of Trivandrum and Kanyakumari is so narrow that it makes the inshore sea steep, sloped and surf-ridden. While the sub-stratum of the inshore sea North of Quilon is mostly slushy or muddy due to a large number of rivers emptying into the sea. Trivandrum and Kanyakumari have sandy substratum due to the lack of muddy inflow into sea. The coastline of Trivandrum is regular sandy beach except in Kovalam (The International Tourist Beach Resort) and Vizhinjam. It has rocky outgrowth in the inshore sea in the depth range 18-40 fathoms (32 to 72 m) in Kanyakumari, the coastline is largely irregular with patches of rocky outgrowth extending from the shore to deep sea.

Compelled by these oceanographic features, fishermen of Kanyakumari and Trivandrum developed highly skilful hook & line fishing and kattumaram rowing and sailing. Trivandrum in 1980 had the largest number (90%) of the kattumarams and hook & line units in the state, ie. 10,302 out of 11,480 kattumarams and 2,133 out of 2,949 hook & line units[5]. In Trivandrum the Kattumarams figured 13,527 in 1990[6]. The fish habitats in Trivandrum and Kanyakumari present a large variety of colourful reef fishes.

3. Development of AFH

Natural fish habitats are the result of biological or geological processes taking place in the sea bottom.

> *"A fish habitat develops when benthic organism build a rigid, wave resistant structure on the sea bottom. The fish habitat provide a shallow water environment favourable to many organisms, where nutrients are readily recycled. Barnacles, algae, mussels and other sessile organisms for instance colonise a artificial fish habitats as they do any firm surface in shallow water. The processes by which organisms invade a previously uninhabited area is known as Ecological Succession" or fouling. It begins with an accumulation of bacterial slime. Benthic diatoms and protozoans appear next. They multiply rapidly utilizing absorbed organic compounds and products of bacterial decomposition. Hydroid and multicellular algae follow and then come the planktonic larvae of barnacles, mussels and snails. Eventually the ecosystem reaches a balanced state or climax community in which no further colonisation occurs and ecological succession ceases unless a disturbance of the system causes the process to start afresh."* [7]

What is an Artificial Fish Habitat ?

An artificial fish habitat (AFH) is any external object or stable structure placed in the sea to attract, aggregate and regenerate pelagic, demersal, migratory and residential fishes.

AFHs - Origin and development of the Idea

As an age old practice, traditional fishermen of Trivandrum operating shore seine used to dump rocks fastened with coconut fronds into sea bottom to attract fish closer to the shore. Fish which got aggregated over the bottom structures were caught by shore seine locally named *"karamadi"* ('kara'=land, 'madi'=seine), a gear pulled from beach from two sides by about ten fishermen on each side. This practice was based on their knowledge that fish tend to congregate over bottom structures.

It may be generally stated that alien objects of virtually any kind placed in the water would cause some form of fish congregation. A well known example is the large number of Japanese warships sunk during Second World War still serving as excellent AFHS.

During the second world war a ship was sunk off Anjengo fishing village 45 KM north of Trivandrum at 25 fm (45m) depth. Local fishermen rescued nine crew members from the sinking ship. Efforts made by authorities to locate the wreck became futile. After nine years in 1949 a hook and line fisherman alias Sukkurappan discovered the wreck while engaged in hook and line fishing. The wreck measured 50 m long and 45 m wide and 7 fathom depth from the top of the ship. The wreck matured into a rich AFH which attracted line fishermen who fished from the AFH using artificial bait (see Fernandez. J, 1994, 'A Bait to Dazzle the Fish'). Artificial bait hooked more fish than natural bait used by local fishermen. Infuriated by this the locals chased the 8 southern fishermen out of the wreck. They justified their action on the basis of their belief that it was morally unjust to catch fish without giving food and artificial bait would chase the fish away from the wreck. But the southerners achieved the fishing right by getting women of Anjengo married and settling down there. This was possible because of the "matrilineal" and "matrilocal" systems prevalent in the fishing communities of Trivandrum and Kanyakumari districts. A folk song in Anjengo stands testimony to this story:

Vernacular: *"Sukkurappan kandupidicha kappalparu*
Irayillathe meen pidichu thekkenmaru"

Translation: *It is Sukkurappan who discovered the ship wreck*
but fished without bait by southerners.

Almost simultaneously two anchors were lost and sunk at about 12 fm from the ships berthed at the Valiathura Pier, 5 Km west of Trivandrum City. One anchor was taken from sea bottom by skin diving by a local fisherman late Mr. John. He was not able to find the second one. About 10 years later line fishermen located the anchor spot which by that time became a rich fishing spot. These were the earliest known examples of external bodies attracting fish and maturing into rich fishing spots. Of recent there were many such wrecks in the inshore waters of south west coast. An oil tanker sank in about 1970 at 31.5 Fathom off Sangumughom beach. Two boat wrecks occurred in the early 80's, one at Vizhinjam at 14 Fm and another at Chouvara at 12 Fm. Hundreds of rocket noses which fell into the inshore water from the weather testing space rockets launched from Indian Space Research Organisation and Vikram Sarabhai Space Centre, established near Thumba fishing village are serving as good fishing spots, Enayamputhenthura has a boat wreck too (See Table I)

An examination of the evolution of AFHs in the South West Coast of India reveals that three factors have simultaneously contributed to the origin and development of th idea of AFHs and there were four phases in its evolution.

i. **The age old practice of dumping rocks fastened with coconut fronds into sea bottom by shore seine operators to attract fish closer to shore.**

ii. **Anjengo ship wreck which not only aggregated pelagic fishes but also attracted deep sea reef fishes like *"kalava"***

iii. Anchor lost from ships berthed in Valiathura pier and became a rich fishing spot (See Map - II).

Four phases of the evolution of AFH

(i) Origin phase

According to well informed fishermen of Puthiyathura and Eraviputhenthura, artificial fish habitats were setup in Puthiathura of Trivandrum in 1953 and in Eraviputhenthura village of Kanyakumari in 1957. Line fishing is the predominant fishing method in Puthiathura, fishing mostly in natural reefs. Among them one rocky reef is at 12 fm and 2.5 km off the coast. Since they found that the nearby rocky reef in Karimkulam which was higher than theirs was more productive, they decided to enhance the productivity of their reef by heightening the reef. Two lorry loads of rocks packed in bags were dumped on the top of the reef making it 0.5 m taller. Productivity substantially increased after six months of the dump. This was the first known attempt to enhance productivity through artificial means.

In 1957 the Panchayat (local government) authorities built a community well in Eraviputhenthura with concrete rings. One ring of the size off 3 m diametre and 0.5 m height was left over after the completion of the well. The ring was taken by some fishermen and dumped at 11 Fm depth and 1.5 km off the coast on a clay substratum, which was already being used as a fishing ground by line fishermen. This was the first time in the village of **Eraviputhenthura an external structure was dropped on the sea bottom which soon became an artificial fish habitat known as *"Vattuparu" ("Vattu" = ring, "paru" = reef)*. These were the two early attempts to create artificial fish habitats in the 50's.**

(ii) Dormant phase

The origin phase was followed by a period of 25 years of dormancy in the AFH construction. Between 1957 and 1980 no effort was generally made by fishermen either to create new AFH or to service the existing ones. In the words of fishermen of Puthiathura and Eraviputhenthura, "Nobody took interest to maintain them or create new ones". This can be due to the introduction of synthetic gear materials like nylon nets (Polyester), synthetic line (Polyamide) and ropes (Polyethylene) in the second half of the 60's which revolutionised the fishing gear technology. The change from cotton to synthetic gear materials increased productivity per unit effort. Resources were not fished to the optimum leaving room for steady increase in production. Also trawlers and purse-seiners were not yet introduced in the region. Hence no compulsion on the part of the fishermen to go in for AFHs making.

(iii) Active phase

With the dawn of 1980, efforts were made by fishermen to reactivate the existing AFHs and construct new AFHs especially in Trivandrum district. Fishermen started feeling the pinch of resource depletion which started with the middle of the 70's. To quote Achari T.R.T, "since the middle of the seventies, Kerala has been passing through a fisheries crisis. The characteristics of the crisis are broadly indicated below:

1. **The demersal fishery wealth of inshore sea of Kerala started diminishing on account of indiscriminate fishing leading to over exploitation. Several bottom species are on the wane. The striking example is prawns.**
2. **Production has been lagging behind since the middle of the seventies in spite of the fact that high and intermediate technology inputs have been fast increasing.**
3. **The monsoon upwellings in the inshore sea (chakara), a manifestation of rich fishery of Kerala, have become a rare occurrence in recent years, indicating certain changes in the environmental and ecological condition.**

4. While the off-shore resources remain virtually unexploited the inshore water is over capitalised with more and more investment on production inputs."[9]

Moreover the impact of the introduction of bottom trawling in the 60's began to be felt severely towards the end of 70's. By ploughing the sea floor with fine-meshed trawling nets, the bottom trawlers caused heavy damages to the benthic vegetation, the food chain, juveniles and the natural habitats of a wide variety of inshore life, the most productive zone of the ocean.

As a measure of rehabilitation or enhancement of areas impacted by overfishing and bottom trawling, fishermen built 19 AFHs since 1980 in Trivandrum and Kanyakumari (See Table II & Chart I). During the same period the two AFHs created in the 50's and remained dormant for nearly 25 years were revived, serviced and enlarged.

(iv) Cooperative and collaborative phase

In 1988 two research institutions, The Central Marine Fisheries Research Institute, Cochin and Department of Aquatic Biology and Fisheries, University of Kerala have cooperated in the study of the biological aspects of AFHs development in the AFHs, which fishermen of Valiathura created in 1988 with the financial assistance of Intermediate Technology Development Group, London through South Indian Federation of Fishermen Societies, Trivandrum. This is the first AFHs construction where fishermen and an outside agency collaborated in financing, planning and constructing a AFH. The CMFRI researchers placed 12 specimen materials in the newly created AFH to study the bio-mass growth to understand the best suitable materials for AFHs building. The total cost of the AFHs was Rs. 10,000. This AFHs was supposed to be larger than the previous one built by the same fishermen measuring 30 m length, 15 m width and 0.75 m height. A structure was built for the first time by fastening worn out tires with concrete rings. While transporting these structures on Kattamarans from the shore to the AFHs site, the rings ripped apart and therefore attempts to place them in the water failed initially. The author has participated in the process of this AFHs building right from planning to execution and evaluation.

(v) Present Trends

Three trends are visible in AFHs programmes around the world. In Japan, where the AFHs technology is the most advanced, AFHs is one of the biggest governemnt financed research project. These huge AFHs are also used for large scale commercial fishing. Since the most advanced technologies are used for the AFHs Programme in Japan, the Government's annual budget for AFHs run into billions of Yen. The Europian and North American AFHs Programmes reveal a trend towards using AFHs for tourism promotion and academic research. Tourism industry is showing strong interest to invest in AFHs to use them for angling, diving and 'Fish Watch'. Marine Science Department of many universities in USA and Europe are involved in small and big AFHs research projects. The third category of AFHs were those developed as a survival technology by traditional and artisanal fish workers in the third world countries especially in Africa and Asia. This has become imperative because of loss of aquatic habitat both in the marine as well as fresh waters. In India efforts were taken by coastal fishing communities during the 80's to construct FADs (Fish Aggregating Devices) mainly in the south east coast in the Bay of Bengal and bottom reef structures (Artificial Reefs) in the south west coast in the Arabian Sea. The artisanal fishermen with the help of NGOs like PCO and SIFFS over the last ten years made many AFHs. They made improvements in design, size, location and placement. The AFHs (bottom structures) created by the artisanal fish workers function not only as fish aggregating devices but also started functioning as habitats. Under water photographs taken recently from the AFHs in Trivandrm show clearly that 'colonisation' or 'ecological succession process' is taking place. Eventually it will contribute to the productivity. The Govenment of Kerala recently implemented the same AFHs programme using ferro-cement triangular structures in Pozhiyoor village. "The community built, community managed" AFHs could be used as a rallying point for village fishing communities to manage the inshore resources sustainably.

Formation of Artificial Fish Habitats

In our analysis of the factors influencing the formation of artificial fish habitats, we found the fishermen have considered several aspects. Over the years their thinking process got improved on better scientific lines. These factors are discussed below:

i. Site selection

Selection of site for constructing AFHs is an important decision in the entire AFHs building process. The failure or success of an AFH depends primarily on the site. The parameters used by fishermen in selecting sites for most of the AFHs were wave damage, shore-seine operating range, gillnet operating range, easy accessibility, live-bottom, and poaching. All but two of the 22 AFHs were built in the 9 to 18 fm depth range (See Chart I). As the sea is surf-ridden the waves are quite strong and in order to avoid damages from the waves the AFHs were placed far enough from the shore. Shore seiners operate from beach to 9 to 11 fm, and hence to keep these away from shore seine obstruction. Most part of the productive seasons gillnet operates beyond 18 fm. Only occasionally they do operate in inshore sea. As users of the AFHs are mainly aged fishermen and children the AFHs must be easily accessible by manual oaring. AFHs constructed in the locations north of Beemapally which is about 7 km south-west of Trivandrum city are restricted to members only and therefore they were built within sight from the shore in order to avoid poaching by non-members. All these AFHs were sited on or near a live bottom or productive substratum. To them AFHs is a productivity enhancement tool.

ii. Materials used

Materials used in the first generation AFHs were concrete rings, fastened with coconut fronds, coconut stumps, screw pine plants. The basis of the selection of materials was the fishermen's knowledge of sea bottom, its benthic vegetation, natural fish habitats and fish behaviour. From their experience they know that fishes use AFHs for shade, shelter and food. Coconut fronds and stumps help plankton and other biomass to grow on them which attract small fishes which in turn become food for AFHs fishes. High structures like rings provide shade and heaps of stones provide the niches and wholes for shelter and refuge from predators.

iii. AFHs design and placement

The productivity of a AFH is found to be related to the size and shape of the AFHs. The size of the first generation AFHs was about 20 m long, 10 m wide and 0.5 m height. The productivity is also related to height. Taller the AFHs higher the productivity. Initially materials were dropped at random without the help of any equipments hoping that they dropped straight and placed on the intended sea bottom. But this 'random dump and hope method' didn't work well. The result was that the AFHs didn't have desirable shape, size or height. The first generation AFHs materials were actually placed in unoriented piles and mounds. According to the AFH fishermen, productivity was low in these AFHs compared to the Sangumughom AFH with 3 m height and at 18 fm depth, that serves as the most productive AFH. The size of the fish school will increase with the size of the AFHs. The ratio of structural height to water depth has been studied and a minimum ratio of 1:10 is required for good aggregation of pelagic fishes[10]

iv. AFHs Direction

Most of the (14 out of 22) AFHs were placed in the east west direction. The local current in the inshore sea usually flows from north to south and vice versa. Current changes within 24 hours some times. These southerly and northerly current shifts to east and west frequently at the instance of change in temperature, direction of wind etc. The traditional hook and line fishermen using sails have intimate knowledge of flow of current through out the year and its seasonal and even daily changes from their experience. In order to do line fishing in the AFHs the Kattamarams have to stay just above the AFHs so that the lines with hooks and the weight go straight down to the AFHs. By constructing the AFHs in the east-west direction across the northerly and southerly current the Kattamarams could anchor either south or north of the AFHs as the current may be and stay over the AFHs one after the other. In this manner each Kattamarams will get sufficient space over the AFHs.

v. Fish behaviour and AFHS

Shade, shelter and food provided by AFHs are mainly the attractors of fish to AFHs. All the 49 fishermen interviewed agreed to this point. According to them some fishes use AFHs as a dwelling place. They are known generally as reef fishes (Parumeen). Others come, rest in the reef shades and leave. Yet some others use the nooks and crannies of a reef to hide from predators. Classification of this behavioural pattern corresponds to what Robert S Grove and Choule J Sonu (1983) say:

> *"One of the fundamental reasons for the fish to be attracted to AFHs may be related to instinct. Some species may be seeking a dwelling in AFHs. This probably explains the strong tendency of bottom dwellers to flock to AFHs. The mid and upper layer swimmers may be using the AFHs as a resting and or feeding station. Others as a shelter or refuge from predators".*[11]

Fish respond to AFHs horizontally and vertically. There are upper fish and lower fish depending on their vertical response. There are residentially and migratory species which respond to AFHs horizontally.

The behavioural response of fish to AFHs changes with light conditions. The Puthiyathura fishermen are of the opinion that hooking rate is the highest early in the morning and gradually reduces to almost nil at noon and increase gradually to almost half that of the morning in the afternoon. The trend of the hooking rate if drawn on a graph looks like a hook.

This is substantiated by the fact that all hook and line fishermen in this region fix the launching time by calculating the distance to AFHs and the time to reach in such a way that they may be on the AFHs just at the time of sun rise.

AFHs fishing is done from December to March, the fair season in the south west coast. As the marine water is non-turbid and clear sun light goes deep down. To escape from the heat and to search for food, fish get more aggregated in the bottom structures during this season. In the rest of the year inshore is turbid and rich with planktonic organisms due to "monsoon upwelling", which produces also a cooling effect in the sea.

vi. Spawning in AFHS

Whether or not spawning takes place in AFHs is the most debated point among fisheries scientists. However Puthiyathura fishermen confirmed that cuttlefish (Sepia pharonis) spawned in their AFHs. Agreeing to this Thoothoor fishermen informed that cuttle fish hither to not found in the inshore water of the region got aggregated in their artificial AFHs. Cuttle fish caught from their artificial AFHs weighed between 5-6 kg. They were spawning in the AFHs. During clear water the fishermen were able to see juvenile cuttle fish in their AFHs.

> *"Perhaps the most likely near term application for designed AFHs for commercial fishing would be related to their use to create or expand nurseries or spawning grounds. Although most American AFHs researchers continue to debate whether AFHs actually increase productivity or merely attract and concentrate organisms from surrounding areas Japanese Scientists generally have little doubt that AFHs, when properly designed, sited and placed can be used to increase the productivity of desired species "*[12]

According to Sanjeeva Raj[13] who has been experimenting with artificial fish habitat and Fish Aggregating Devices in Madras in the east coast the most encouraging feature was that the fry of about 5 species were collected amidst the coconut fronds so that it is suspected that these species might be breeding at these artificial fish habitats. How ever this point is now being put to investigation and confirmation.

Later experience support the view that fish breeding also take place in artificial fish habitats (see cover page photographs by under water divers)

vii. Fishing methods in AFHS

The only fishing method used in these AFHs is hand lining from Kattamarams. Most popular baits used in the AFHs are artificial baits. Occasionally natural baits are also used particularly to catch AFHs resident species. Active migrating fishes like little tunnies (tunas) are caught by *Thoottavu*, a surface hand lining with only one hook hidden in a live bait usually mackerel or scads that are caught by *Achil* a hand line with 25 to 50 hooks baited with artificial baits. Occasional visitors form the bulk of the fishes caught by *Thumbu*, a hand lining with two hooks baited with natural baits. By means of these three kinds of line fishing AFHs fishermen are able to catch all species related to a AFHs. (For details see Fernandez. J,1994, 'A bait to dazzle the fish').

Latest Developments in AFHS

i. Recreate the complexities and surface of natural fish habitats

> Initially, AFHs builders concentrated on recreating the complexities and surface of natural fish habitats. Hence materials selected were similar in sight and substance to those in the natural reefs. Stones often taken from sea walls fastened with coconut fronds, well rings, screw pines and coconut stumps were the materials used in the first generation AFHs. These AFHs

were small in size and short. Average size 17 m long and 10 m wide and 1 m height. They chose what ever materials freely available in their respective localities example Tar roller wheel in Eraviputhenthura, empty iron barrels and telephone post in Valiyathura, Concrete waste from demolished structures in Valiyathope, sea weeds in Vizhinjam etc. These materials were dumped as they were. (Fig A and B)

ii. Modified AFHS materials

From the experience gained from first generation AFHS following modifications were made in the AFHS materials.

(a) Stones packed inside coir and rope nets.

The sandy bottom of inshore sea is subjected to the fury of monsoon waves and upwelling. The cumulative effect of this process exerts heavy siltation and gradual burial of AFHS materials placed in a scattered manner. In order to withstand the siltation and burial the Puthiyathura and Beemapally fishermen packed stones in large coir or rope nets with mesh size big enough for fishes to enter and small enough to retain the stones together(Fig B). Similarly, parts of trees were packed and dumped to create vegetation in the AFHS site for the decay which will enhance the nutrients.

(b) Painted Stones

In Thoothoor, fishermen observed that the natural reef with red colour attracted certain resident reef fishes. Motivated by this, they created AFHS with stones painted with red colour. The fish workers in Thoothoor claim that stones painted with different colours will attract fish with different colours. It is the red sea weeds that create red colour in the natural reef. Fishermen also claim that 'maturing' of an AFHS can be reduced considerably if the materials used are painted with the desired colours.

(c) Tyres fastened with concrete rings to give 'shape' to AFHS materials

A recent development in artificial fish habitats construction in Valiathura is characterised by model making. Discarded tyres were used with rings to give particular shapes to attract resident fishes which use the spaces as hideouts.

(d) Materials modified for protection of AFHS

Drift nets are menaces to the AFHS. The 'sliding wall' effect of drift nets keep away fish from the AFHS. Fishes in shallow waters when exposed to sunlight during fair whether season occupy the bottom zone of the sea. Drift nets are operated over the AFHS to catch these species. Nets may get entangled in the AFHS which may act as a barrier to fish to enter the AFHS. AFHS builders made many modification in the construction to protect the AFHS from entangling and sliding wall effect of drift nets (See Fig C). Modifications made are as follows :

a. Iron hooks over the concrete ring (Poothura).
b. Installation of iron pillars around the AFHS (Thoothoor).
c. Installation of anchors around the AFHS (Valiathura).
(See Table III for Details)

Motivations For Artificial Fish Habitats

i. Loss of natural habitat by over fishing and bottom trawling

The accumulated effect of trawling introduced in the mid 60's resulted in the degradation of marine environment especially natural marine habitats and fragile coral fish habitats systems in the south west coastal waters. In an earlier attempt in 1987 to study the status of natural reefs, the author was told by the late Mr. Arogyam, the then oldest living line fisherman aged more than 90 that in his younger days he used to fish from at least 150 small natural fish habitats in the inshore waters. All of them have been destroyed or rendered unproductive by Norway ships, local name of trawlers as they were introduced with the help of Norway. Its impact on resources began to be felt severally with the beginning of 1980. Line fishermen whose main source of fish were natural fish habitat sites began to build AFHS as enhancement of areas impacted by trawling.

Over fishing, the characteristic feature of Kerala fisheries since the middle of 70's resulted in fall in production particularly the share of traditional fishermen. Over fishing was mainly due to discriminate fishing, bottom trawling and mechanised fishing. Artificial fish habitats are built to regenerate the fish habitat destroyed by overfishing and bottom trawling. They are used as protection grounds for marine living resources and obstruction to trawler operation in inshore waters.

All except one artificial fish habitats were built with in the depth range of 9-16 fm. This is to bring fish as close as possible to save fuel and labour. The artificial fish habitats can be reached by oars without the help of outboard motors and far enough to avoid wave damage. Though fishing in the outer natural fish habitats is done individually a crew of six fishermen who go in plywood canoe powered by an OBM to reach the natural fish habitats. Maintenance of engine and fuel cost become unbearable for them. An AFH in close waters solves these problems.

ii. Role of formal R&D

The formal scientific R&D institutions and personnel maintained until very recently a don't care attitude towards artisanal fisheries sector. This was because of the fisheries policy followed by state and central governments since the introduction of planned development in the 1950s. Neglecting the knowledge and fishing methods of artisanal fishermen as 'primitive and unscientific' the central Government with the support of the formal R&D went all out for modern technologies like trawling. Attention of formal R&D was concentrated almost completely on modern mechanised sector which caters generally towards international market.

Technology development based on the traditional sector was little cared for. Hence the initiative for this fell on the shoulders of the fishermen themselves and the non-governmental organisations working in support of artisanal fishermen. The much popularised motorisation of country craft in Kerala today had its early experiment at Muttom of Kanyakumari district of Tamil Nadu in 1970 under the Indo-Belgian Fisheries Project, a non-governmental organisation and through Marianad Fishermen Cooperative in Trivandrum District in 1974[14]

In fact the formal fisheries scientist community in Kerala came to know of the construction of artificial fish habitats by artisanal fishermen when the author informed about this in an all Kerala Fisheries Conference held in Trivandrum in 1987. Initially, the scientists could not believe it. On the same day the Director of CMFRI and a team visited Valiathura and confirmed the author's claim. This is a typical example of the extent of 'negligence' of formal R&D of the technology developments in artisanal fisheries. The Central marine Fisheries Institute, Vizhinjam and Department of Aquatic Biology and Fisheries University of Kerala started collaborating with PCO since 1988 to study the biological process of the AFHS.

Apart from the 1988 Society (SIFFS) AFHS all the 21 AFHS constructed were of the fishermen, by the fishermen and for the fishermen. The only outside help received was a donation of Rs.700 from the village church for the construction of one of the AFHS.

The study reveals that AFHS construction is an area where artisanal fishermen with their intricate knowledge of oceanography and fish behaviour, marine Biologists, with their knowledge of AFHS biology and Marine engineers with their knowledge of structural engineering could join hands to improve productivity of AFHS. The productivity of all but one AFHS is very low because many biological and engineering parameters were not considered seriously in the artificial fish habitats construction. The rate of siltation, time or maturity, materials and structuring of AFHS were not properly assessed before its construction. This is where formal R&D could participate in AFHS construction.

In the case of artificial bait it was entirely innovated, designed, adapted and spread horizontally by fishermen themselves. The formal R&D did not play any role. The most popular artificial bait known as 'minisum' was evolved on the basis of their knowledge acquired through constant interaction between fishermen and fish and observation of fish behaviour to bait.

The ship wrecks of Anjengo and Sangumugham still serving as rich fishing ground are source of motivation for AFHS construction.

Highly adventurous and innovative nature of Trivandrum and Kanyakumari districts, prompts them to explore new ways of solving their problems. E.g. Kattamaram launching from Valiathura Pier.

The present concrete pier (213 m long and 7 m wide) built in 1956 for loading and unloading cargoes was declared a dead port for shipment. Taking advantage of this fishermen in Trivandrum are making use of this pier for launching their kattamarams during monsoon when beach launching is extremely difficult owing to the presence of high surfs in the coastal sea. "The way the fishermen of Valiathura and adjacent villages in Trivandrum launch out their kattamarams into sea during the period of north west monsoon (June-August) is an example of over-coming obstacles of nature through innovations and ingenuity. Fishing activity in many parts of the south west coast lying between Cape Comorin and Quilon remains suspended often at many centres in monsoon season mainly because the fishermen find it difficult to negotiate their kattamarams through the unfavourable breakers. On account of this, the fishermen move to certain centres that afford favourable conditions for setting off their craft in the sea. Centres like Colachil, Kollengode, Vizhinjam and Quilon have bays or barriers and hence considered good for fishing operations during monsoon period. The fishermen of the area from Kovalam to Veli where that coast is rather straight, sandy and much exposed to the fury of monsoon waves, solve this problem by taking advantage of Valiathura pier for launching the craft safely into the sea"[15]

Impact of Artificial Fish Habitats

The impact of AFHS is assessed at the micro level and macro level by considering the multi-faceted aspects. At the micro level, costs and earnings, social and ecological sustainability and effect on employment are assessed. Resource management and energy conservation are considered at the macrolevel.

A. Micro-level assessment

(i) Costs and Earnings: From no cost to low cost

Artisanal AFHS constructed with massive support and left open like in the village of Eraviputhenthura cost them nothing as the materials used such as concrete rings, coconut fronds and stones were available freely in their locality. Transportation and labour were contributed freely by the interested fishermen. However, AFHS constructed by and restricted to specific groups and individuals cost them from Rs.900 in 1983 for Valiathura AFHS to Rs.10,000 in 1988 for SIFFS sponsored AFHS. AFHS varied from no cost to low cost depending on the types of materials used and the size. In 1988 the Kochuthope artificial fish habitat was built at the cost of Rs.6,000. Initially 100 fishermen used to fish from this AFH and the membership subsequently rose to 300. About 94% of the AFH fishermen were able to get a daily income of Rs.18 to 50. Around 4% of them had upto Rs.200 per day per fisherman during high catches. An average of Rs.39 was earned by fishermen per fishing day[16]. According to a rough estimate of the SIFFS society fish worth of Rs.10,000 were caught from the AFHS built at the cost of Rs. 6,000 in the first year of operation.

The cost of construction of AFHS is around Rs.2,000 upwards. The average income per day has been Rs.600 but some of the higher incomes have been Rs.2,000 to Rs.3,500 and a single record catch was 10,040 kg of the round scad was sold for Rs.3,500[17].

Moreover AFHS fish landed afresh and just in time for marketing fetches higher prices. The addition of the amount over and above the normal market price is a bonus for bringing the fish fresh. Artisanal AFHS built in the close coastal waters enables fishermen to make more than one trip to artificial fish habitats within a day.

AFHS constructed in the "active phase" earned more than the cost. It is truly a low cost technology. There is tremendous scope for increasing productivity of AFHS. Because of the random dump and hope followed in the construction of all but one AFHS the materials were placed in unoriented piles or mounds. Since they are not structured the height of the majority of the AFHS were between 0.5 m to 1.5 m. They were so short that they get buried by siltation due to soft sandy substratum and monsoon waves. Maintenance and reinforcement of the AFHS become necessary every year soon after the monsoon. Though the initial cost is very low, recurrent costs to maintain them would be high.

(ii) Ecological and Social Sustainability

A technological innovation should not only be economically sustainable but also socially and ecologically sustainable. While the formal R&D in fisheries concentrate on harvesting and post-harvesting technologies, AFHS by artisanal fishermen is essentially a pre-harvesting technology in that they are regenerating the benthic vegetation so much devastated by indiscriminate fishing including commercial bottom trawling. It is nourishing the sea or 'nurturing nature'. By creating the marine habitat AFHS preserve what is called the 'bio-diversity'. If knowledge is the mother of all resources, the physical, chemical and biological processes of resources is the father. Only by blending both the mother and father aspects judiciously that we can be able to utilize resources in sustained manner and leave them without damaging permanently to the posterity.

Traditional fishermen innovate and develop technologies in response to both these aspects. For example the only method used to catch fish from artificial fish habitats is hook and line fishing which does not disturb the artificial fish habitats environment and catch only the targeted fish leaving the juveniles and other species. Selective and passive line fishing keep the ecological succession or food chain undisturbed. Materials used for artificial fish habitats constructions were non-polluting and mostly biodegradable to enhance growth of marine organisms. They provide ecological niches for fish to feed and breed. It is essentially an eco-technology.

(iii) Effect on employment

AFHs make line fishing possible round the year except during monsoon season (June-August) when the sea becomes turbid and turbulent. Earlier line fishermen of Trivandrum and Kanyakumari used to go far beyond 50 fm upto 150 fm for deep water and reef fishes. It took 2 to 3 days to complete the fishing operation including journeys both ways. Using sails powered by wind fishermen often get stuck in the sea for want of appropriate wind. Only daring and adventurous adult fishermen used to take such risks. Deep water line fishing was during the fair weather season (Dec-March). The majority of the line fishermen were depending on natural fish habitats in the range of 16-24 fm depth. As they were all destroyed or rendered unproductive, these fishermen were affected badly particularly the old and the young. After a certain age the sight becomes too poor to see the geographical fixed land markings in necessary details to line up to locate the fishing spots. Either they have to accept the status of a permanent member crew or remain unemployed. The younger ones learning the fundamentals of line fishing need to be in closer sea to be safe. AFHs constructed in close waters not only provided employment opportunities for the fishermen in general put also to the old and young fish workers.

B. Macro-level Assessment

Resource management and energy conservation

At the macro level AFHs may be a resolution of the conflicts between the artisanal fishermen and commercial fishermen. AFHs are built to regenerate the natural fish habitats and used as protection grounds for marine living resources by effectively obstructing bottom trawling in inshore waters.

AFHs built in close coastal waters save fuel which otherwise will be spent for reaching for fishing grounds and searching for specific fishing spots. All catamarans fishing in the AFHs use oars as most of the AFHs are within 45 minutes reach.

The AFHs is now being used by village communities who have the management of the habitats under their common ownership. In Puthiyathura, Adimalathura and Thumba community AFHs were constructed by the fishermen themselves under the guidance of social organisation.

Learning Process and Constraints

Generally learning takes place through three domains: cognitive, psychomotor and affective domains. Reading and writing are the prerequisites for learning through cognitive domain. As the fishermen in Trivandrum and Kanyakumari are generally illiterate (80% approximate) their learning of fish and their environment takes place through Psychomotor domain requiring very skilful movement of hands and legs and affective domain requiring acute human senses, all the five, work simultaneously to get a 'feel' of fish and the ocean.

> *"Any particular fishing operation in progress is a simultaneous integration of large numbers of discrete thought processes of past experiences with the immediate observation aided by all the human senses. The feel of the sea bottom acquired by touching the plumb line, the smell of the sea, the sight of birds, land marks, stars the colour of the sea and ripples on it, the sound of the shoal movement to mention a few. The coming together of these aspects initiates the response of dropping the hooks, casting the nest or laying the traps. The result: fish is soon caught".* [18]

The sum and substance of artisanal fishermen's science is their intricate knowledge of fish and their environment and the process of inter-relationship, the father aspect of natural resources. Line fishing is an individual operation. Therefore, fishermen in Trivandrum and kanyakumari are always learning to be independent producers. The art of lining up a specific fishing spot of artificial fish habitats is required if a fisherman is to become an independent producer on his own kattamaram. Lining up requires an acute sense of vision. All fishing artificial fish habitats or spots are marked and remembered by individual fishermen using a visual system of triangulation which utilises a series of and marks which can be seen on clear days from most of the fishing grounds. The land marks used by Trivandrum and Kanyakumari districts are steeples of churches, mountains, coconut palm groves, sand bars by the sides of the river mouths etc. By lining up these fixed land marks, they constitute a directional clue to locate the fishing spot. They can distinguish landscapes from sea out to this distance. Distance itself is expressed in terms of depth.

Knowledge of visual triangulation by lining up geographical marks, fishing spots, fish and their behaviour and environment, local wind and current to judge the drift of his cattamaram and lines are learned, accumulated and passed transgenerationally. Though this knowledge is passed from father to son one has to acquire more and more skills and practice fishing regularly to master the art of fishing.

Trivandrum and Kanyakumari fishermen have extensive and detailed knowledge of artificial fish habitats ecology and fish behaviour based on their fishing experience in a limited number of natural reefs. With the plumb line they learn about the length, width and height of a artificial fish habitat with reasonable accuracy. From the pieces of materials entangled in the hooks, like plants, corals and other organisms they learn the biota of artificial fish habitats. These give them the clue to the nature and characteristics of a natural reef.

There are two fish channels in this region. One a monsoon fish channel in 15 Fm and the other is fair whether fish channel in 18 Fm. The knowledge of this is derived from local fishing experience and is virtually impossible to explain by physical parameters like temperatures and salinity. Thus ecological details, fishing grounds and spots bait materials, fish behaviour, feeding habits, fish channels etc. are common knowledge among fishermen.

Spread of innovations

Knowledge of marine environment and fish behaviour accumulated through generations lead to innovations that get spread horizontally. In the case of AFHs, what one fishing village does on

AFHs construction is observed by the neighbouring villages. South west coast is a long stretch of villages situated very closely (see map. Collection of materials, transportation and dumping are done so openly about artificial fish habitats construction. Within a span of 8 years it has been spread to 17 villages from one end of Kanyakumari to the other end of Trivandrum.

The social factors that help spread the AFHs and bait innovations are reciprocate invitations for church festivals, matrilocal system whereby husband stays in wife's house, standing god father to children of friends in other villages etc. Most of time the talk during these social interactions are like the talks around the artificial fish habitats.

Politics of People's technology

People's technology is the answer for overfishing. International market controlled by multinational companies dictates the technology options to commercial fishermen who operate to fulfil the requirements of multinationals at the cost of artisanal fishermen. Example trawling for prawns an export commodity contributed to a large extent to the destruction of natural fish habitat and over fishing. The politics of commercial technology motivated by multi nationals is to extract maximum resources at minimum time to maximise profit. People's technology is based on 'give and take'. So far fishing has been considered as taking or capturing or hunting only. This has desertified the sea. Artificial fish habitat is reforestation of bottom sea.

Constraints

(i) Transportation of AFHs materials and structures

Most of the AFHs are built with light and small size materials for easy transportation by kattamarams. Heavy structures transported in kattamarams often get lost or broken by strong waves. In the 1988 society AFHs at Valiathura many concrete rings were broken on the way to AFHs site. Transportation was a big problem to be solved. Kattamarams are too small and have uneven surface to carry big structures. In the recent, Pozhiyoor AFHs programme a new method of transportation was tried and it became highly successful.

(ii) Random dump and hope

Placement or dropping the materials was done haphazardly by overturning the kattamaram. The result was unoriented piles on the sea bottom making the AFHs short and unshaped. Also these materials may not have dropped on the desired points. Productivity was low in all except one AFHs because of the random dump and hope method.

(iii) Bottom trawling

Sometimes the AFHs structures were dragged by bottom trawlers. Trawlers hunting for cuttle fish operated over the AFHs and rendered them unproductive for a long time.

(iv) Sliding wall effect of drift nets

Bottom drift nets operated during fair weather season sometimes operate on AFHs. Its net sets entangled in the AFHs making a barrier to fish to enter the AFHs.

(v) Siltation

The high rate of silting due to sandy substratum and monsoon waves, affects adversely the growth of biomass and productivity of AFHs. Moreover maintenance and reinforcements become necessary every year as the AFHs gets buried fast. In the Valiathura society artificial fish habitats 12 specimen materials placed to find ecological succession rate on different materials were all buried. So great a loss that nothing could be learned so far.

Suggestions and Conclusion

i. AFHs could be spread in other parts of the south west coast from Cape Comorin to Alleppey where we have the largest number of Hooks and Line fishermen in India. In future, extension of AFHs construction to other villages of Trivandrum and Kanyakumari are possible. Possibility for building AFHs in Quilon must be explored.

ii. The State and/or Central Government should appoint a task force to study the problems and prospects of AFHs and fully subsidise construction of AFHs as it will be an effective tool for conservation of marine living resource and regeneration of lost habitats,

iii. As it is a people's technology, grass root voluntary organisations working with the fishermen may be involved in the construction of AFHs.

iv. An immediate study must be undertaken to find out the siltation rate and ecological succession rate in order to find out the best material suited for our marine environment. The Central Marine Fisheries Research Institute may be requested to take up this study as it is the best equipped agency in India to do such a study.

v. Future AFHs should have materials important for desired target species especially for cuttle fish. The experience of Thoothoor and Puthiathura AFHs confirm that cuttle fish, were atracted to and spawned in the AFHs. As cuttle fish do not have any permanent ground, they settle as a colony locally known as "mada" in different places in different seasons and years. AFHs structured to suit sheltering, feeding and breeding cuttle fish may be the future direction that AFHs construction must take.

vii. Food, shade and shelter are the main attractors of fish to a AFH. The size of the school of fish depends on the size and height of a AFH. Studies in other countries reveal that 10% of the water depth should be the height of the AFHs. The majority of the 22 AFHs didn't maintain this ratio. Future artificial fish habitats must maintain this minimum ratio atleast.

viii. In the selection of AFHs site fishermen were chiefly guided by two factors: Nearness to shore and already known productive muddy ground. But these factors are not very important as far as life and productivity of a AFHs is concerned. AFHs created on an already live bottom would disturb the natural fish habitat there and sinks very fast as the bottom is soft and muddy. AFHs must be sited on firm sandy bottom preferably in the fish channels. In the south west coast there are two fish channels, the monsoon channel at 15 fm and the non-monsoon channel at 18fm. The channels may shift - 1fm or 1fm. Since fishing in AFHs is not done during monsoon it is advisable to select AFHs sites in 18 fm channel. For example Sangumughom AFHs at 18fm is the most productive AFHs in this region.

Conclusion

It becomes necessary to find out the indicators of tradition in order to go to the post industrial era with a clear perception. Kerala is a state which keeps tradition in high esteem.For example Kerala's traditional arts like world known "kathakali", indigenous medical system like "Ayurveda" are preserved and practiced till today.

This generation is going to the post industrial era. We can reach there only by looking at the indicators of tradition in the light of modern science and technology.

Even today there are people in Japan who construct huge and tall building without drawing any plan but keeping the traditional knowledge in mind. But their science is not taught in the Engineering Colleges. We have to integrate the essence of tradition with time. There is no meaning in keeping the indicators of tradition in Museums. They must be subjected to analysis and reinterpretation.

Notes

1. The hook and line fishing is a method of fishing in which the fish has to be baited by live or artificial bait attached to the hook. One end of the line is weighted down with iron or stones and the other end is held between the thumb and forefinger. The plumb line is gently jerked to attract the fish to the bait. Once bit, the line is drawn in, the fish removed and the process repeated. It is the size of the hooks and the depth to which the line sinks that determine the nature and the size of fish caught. After the line is laid, the craft may either remain anchored or drift with the current.

2. Kattamarams in Kerala or Kattumarams in Tamil Nadu are basically a raft of 3-5 log of wood fastened together with ropes. These logs are specially shaped to give the craft a boat-like appearance. *Melia dubia* and *Albizziya* spp are the timber most preferred for construction of these crafts.

3. Traditional fishermen in this region most commonly express distance in terms of the depth of the sea, i.e., in 'Maar' (1 'Marr' is approximately equal to a Fathom, and is the length of the outstretched hands of a fisherman). Sometimes, distance is measured in terms of the time it takes to sail there. Very rarely do they express distance in terms of geographical or nautical miles.

4. The National Workshop on Technology of Small-scale Fishworkers was held in Trivandrum from 27 Feb 1989 to 01 Mar 1989. It was sponsored by the Council for Advancement of People's Action and Rural Technology (CAPART) and organised by the South Indian Federation of Fishermen Societies (SIFFS).

5. What makes the monsoon launching of kattamarams adventurous is the tremendous amount of risk involved in the operation. The fisherman throws himself into the sea from the edge of the pier which is about 8 metres above the sea level. He holds on to one end of a rope, the other end of which is fastened to the kattamaram that is pushed into the sea. As soon as the kattamaram falls on the turbulent sea, he pulls it to him and rows to outer sea. This is highly risky and sometimes fatal too.

Table - I : Accidentally Formed Reefs

Sl. No.	Fishing Villages with accidentally formed reefs	Local name if any	Year of incident	Depth (in Fm)
1	Anjengo ship wreck	Kappal paar	1940	24.5
2	Puthukurichi		1986	8
3	Thumba (ISRO) Rocket nose		Since 1960's	15 - 40
4	Shangumugham ship wreck	Kappal paar	1960's	31.5
5	Valiathura pier and anchor		1940's	0-5 & 12
6	Vizhinjam boat wreck	Boat paar	1982	14
7	Chovvara boat wreck	Boat paar	1980's	12
8	Enayamputhenthura boat wreck	Boat paar	1980's	14

Table - II : Features of Artificial Fish Habitats

Sl. No	Fishing Villages with Artificial Reef	Local Name of reef if any	Year of Construction	Depth (Fm)	Distance (Km)	Substratum in which the reef is constructed	Length of Reef (M)	Breadth (M)	Height (M)	Direction of Construction
1	Eraimmenthura		1985	12	1.5	Clay	10	5	0.5	WE
2	Thoothoor	Chem paar	1987	10	1.5	Rocky Natural Reef	10	5	1	NS
3	Eraviputhenthura	Vattu paar	1957	11	1.5	Benthic Vegetation	15	5	1	WE
4	Paruthiyoor	Ora paar	1980	15	2	Benthic Vegetation				
5	Poovar	Kytha paar	1979	12	1.5	Rocky Natural Reef	40	10	0.5	NS
6	Puthiathura		1955	12	1.5	Rocky Natural Reef	20	15	1	NS
7	Pulluvila	Palli paar	1984	12	1.5	Sandy	10	5	0.5	SE-NW
8	Adimalathura	Kytha paar	1965	15	2	Sandy	15	7	0.5	NS
9	Vizhinjam	Boat paar	1982	14	1.8	Sandy	30	10	2	WE
10	Vizhinjam		1985	15	2	Sandy	7	3	0.5	WE
11	Vizhinjam	Kytha paar	1987	9	1.2	Sandy	15	5	0.5	WE
12	Beemapally		1984	10	1.5	Sandy	20	5	0.5	NS
13	Cheriyathura	Ora paar	1982	9	1.5	Sandy	25	4	0.5	WE
14	Cheriyathura	Ola paar	1963	11	1.5	Sandy	13	1	0.5	WE
15	Valiyathuta	Ouseph paar	1983	15	1.5	Sandy	50	15	1.5	WE
16	Valiyathura	Ora paar	1984	13	2	Sandy	10	5	0.5	Scattered
17	Valiyathuta	Society paar	1988	14.5	2	Sandy	30	15	0.75	SE-NW
18	Kochuthope	Ola paar	1984	15	2.25	Sandy	25	5	0.75	NS
19	Valiyathope		1984	18	3	Benthic Vegetation	50	25	3	SE-NW
20	Vettucadu		1983	8	1	Sandy	Very small size			Scattered
21	Puthukurichi		1986	8	1	Sandy	20	2	1.5	NS
22	Poothura		1982	12	2	Benthic Vegetation	10	2	1.5	WE

Fig. A: MATERIALS USED FOR ARTIFICIAL FISH HABITATS

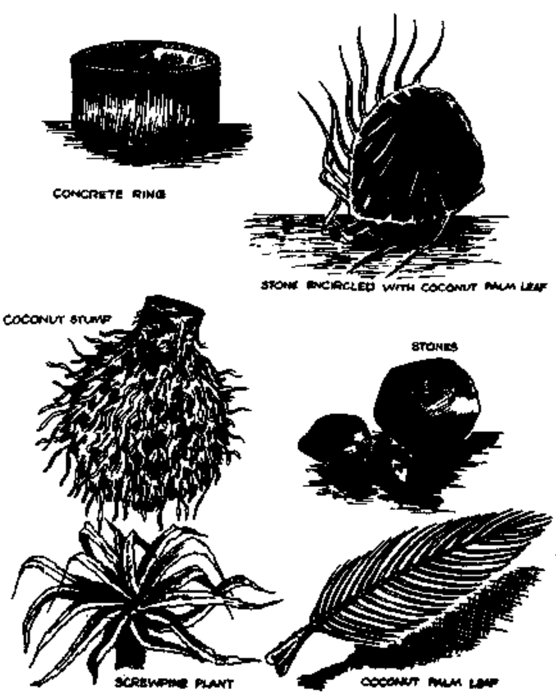


Fig. A: (Contd.)

Table - III : Incremental Changes in Artificial Fish Habitats

Sl. No.	Fishing Villages with Artificial Reef	Local name of reef if any	Year	Materials used in the first installment	Year	Material used in the second installment	Year	Materials used in third installment
1	Eraimmenthura		1985	Stones, Coconut fronds	1986	Stones, Concrete ring	1987	Stones, Coconut stump
2	Thoothoor	Chem paar	1987	Stones painted with red color, Coconut fronds				
3	Eraviputhenthura	Vattu paar	1957	Stones, Ring, Coconut tree	1989	Stones, Coconut tree, Tar roller wheel	1987	Stones, Coconut tree, Palm fronds
4	Paruthiyoor	Ora paar	1980	Coconut fronds, Ring				
5	Poovar	Kytha paar	1979	Coconut fronds, Ring				
6	Puthiyathura		1955	Stones, Coconut fronds, Ring		Stones packed in bag		
7	Pulluvila	Palli paar	1984	Stones, Coconut fronds, Ring				
8	Adimalathura *	Kytha paar	1965	Stones, Ring, Screw pine				
9	Vizhinjam	Boat paar	1982	Boat wreck, Stones				
10	Vizhinjam		1985	Stones, Sea weeds	1989	Stones		
11	Vizhinjam	Kytha paar	1987	Stones, Screw pine				
12	Beemapally		1984	Stone, Coconut fronds, Stones and part of plants picked in the bag				
13	Cheriyathura *	Ora paar	1982	Stone, Coconut fronds, Ring				
14	Cheriyathura	Ola paar	1983	Stone, Coconut frondes/ fronds/ stones				
15	Valiyathura	Ouseph paar	1983	Stones, Coconut stump, Screw pine, Tele. post	1986	Stones, Coconut tree, Anchor, Empty barrels		-
16	Valiyathura	Ora paar	1984	Stone, Ring, Coconut tree				
17	Valiyathura	Society paar	1988	Stones, Coconut stump, Coconut fronds	1989	Stones, tyre tied over ring		
18	Kochuthope	Ola paar	1984	Stones, Coconut tree	1985	Stones, Coconut tree		
19	Valiyathope	"	1984	Stones, Coconut stump, Coconut fronds	1984	Stones, Coconut stump	1984	Stones, Coconut stump
20	Vettucadu *		1983	Coconut stump, Ring				
21	Puthukurichi		1986	Coconut fronds, Ring, Boat wreck	1989	Coconut fronds, ring		

* Reefs non functional now

Fig. B: INCREMENTAL CHANGES IN ARTIFICIAL FISH HABITATS

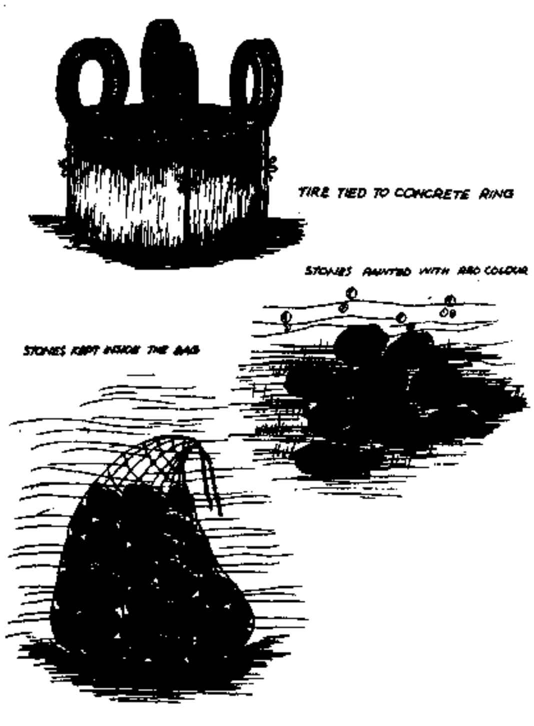
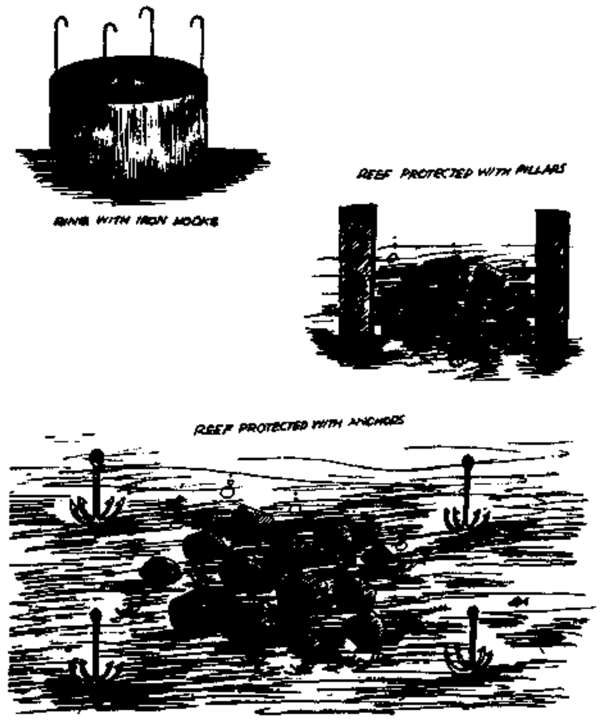
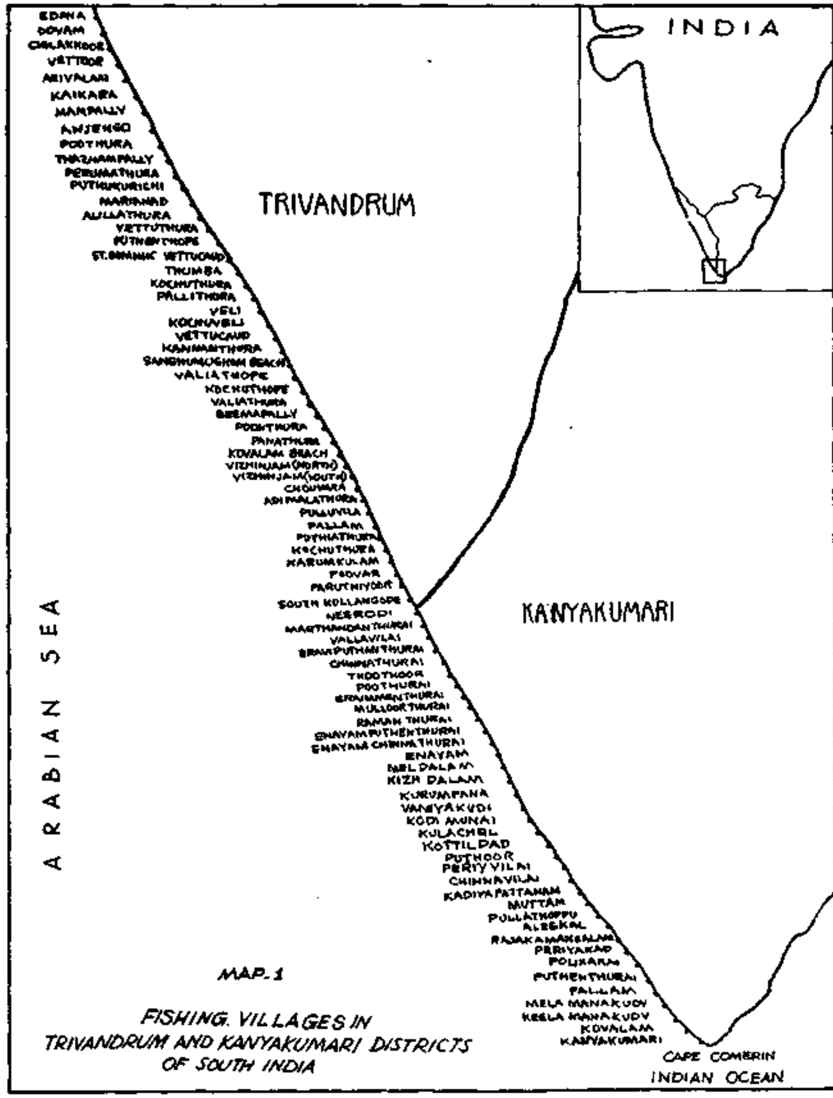


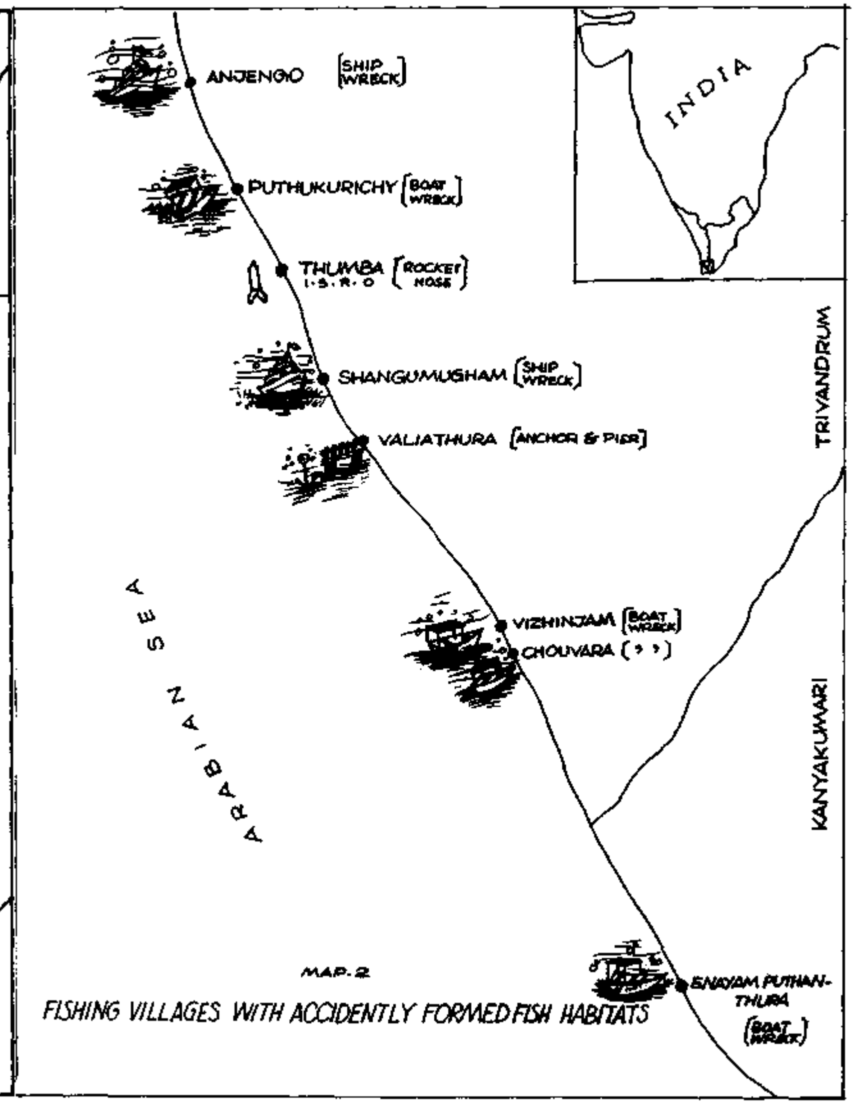
Fig. C: MATERIALS MODIFIED FOR THE PROTECTION OF ARTIFICIAL FISH HABITATS





MAP-1

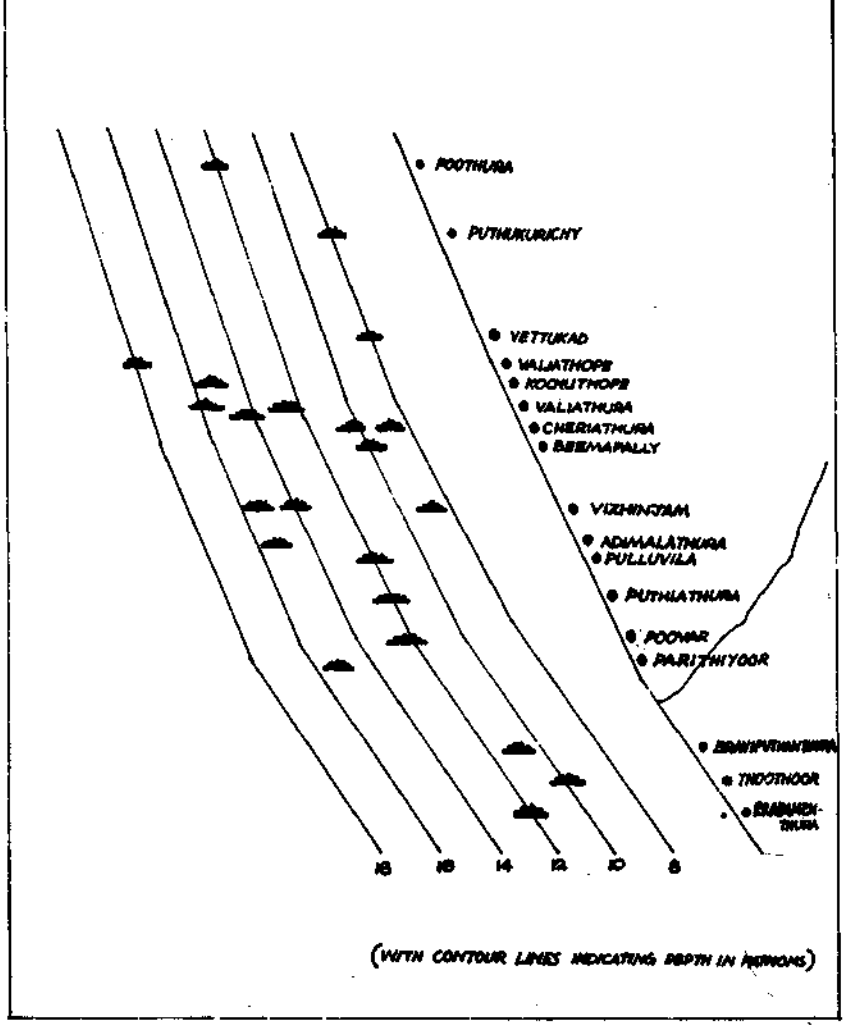
FISHING VILLAGES IN TRIVANDRUM AND KANYAKUMARI DISTRICTS OF SOUTH INDIA



MAP-2

FISHING VILLAGES WITH ACCIDENTLY FORMED FISH HABITATS

Chart I: DISTRIBUTION OF ARTIFICIAL FISH HABITATS IN TRIVANDRUM AND KANYAKUMARI



6. **Innovation of artificial bait began with bait made from coconut fibre freely available in Kerala (*Kera=Coconut tree, Kerala=land of coconut trees*). For many years artificial bait didn't cost anything. With the introduction of 'maral' made from the bark of a tree, artificial baits began to be economic goods but costing very little compared to natural baits especially prawns and squids.**

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10

PEARL OYSTER FARMING AND PEARL PRODUCTION

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Introduction

Natural pearls were the oldest gems known to mankind. Long before man discovered the diamond and other precious stones, pearls were considered to be the first precious gem. The Vedas of India, the Bible and the Quran make several reference of pearls as objects of adoration and worship. The natural pearls of the Gulf of Mannar and the Persian Gulf enjoyed very good reputation in the world trade from the time immemorial. The Gulf of Mannar pearls are famous throughout the world as 'Orient Pearls'.

Man has wondered how the oyster produces the pearl and many imaginative minds propounded many interesting theories. Some believed that pearl was formed when a rain drop or a droop of dew fell into the shell when it came to the surface. Some others felt that it was the tears of angels that crystalised into pearls. The truth behind this mystery was unraveled in 1907 when a Japanese scientist Tokichi Nishikawa gave a plausiable explanation "the pearl-sac theory" for pearl production. According to him, the pearl-secreting cells of the mantle migrate into the body of the oyster under the stimulus of a foreign body and by a series of cell division form a pearl-sac around the foreign body. The pearl-sac in turn secretes the nacre which becomes deposited over the body, forming a 'natural pearl' in course of time. Natural pearls are rare in occurrence, small in size and generally irregular in shape. The 'cultured pearl' is produced by human interference by inserting a shell bead "nucleus" and a mantle piece into the gonad of the oyster and growing the oyster in the sea. 'Artificial pearls' are those made of plastics, glass, etc. They are painted with pearl essence which is a mixture of enamel and silvary extract of fish scales.

Pearl oysters and their distribution

The pearl oysters occur in almost all the seas of the tropical and subtropical regions of the world. Although 28 species of pearl oysters have been identified, only 3 species have been found to produce pearls of gem quality having commercial value. They are *Pinctada maxima* (Jameson), *P. margaritifera* (Linnaeus) and *P. fucata* (Gould) (Pl. I A). *P. maxima* commonly known as the "white-lip" or "silver-lip" or "gold-lip" pearl oyster, is the largest of all the pearl oysters. It is prized for both its shell and the gold coloured and white pearls it produces. It occurs in the South Seas, Australia, Burma, Thailand, Indonesia, Philippines and Papua New Guinea at depths raning from low tide level to 80 m. It grows to 28.3 cm in shell height and weighs upto 5.5 kg (Bolman, 1941; Hynd, 1955). *P. margaritifera* the "black-lip" pearl oyster is famous for its production of fine grey to black pearls. It is distributed in the Persian Gulf, Red Sea, Sudan, Papua New Guinea, Australia, French Polynesia, Indonesia, Andaman and Nicobar Islands, southwestern part of the Indian Ocean, Japan and the Pacific Ocean. It grows to about 17 cm in shell heights. It thrives well in 2 to 40 m depth. The pearl oyster *P. fucata* is distributed in the Red Sea, the Persian Gulf, India, China, Korea, Japan, Venezuela and Western Pacific Ocean.

In the Indian waters, six species of pearl oysters namely *Pinctada fucata* (Gould), *P. margaritifera* (Linnaeus), *P. chemnitzii* (Philippi), *P. sugillata* (Reeve) and *P. atropurpurea* (Dunker) have been recorded. Among these, *P. fucata* is the most dominant species. It occurs in large numbers in pearl 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. In the southwest coast in India at Vizhinjam, large numbers of spat of *P. fucata* have been collected from mussel culture ropes. *P. margaritifera* is confined mostly to the Andaman Islands where it is common in some places. From Lakshadweep, spat of *P. anomoides* has been recorded on the ridges of rocks and corals.

Pearl oyster farming

Farming of pearl oysters can be done either in a bay or in a lagoon or in coastal waters or in onshore tanks, where the environmental conditions are conducive for the growth of oysters. In a pearl culture establishment, farming activities go round the year. Therefore, the establishment must have good laboratory for oyster surgery, pearl collection centre, pearl grading and processing unit, farm stores, cage cleaning yard, mechanical workshop and boat for transport of workers, oysters and farm materials.

Pearl oyster farming can be divided into two phases, *viz.* mother oyster culture and post-operative culture. Mother oyster culture refers to farming of oysters from the time they are brought to the farm till they are used for nucleus implanation. The post-operative culture refers to rearing of oysters from the day of implantation upto the day of harvest.

Source of oysters

There are three ways to raise pearl oysters for mother oyster culture in the pearl culture farm. They are (1) collection of oysters from the natural beds, (2) hatchery production of seed and (3) collection of spat through spat collectors. In the Gulf of Mannar, the pearl oysters occur in large numbers on the submerged rocky substrates known as 'paars'. The paars lie at depths of 12 to 25 m off the Tuticorin Coast along a stretch of 70 km. The extent of these paars varies from a few hectares to several km^2. Pearl oysters from these beds are collected by skin and SCUBA divers. In the Gulf of Kutch, the pearl oysters are found sporadically on the intertidal reefs known as 'Khaddas'. Collection of oysters is done by hand-picking. The source from hatchery is more dependable than the sources from natural beds and spat collectors, as the hatchery alone can ensure a sustained supply of pearl oysters for pearl culture throughout the year. The pearl oyster hatchery of CMFRI has produced several million seeds of oysters over the last 13 years. Large scale collection of pearl oyster spats from the sea is possible if only the right type of spat collector is provided at the most propitious time. The oysters obtained from these three sources are cleaned and placed in cages and hung vertically in the sea from the raft/rack at desired depth.

Rearing methods

Raft culture, rack culture on bottom culture and onshore culture are the 4 methods of rearing pearl oysters.

Raft culture

Raft culture method is one of the most suitable method of farming oysters in sheltered bay and in open areas. The size of the rafts can be altered according to the sea and weather condition of the locality. A raft of the size 6 m x 5 m is found to be suitable. Rafts are usually constructed with teak, casuarina or eucalyptus poles of chosen length with the base of the pole having 10 cm dia, tapering to 6 cm dia at the tip. These poles are lashed with coir ropes. Four floats are attached to the four corners of the raft to give buoyancy. Floats can be empty diesel drums of 200 lt capacity with fibre glass coating, mild steel barrels painted with anticorrosive paints or FRP styrofoam floats. Rafts are moored with two anchors at opposite sides with tested quality chains and their position is decided according to the prevalent wind direction at the site. The oyster carrying cages (Pl. I B) are suspended from the raft at 5 m depth in the sea (Alagarswami, 1991).

Rack culture

Rack culture is possible only in shallow and calm seas of 2 to 4 m depth. In rack system which is a fixed structure, 121 teak or eucalyptus poles of chosen length are driven vertically into the sea bottom in 11 rows, 1 m apart. Cross and horizontal poles are arranged as per requirement on the top of the poles and lashed with coir rope at a convenient height of 0.5 m above the water level so that the rack thus erected remains always above the water. The overall size of the rack is 10 m x 10 m. A total of 400 box-type cages holding oysters can be suspended from the wooden frames (Pl. II A).

On bottom culture

On bottom culture of pearl oysters can be done in areas where the sea bottom is hard or rocky in nature. Oysters are placed in box-type cages and arranged on the sea bottom in rows.

Onshore tank culture

Pearl oysters can be successfully reared in a 50 t capacity concrete tank filled with clean seawater. Mother oysters/seeded oysters numbering 1250 can be successfully stocked and grown in the tank. The microalga *Chaetoceros calcitrans* cultured in the outdoor tanks is given as food for the oysters. This technology has greater advantages over the open sea culture system, as the growth of the oysters in the tanks is much faster, survival rate is high, predation and fouling are practically absent and ensures greater control over the environment.

Besides the above four methods, long lines and underwater platforms are used in some parts of the world. In the long line culture method, a series of spherical or cylindrical floats are attached to strong ropes at uniform intervals. The ropes are moored with anchors. The oyster cages are suspended from the strong rope of the line. Long lines are ideal for turbulent sea condition. In another method of hanging, a hole is drilled near the hinge of the pearl oyster. A small thread is put through the hole, which is then tied to a straw rope coated with tar. The straw ropes are hung from a raft. Underwater platforms are used in French Polynesia for farming black-lip pearl oysters in deeper lagoons. Oysters in strings are suspended from these platforms (Alagarswami, 1991).

Rearing containers

Culture of mother oysters

Box cages, measuring 40 x 40 x 15 cm with a lid and covered by synthetic webbings are used to rear mother pearl oysters and nucleated oysters. The size of the mesh varies with the size of the oysters to be reared. The frames of the cages are made up of 6 mm mild steel rods, coated with anticorrosive paints or coal tar. Box cages are useful in general mother oyster culture. A box cage can hold 125 oysters of 35-45 mm size, 100 of 45-55 mm, 75 of 55-60 mm and about 50 in the case of larger oysters (Pl. II B).

To trace the history and performance of individual oysters, frame nets are used. The frames, measuring 60 x 40 cm each with five compartments, meshed and hinged at one end, open as a book. The oysters are arranged in rows and held in the compartments when closed. The space available inbetween the two frames is about 10 mm which is sufficient for the oysters to open their valves for feeding and respiration.

Juvenile rearing

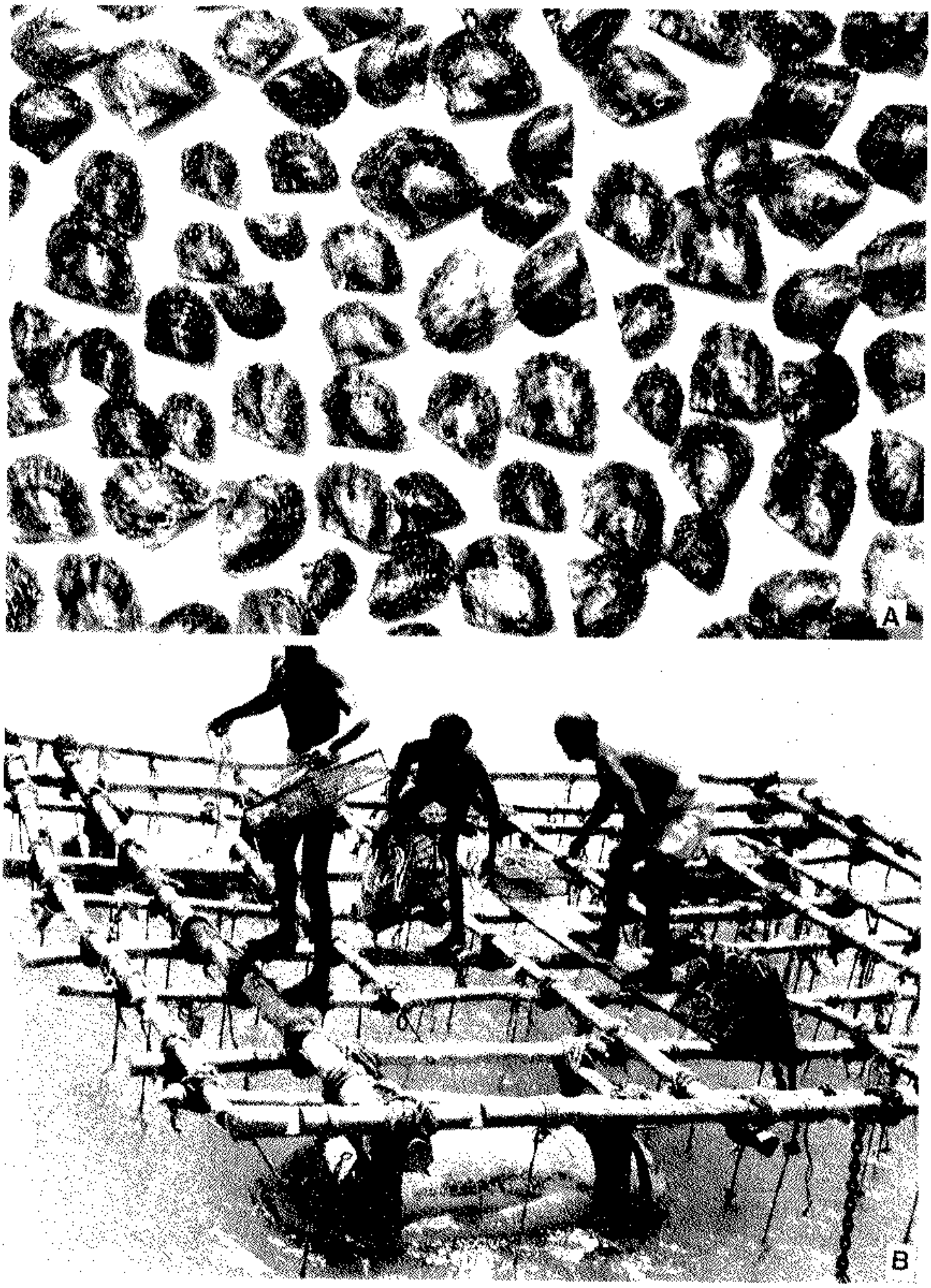
Juvenile pearl oysters are reared in net cages. Synthetic fabric of velon screen bags whose sides are stretched with a steel rod in the form of a prism are used for rearing juveniles (Pl. II C). The mesh size of the screen depends on the size of juveniles to be reared. The mouth of the bag is tied with synthetic twine which facilitates opening or closing when required. To provide further protection from predators the bags are placed in old nylon fish net bags. Clogging by silt and by the growth of fouling organisms can be prevented by periodical replacement of the velon screen bag which can be cleaned, sundried and reused. Spat of upto 2 cm in size are reared in these small net cages. Box-cages which are used for rearing mother oysters can also be used for juvenile rearing by providing an additional velon screen cover inside the cages.

Environmental conditions

The success of pearl oyster farming and pearl production depends largely on the environment in which the oysters are reared. The oyster being a filter feeder wholly depends on the environment for all its life functions such as osmoregulation, respiration, nutrition and reproduction. Many industries let out agro-chemical and industrial effluents into the sea which adversely affect the well being of the oyster population. Therefore, the set of environmental conditions has to be ideal and this should be ensured while selecting the site for the farm (Alagarswami, 1991).

Topography

Sheltered bays are ideal locations for establishing pearl culture farms. They offer good protection to the culture structures such as rafts and cages from strong winds and waves. Shallow coastal waters where the sea is calm during most part of the year can also be considered as a suitable site. The Gulf of Mannar in India where pearl farming is practiced has been found to be moderately acceptable in the absence of better



[illegible] The Indian pearl oyster *Pinctada fucata* and B. Raft for culturing oyster

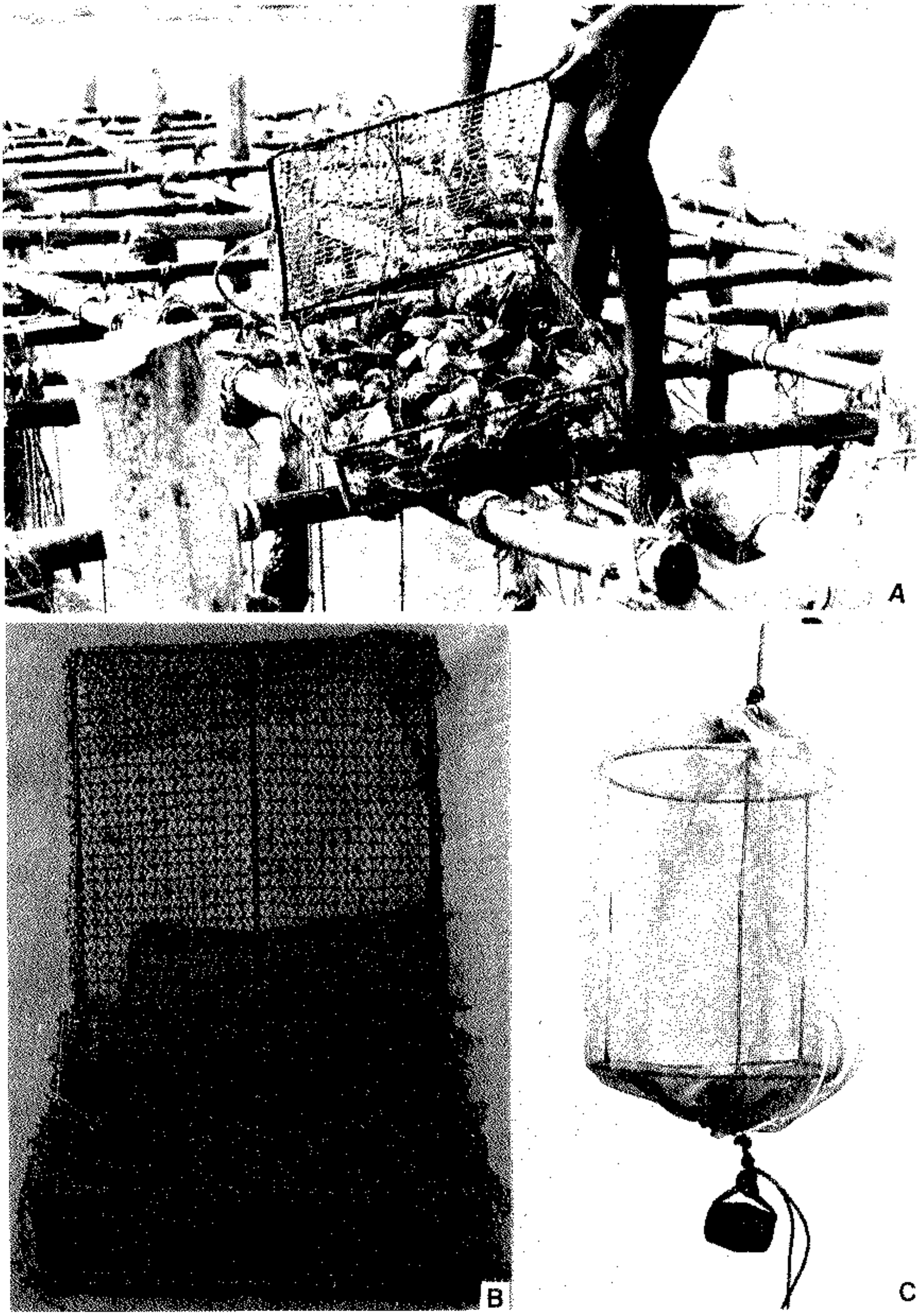


Plate II A. Wooden racks with oyster cages in shallow water farm, B. A box cage for rearing mother oyster and C. Juvenile pearl oyster rearing cage.

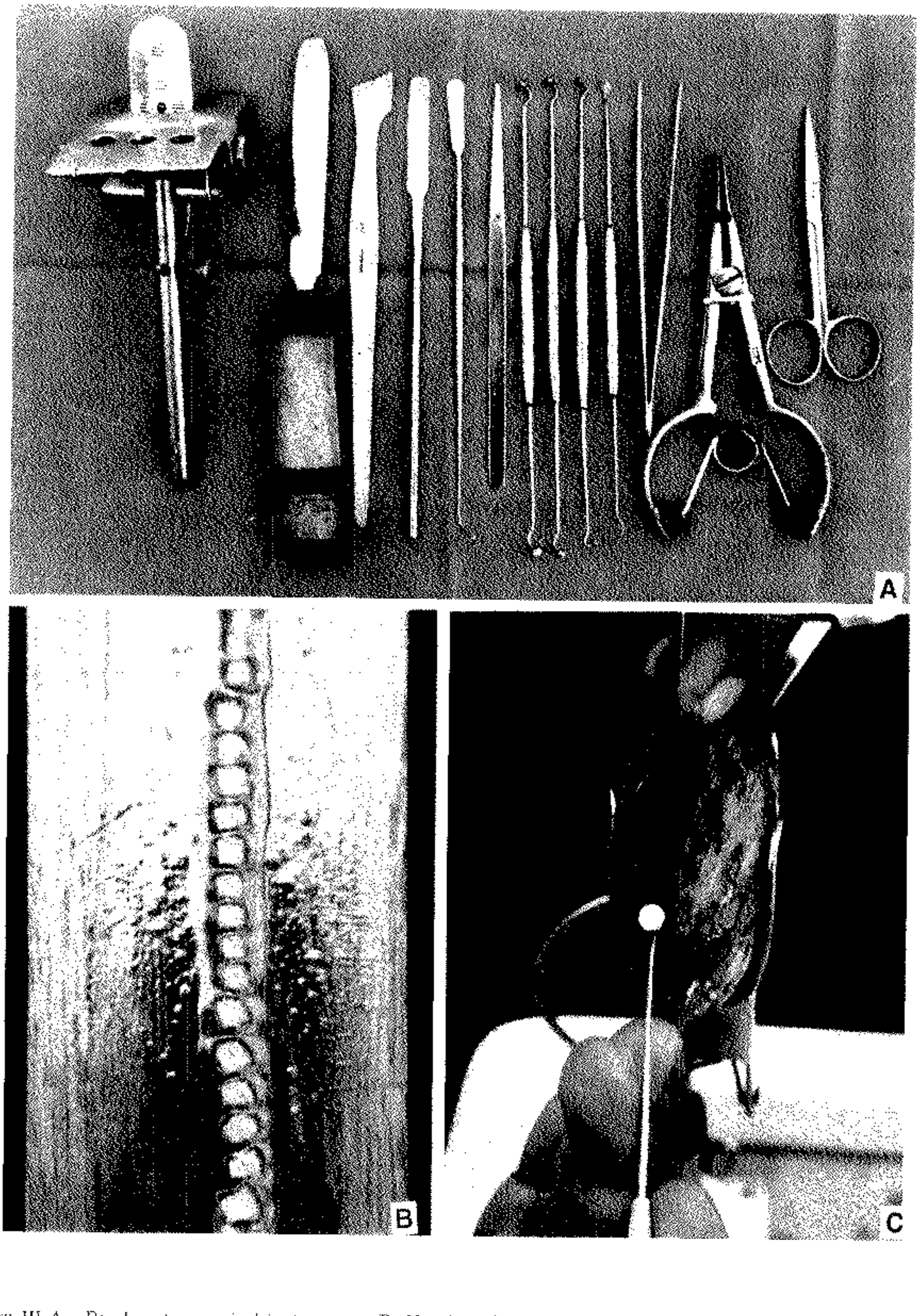


Plate III A. Pearl oyster surgical instruments, B. Mantle strip taken from the pallial zone and cut into small pieces and C. Implantation of shell bead into the oyster.

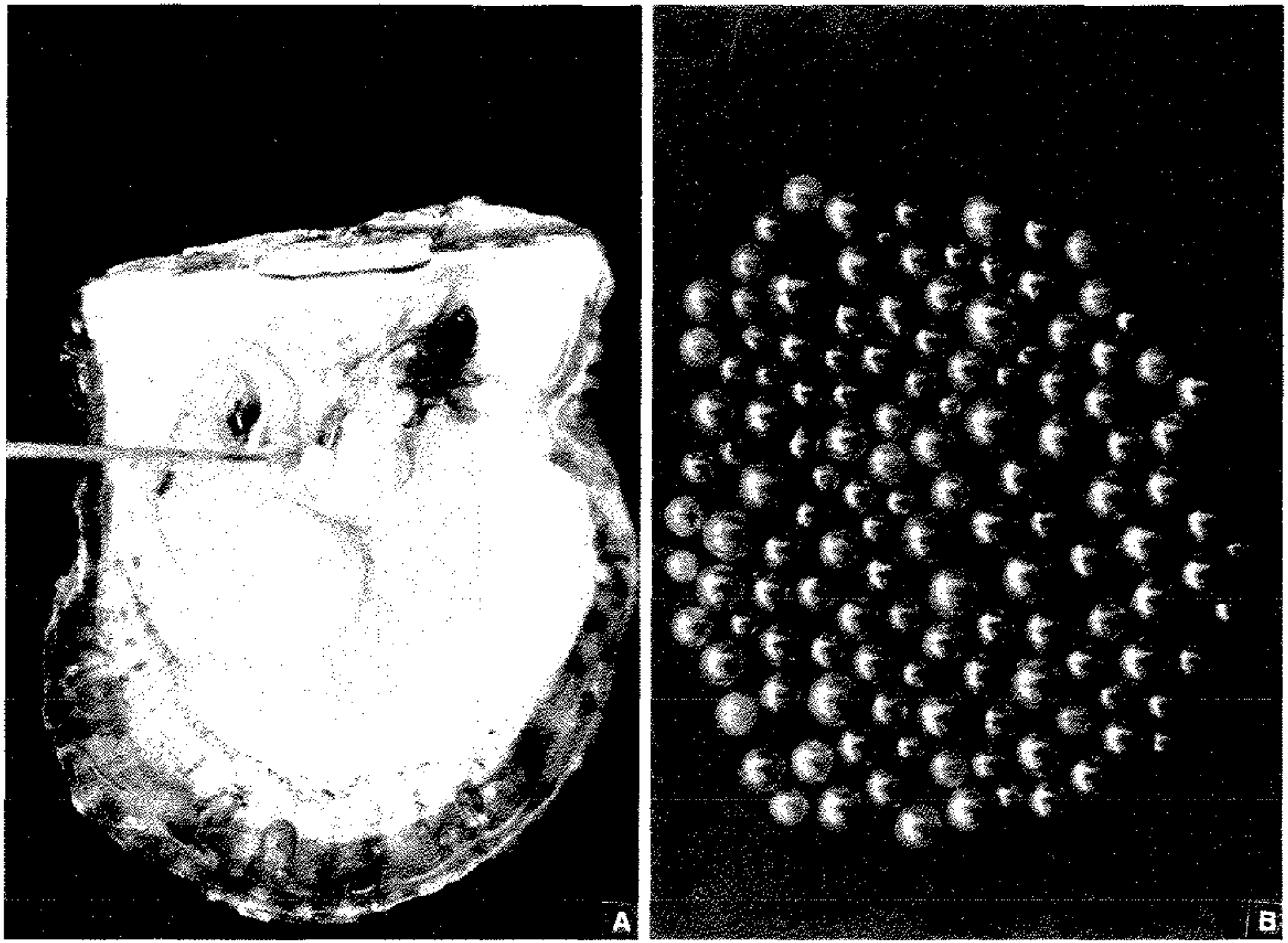


Plate IV A. Pearl *in situ* in *Pinctada fucata* and B. Lustrous cultured pearls.

locations on the coast of mainland. The small islands such as Krusadai, Pullivasal, Manoli, Hare, Nallatanni, Karaichalli, Vilanuguchalli and Vanthivu give some protection. The Andaman and Nicobar Islands have many areas which provide ideal conditions for pearl oyster farming (Alagarswami, 1983). The lagoons of some islands of Lakshadweep especially Bangaram, would seem to be favourable (Alagarswami *et al.*, 1989).

Hydrography

Depth is an important factor in rearing pearl oysters, the preferred depth is about 10 m in the open sea and 2 - 4 m in the sheltered bay. Sea bottom should be either gravelly or rocky. Muddy or sandy bottom should be avoided. A high amount of silt in the farm water may choak the gills and affect the filteration efficiency of pearl oysters. A mild water current of less than one knot/hr is essential not only as a source of oxygenrich water, but also to bring in fresh plankton on which the oysters feed as well as for the removal of metabolic products and faecal matters from the farm. Repeated culture in the same ground often deteriorate the quality of the pearls. Accumulation of biological waste of the oysters and fouling organisms on the sea bottom often affects its physical and chemical state.

The environmental factors such as temperature, salinity, hydrogen ion concentration and nutrient salts play a crucial role in the settlement, growth and reproductive pattern of oysters both in the farms and natural beds. Unlike in Japan, the variation in temperature and salinity is not much pronounced in the Gulf of Mannar. The lowest sea surface temperature is about 23.8°C and the highest 33.5°C, the monthly averages ranging from 25.9°C to 31.5°C (Victor and Velayudhan, 1987). In the Gulf of Mannar and the Gulf of Kutch, oysters show a higher growth rate in winter months in the lowest range of temperature. Higher temperature within the ambient range helps in faster growth of pearls. The salinity of the Gulf of Mannar normally varies from 30 to 35 ppt. If salinity falls below 15 ppt, and if such condition is prolonged, it may lead to mortality. This may happen during unusual heavy rain and heavy discharge of freshwater by rivers in the farm. The pH should be around 7-8. The rich nutrients discharged by rivers into the sea increase the productivity of the water. The oysters probabily derive their chief source of conchiolin from the nitrogen substance of the plankton. The organic matter and calcium dissolved in the sea water are directly absorbed by the food consumption cells. In Tuticorin bay, it ranges from 316 to 485 mg/litre. The calcium passes through the mantle to be deposited on the surface of the shell or pearl in the process of their formation. The normal level of calcium in the sea water is about 400 mg/litre. In Tuticorin Bay, it ranges from 316 to 485 mg/lt. The presence of trace elements in small quantities influences the colour of nacre. Gold and cream coloured pearl contain more copper and silver, whereas skin and pink coloured pearls contain more sodium and zinc (Matsui, 1958).

Biology of pearl - pearl formation

The pearl oyster's mantle is a thin fold of skin covering the soft body below the shell. It is formed of two lobes on either side. The two lobes are fused together dorsally below the hing line, from this point they hang down on both sides of its body. The nacre or mother-of-pearl found on the inner surface of the shell is formed by the secretion of the outer epithelial layer of the mantle. When some minute extraneous matter such as sand grain, silt particle, parasite, larva, etc., accidentally enters within the tissue of the oyster, it causes irritation to the oyster. As a means of defence against the irritant, the oyster encloses the foreign particle in a sac of epithelial tissue. If the sac happens to be formed by the outer epithelial cells of the mantle, it secretes nacre which gets deposited around the particle. The sac is the *pearl sac* and the foreign particle the *core material*. The pearl sac keeps growing with the growth of the pearl inside. The secretion continues throughout the active life of the oyster leading to the formation of natural pearl. The natural pearl generally takes the shape of the core material and is small in size and irregular in shape. The natural pearls are formed either within the mantle or in other soft tissues of the oyster or between the mantle and the interior surface of the shell. Therefore it is evident that the two pre-requisites for the formation of a pearl are the outer epithelium of the mantle lobe and a core substance or nucleus. Formation of a natural pearl is a matter of chance and therefore only a very small percentage of pearl oysters produce pearls in nature.

In the cultured pearl technique, the same process is manipulated in the oyster. A small piece of mantle from a donor oyster and a spherical shell bead, the nucleus are implanted into the gonad of a recipient oyster in proper orientation by skillful surgery. The surgery operation is called 'implanting' or 'grafting'. The inner epithelium and connective tissue of the mantle disintegrate and become absorbed by the surrounding tissue. The outer epithelium of the mantle piece undergoes cell division and rearrange themselves over the shell bead nucleus, forming the pearl sac. The epithelial cells of the pearl sac secrete and deposit the nacre or mother of pearl over the nucleus in the form of concentric micro-layers. When a large number of these layers have been deposited over a period of time, the pearl grows in size and attains its 'gem' quality. Since the pearl is produced in the oyster by manipulation through surgery and by further cultivation of the seeded oyster, it is called the cultured pearl. In cross section, a natural pearl will reveal a minute nucleus of extraneous origin surrounded by nacre. In a cultured pearl, the nucleus is large and the nacre forms only one fifth to one third of the pearl in thickness.

Production of cultured pearls

After the oysters have grown in the farm and attained the size suitable for nucleus implantation, they are brought to the laboratory. Their shells are cleaned of all fouling organisms and other encrustations and kept in seawater. Pearl production can be divided into two phases (i) the laboratory phase and (ii) farm phase. The laboratory phase is very short, which includes selection of oysters, conditioning, graft tissue preparation, nucleus, surgery and convalescence. The farm phase includes post-operative culture and pearl harvest.

Laboratory phase

Selection of oysters

The factors to be considered in the selection of oysters are their age, weight, stage of sexual maturity and overall health. Oysters of 25 g weight and above (1.5 to 2.0 years) are ideal and even smaller sizes are also considered for implanting smaller nuclei of 2-3 mm diameter. The gonad of the oyster should be in the spent resting stage. Nucleus implantation in these oysters yields good results since correct orientation of mantle piece with the nucleus is always ensured. Ripe gonads are not suitable, since during surgery the gametes tend to flow out and block the visibility of the implantation site so that proper orientation of the mantle piece and nucleus cannot be ensured. In addition, the oysters infected with polychaetes, sponges and trematodes are to be avoided.

Conditioning

The selected oysters are conditioned for nucleus implantation. Preconditioning of oysters for surgery is an essential process. Healthy oysters, when taken outside seawater close their valves tightly by contracting the adductor muscles. For surgery, a gap of 1.0-1.5 cm between the valves is required. When the valves of the oysters are opened forcefully their adductor mussels get cut and the oysters die immediately. Hence the oysters are allowed to open their valves gently by themselves. This is done by using a chemical 'menthol'. The oysters are arranged in a plastic basin with their hinges pointing downwards. Seawater is slowly poured into the basin till the oysters get immersed in the water. Sprinkle a little amount of menthol powder over the water and cover it with a lid. In about 60-90 minutes the oysters get narcotized. The adductor muscle relaxes and the shell valves open. Immediately a small wooden peg is inserted in between the valves to keep them open and thus the oysters are conditioned. The conditioned oysters should be operated as early as possible, as the delay causes swelling of tissues, increased mucus secretion and mortality. For this reason conditioning is done in batches. The conditioned oysters are washed individually in seawater and arranged in an empty plastic basin.

Surgical instruments

A set of specially made surgical instruments is needed during graft tissue preparation and nucleus implantation. The instruments can be made to specification by any surgical instrument manufacturing company. The following are the necessary instruments (1) oyster stand, (2) shell speculum, (3) incising-cum-grafting needles, (4) nucleus insertion needles, (5) graft cutting knife,

(6) spatula, (7) needle hook, (8) forceps, (9) knife and (10) scissors (Pl. III A). The other instruments needed are graft cutting wooden blocks, wooden pegs, camel hair brush, trays, rubber sponges, towels, glass beakers, etc.

Preparation of graft tissue

As soon as the oysters are narcotized, the preparation of graft tissue should commence. Preparation of graft tissue is an important step in surgery. Many graft tissues can be prepared from the mantle of a single oyster. A healthy oyster is taken from the stock of oysters. The oyster should not have been subjected to any narcotizing process. A sharp knife is inserted in between the two valves of the oyster upto the adductor muscle and the latter is cut vertically. The knife is pushed further down so as to cut the soft body into two. Care is taken not to injure the mantle tissue in any way. With a pair of scissors, a strip of 5 cm long and 0.5 cm wide mantle is cut and transferred on to a rectangular soft wooden block. The mucus of the mantle is removed gently with the blunt end of the scalpel. With the graft cutting knife, the thickened outer edge of the mantle is cut and removed. In the same manner, the inner muscular portion of the mantle on the opposite side is also cut and removed. Now a long ribbon of 5 cm length is obtained from the pallial zone of the mantle. The ribbon is then cut into pieces of 2 to 3 mm squares. Mantles from both side are used in the preparation of graft tissues. About 20-25 pieces can be cut from each ribbon. The graft tissues should be kept wet with sterilized filtered seawater all the time during preparation. Smearing a weak solution of Azumin will help to keep the cells alive for a longer duration. The graft tissues should be used within 15 minutes of preparation (Pl. II B).

Nucleus

A piece of graft, when inserted into the gonad of an oyster results in the production of an irregular pearl. In order to get a larger and spherical pearl in a short period, a spherical shell bead known as 'nucleus' is inserted along with the graft tissue. The beads are manufactured in Japan from the thick shells of fresh water mussel, pig-toe, washboard, dove, three-ridge and butterfly - which occur in the Tennesse and Mississippi Rivers in USA. The hardness and specific gravity of these nuclei are nearly identical with that of the deposited nacre. These shells are collected and exported to Japan, where they are cut, ground and processed into precisely spherical shell beads of different diameter, generally 2-7 mm. In India, chank shells have been cut and processed into beads and used in experimental pearl production.

Surgery

The conditioned oyster is mounted on the oyster stand with the right valve upwards. The shell speculum is inserted inbetween the valves to regulate the gap. The mantle, gills and labial palps are smoothly pushed aside to get a clear view of the gonad region. A sharp incision is made with incision-cum-grafting needle at the base of the foot of the oyster and a passage is cut subcutaneously through the gonad upto the predetermined site of implantation. In the case of single implantation, the site is close to the turn of the intestinal loop. In double implantation, a second site is chosen close to the hepatopancreas. In multiple implantation several other sites between the above two are selected. A piece of mantle is inserted through the passage with the incision-cum-grafting needle and left at the site. Then the shell bead nucleus is inserted through the same passage and placed in such a way that it is in contact with the outer epithelium of the mantle piece. The incision is smoothened with the cup end and the two margins of the incision come in content. With this step, the nucleus implantation operation is completed (Pl. III C).

Convalescence

The operated oyster is then removed from the stand and the peg or shell speculum is removed from between the valves. The oysters are then placed in a plastic trough or FRP tank, where seawater is allowed to flow gently. If no flow-through system is available seawater is to be changed frequently until the oyster fully recovers from the effect of narcotization. Within 30 minutes, the oysters slowly reopen their valves and commence their pumping and filtering activity. Then the oysters are placed in netlon baskets and hung in the one tonne FRP tank containing fresh seawater. A mild flow of seawater is always good and this is ensured by aerating the seawater. The faecal matters are either washed away by the mild current or kept away from the oyster. The operated oysters are kept in the laboratory for 2-3 days under observation. The dying oysters and the oystrs which reject nuclei are removed from the netlon basket. Within 2-3 days, the incision wound heals completely.

Farm phase

Post-operative culture

After convalscence, the oysters are placed in box cages, transferred to the farm and suspended from the raft/rack at 5 m/3 m depth in the sea. During the post-operation rearing period, the oyster density in culture cages at culture grounds should be kept at a minimum. Over-crowding may cause adverse effects such as production of low quality pearls, slow formation of nacreous layer, etc. In a box cage, 50-75 oysters with size 40-45 mm (25 g wt) can be accommodated. The cages are numbered with plastic number plates. The oysters are reared in the farm without much disturbance. It is ideal if oysters are reared in areas of high phytoplankton production. Once in a month, the cages are lifted to remove the predators from the cages and to scrap off the epifuna from the outer shells and cages. In Indian waters, the deposition of nacre on nuclei is much faster than in sub-tropical and temperate waters. The duration of post-operative culture varies from four to eighteen months depending on the size of the nuclei inserted and the desired size of the pearls to be obtained. When a 3 mm nucleus is inserted in an oyster, it takes a minimum of 4 months for the pearl to attain maturity and it is 15-18 months for a 7 mm diameter nucleus.

Pearl harvest

Harvesting of cultured pearls is usually carried out manually. The oysters are brought to the laboratory from the farm. With a sharp knife, the oyster's adductor muscle is cut and the pearl is squeezed out of the gonad region. In case the oysters need to be re-used for a second time, the oyster's valves are gently opened without damaging the adductor muscle and the pearl is carefully removed with instruments. The oysters are then returned to the farm for recovery and after a certain length of time they can be operated for a second time to produce additional pearls. Pearl harvest is done usually during the cooler season of the year during which time the pearl coating is thin and fine (Pl. IV A).

Cleaning and grading of pearls

After harvest, the pearls are cleaned with distilled water and given a salt wash. The pearls are mixed with powdered salt in equal volume and placed in a tub with small amount of water. Then the pearls are taken out and cleaned with distilled water. The residual mucus on the surface of the pearl is removed by rubbing with salt to obtain good lustre. The cleaned pearls are seived to size (mm) using gauging seives. Then they are sorted by size, shape, colour, lustre surface quality and flaws. They are graded into three categories (Pl. IV B).

A - grade : Flawles, one flaw, small flaws, small stain, pink, silver or light cream.

B - grade : Fairly large flaws, stains, cream colour and irregular shape.

C - grade : Trash pearls, wild shaped, badly coated, heavily pock-marked, clayey lumps, half good and half bad.

In Valinokkam farm, A - grade formed 36.2%, B - grade 54% and C - grade 9.8%.

Colour of pearls

The colour of 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 physiological condition of the oyster, the nature of the culture ground, depth, light penetration, feed, water quality, minerals and trace elements in the seawater also determine the pearl colour to some extent.

The Indian pearls show diversity in colours. In the Gulf of Mannar, the pearls produced are largely yellow in colour followed by white, ivory white, cream, grey, silver and light pink. Indian preference is mainly for yellow, golden yellow and white colours. Europeans prefer pink coloured pearls followed by white and cream coloured ones. In U.S.A, the preference is for rose, pink and cream coloured pearls. In general, the demand for white and cream coloured pearls is always good.

Drilling and processing

It is rather a common practice of the trade to improve the quality of culture pearls through processing. The pearls that need processing are drilled for holes using specialised drilling machines. The drilled pearls are treated with dilute hydrogen peroxide which not only removes the organic impurities, but also bleaches the pearls.

Marketing

The 'A' grade pearls are sold at the rate of Rs. 150-200 per carat, 'B' grade Rs. 100-150 per carat and 'C' grade Rs. 50-100 per carat. Pearls being a biological product, it is rather difficult to find homogeneity or uniformity in size and quality among them.

Quality improvement of pearls

For obtaining good quality pearls, the oysters should be grown at depths 5-10 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 the pearl.

Basically the colour, lustre and quality of pearls depend largely on the genetic character of the oyster that produces the pearl. The culture ground, the water quality, the feed and the physiological condition of the oyster also determine the quality to some extent. Graft tissue preparation is also an important factor. The tissues must be taken from the central portion of the mantle of a healthy oyster. Now-a-days in Japan, various chemicals and medicines are used to condition the oysters and make them grow healthy. Food dyes are also used in seeding operation to colour the graft tissue; activisers are used to activise the growth of pearl sac and growth promoters are used to get accelerated growth (Daniel and Durairaj, 1993).

Besides the factors mentioned above, much attention should be paid on the application of modern tools such as genetic improvement and tissue culture. The future of pearl quality improvement lies only in these two areas.

General remarks

The world production of marine pearls accounted for 78 tonnes valued at US $ 1042 million. Japan still holds the monopoly in the production of sea pearls. Even though India had the distinction of producing culture pearls in 1973 itself, it could not produce cultured pearls for world trade. India has ample scope to develop and expand the cultured pearl industry in different locations, mainly in the Gulf of Mannar and Andaman & Nicobar Islands. There is good scope for privitisation in the field, if firms which have technical and marketing collaboration with foreign countries are willing to come forward. Pearl culture is a long term investment and huge profits can be made in a successful culture operation as there is still a great demand for pearls. According to Wada (1973), in Japan, the returns from the cultured pearls are the highest among all marine product exports. The pearl industry is a biology based industry and is risk-prone as any other marine industry. India can also join with other leading pearl producing countries, if intensive and sincere efforts are put in the right direction.

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11

TECHNOLOGY OF EDIBLE OYSTER CULTURE

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Introduction

Oysters, mussels, clams, scallops, cockles and abalones are major groups of molluscs which are cultured in different parts of the world. Edible oysters are the most important among them, as they are great delicacy and there is growing demand. There is an increasing interest in oyster culture in tropical countries in recent years. Apart from the edibility of meat, the shells have various industrial and agricultural use. Considering the oysters as a renewable resource of much needed animal protein and the employment potential, oyster culture offers to the rural communities, its culture has been taken up as an R & D programme of the Central Marine Fisheries Research Institute. The studies carried out since 1970, have resulted in developing simple culture methods suitable for Indian conditions.

The Institute is operating a pilot scale semi-commercial oyster culture project at Tuticorin in collaboration with the National Bank for Agriculture and Rural Development and the oysters grown in this farm are marketed by the Integrated Fisheries Project, Cochin. The Institute has undertaken a research programme on location testing to assess the suitability of various areas in the States of Karnataka, Kerala, Tamil Nadu and Andhra Pradesh for developing oyster culture.

Resources and distribution

The edible oysters enjoy wide distribution along the Indian Coast. Out of six species of oysters belonging to the family Ostreidae, *Crassostrea madrasensis, C. gryphoides, C. rivularis* and *Saccostrea cucullata* are commercialy important.

Crassostrea spp. are euryhaline and occur in estuaries, creeks, backwaters, lagoons and shallow coastal regions. *S. cucullata* is purely a marine form.

In Orissa, oyster beds are located in Bahuda Estuary near Sonapur. In Andhra Pradesh oyster beds occur in Sarada, Bihmunipatnam, Kakinada and Gokulpalli. Along Tamil Nadu Coast, oysters are distributed in the Pulicat, Ennore, Killai Backwater, Muthupet swamp, Athankarai, Tuticorin and Tambraparani Estuaries. Along Kerala Coast, Ashtamudi, Cochin Backwater, Korapuzha, Dharmadam, Valapatinam and Chandragiri Estuaries have sizeable population of oysters. There is regular exploitation of oysters along Kerala Coast in small quantities from natural beds. In Karnataka, the oysters are distributed in Nethravathi, Mulki, Sharavathi and Kali River Estuaries.

C. gryphoides occurs along north Karnataka, Goa and Mahrasthra.

C. rivularis occurs along the coastal creeks of Gujarat and the oysters are mainly exploited for the shells.

S. cucullata is distributed throughout the Indian Coast on rocky substrata, in swallow intertidal areas and withstands surf and wave action.

Biology

Edible oyster is sedentary animal usually elongate with highly variable shape. The animal is attached to the substratum by lower left valve which is cup-shaped. The upper valve is flat, acts as a lid covering the soft body of the animal. The two valves are hinged at the anterior which is pointed and termed the umbonal end. If the upper right valve is removed, mouth or labium lies at hinge end and the posterior is the rounded end. This long axis in common usage is indicated as the length. Food of oyster mainly consists of diatoms and detritus. Sexes are separate, but hermaphrodites also occur. Oysters spawn throughout the year with 2 peak periods in April-May and

August-September. The peak period varies from place to place, depending on environmental factors. In Kerala Coast, the peak spawning occurs during postmonsoon months (September-December); in Mulki, Karnataka, peak period is in April-June followed by a minor one during November. At spawning, eggs and sperms are discharged directly outside into the water where fertilization and subsequent development takes place. The larvae are pelagic. When the larvae attain pediveliger stage, they begin to crawl with the help of foot and settle on suitable substratum. This process is called spatting or setting and the young oyster is called spat or seed oyster.

Growth

Growth of oyster is generally measured by volume, length or weight. Oyster growers measure volume by the number of oysters required to fill a standard box. Length of oyster is measured usually with a caliper. In *C. madrasensis* the growth of spat is rapid during the first 3 months, with a growth increment of 12.6 mm per month, attaining 38 mm in length. At the end of one year a mean length of 87 mm is obtained. The growth of oysters varies from place to place and depends on food availability and environmental conditions, particularly temperature and salinity.

Meat condition or condition factor

Condition of oyster meat denotes the degree of fatness or the extent to which the meat fills the shell cavity. The size and weight of meat undergoes changes associated with breeding. This is accomplished by increase in size of gonad during maturation followed by considerable reduction after spawning. In temperate water subsequent to spawning slow increase in the size of the meat, is due to accumulation of glycogen. In tropics, development of gonad takes place without a significant glycogen phase. The condition factor is a ratio of dry meat weight to volume of shell cavity and is calculated by

$$\text{condition factor} = \frac{\text{dry meat weight} \times 1000}{\text{volume of shell cavity}}$$

The knowledge on condition factor is essential for determining the harvest time and for successful marketing of the oysters.

Technology of oyster farming

As early as the first century BC, the Romans practiced simple method of oyster culture by collecting oyster seeds and growing them for food. The important oyster producing countries are Japan, Korea, France and China and together they contribute 78.7% of the total oyster production by culture.

The technique of oyster farming involves two important phases namely (i) oyster seed collection/production and (ii) rearing seed oysters to marketable size.

Seed collection from wild

The seed required for culture is met either from natural spat collection or through hatchery system. For collection of spat from nature, suitable spat collectors or cultch materials are provided at appropriate time. The spat collectors should be able to retain the oysters till they reach marketable size or upto the size at which they could be scrapped for further rearing. The choice of spat collectors depends on the culture method adopted, local availability, economic and practical considerations. In culture experiments at Tuticorin, cultch materials *viz.* semi-cylindrical roofing tiles, oyster, mussel and coconut shells, asbestos sheet, netlon and automobile tyre pieces were used. The tiles are given lime coating for roughness. The oyster shells are made into strings on a G.I. wire or synthetic rope. The collectors are laid on the racks. Of these collectors, lime coated tiles (with an average of 34 spat/tile) and oyster shell (with an average 7 spat/shell) were found suitable for large scale spat collection from wild.

Spat fall prediction

The prediction of spat fall is essential for collecting seed oysters in the appropriate time with minimum foulers interference. This time is called as cultching time. The prediction of spat fall is based on the study of maturation and spawning of ripen gonads in the oyster population or by the appearance of oyster larvae in the plankton samples of the area. The collectors are exposed just a week before peak spawning period. Large scale spat collection experiments showed the abundance of seed oysters in intertidal areas, creeks and bays. The method, season of spat collection and the type of spat collectors to be used vary from place to place, depending on the local conditions.

Seed production through hatchery system

On the establishment of a Shellfish Hatchery in 1980, the Central Marine Fisheries Research Institute succeeded in mass production of both cultched and cultch free spat. The production of seed through hatchery system involves 6 phases of operation *viz.* (i) Selection and holding of broodstock, (ii) induced spawning, (iii) larvel rearing, (iv) preparation of cultch materials, (v) production of spat, and (vi) culture of algal food.

The broodstock of oysters are conditioned at 4° to 5°C below the ambient temperature for 10-15 days. During this period they are intensively fed with algae. The conditioned oysters are induced to spawn by thermal stimulus, by transferring them to seawater with a temperature of 34 - 35°C. The thermal stimuli induce spawning and the gametes are mixed and fertilization is effected. The fertilized egg undergoes divisions and at the end of 20 hrs, 'D' shaped veliger larvae develop and they are transferred to rearing tanks. The larvae are fed with micro alga *Isochrysis galbana* in the following schedule :

Larval stage	*Size*	*Cells/larva/day*
'D' shape veliger	60 - 70 μm	3000 - 4000
Umbo stage	150 μm	4000 - 5000
Eyed stage	280 - 290 μm	5000 - 8000
Pediveliger	330 - 350 μm	10000 - 12000

On 18-20th day the larvae settle down as spat. The cultch material provided is oyster shell valves for attached spat or polythene sheet for production of cultchless or free seed.

Methods of culture

The farming methods are broadly divided into (i) on-bottom and (ii) off-bottom culture. In the on-bottom culture, the seed oysters are sown on the ground. This method is substrata-specific and the area sown be free from silting and predators. When oysters are grown by off-bottom methods, the advantages lie in better growth and good condition of the meat. The methods involved in off-bottom culture are (1) rack & tray, (2) rack & string, (3) stake and (4) raft.

Site selection

The following requirements are essential in the selection of farm site:

- sheltered areas offering protection from strong wave with a depth ranging from 2-5 m.
- salinity range of 22 to 35 ppt.
- temperature range is 21-31°C.
- area with pollution free water.

Rack and tray method

The spat, attached on lime coated tiles, on attaining 25 mm were scrapped or the cultchless seeds produced in the hatchery are stocked in box type cages. The cages are of 40 x 40 x 10 cm size webbed with 2.5 mm synthetic twine. For nursery rearing of hatchery produced cultch free seed (of 5-10 mm) the cages are covered with velon screen.

Fig. 1. Rack and tray method of oyster culture.

The cages are suspended from a rack. After 2 months rearing oysters attaining 50 mm and above, are transferred to rectangular trays. Each tray is of 90 x 60 x 15 cm size. Twenty such trays are placed on a rack. Rack, a wooden platform for this purpose is constructed using casurina or eucalyptus poles. Each rack occupies an area of 25 sq. m and holds 3000 - 4000 oysters.

Rack and string method

This method can be practiced in areas having 1-2.5 m depth. The oyster spats collected on shells are made into strings having six shells using

5-6 mm synthetic rope. These strings numbering 2 to 3 are kept inside a velon screen bag and suspended from racks for nursery rearing. After 2 months, the velon screen bags are removed, the strings are suspended from the racks in the farm. Rack-and-string method is mainly advocated for oyster culture in shallow esturies, bays and backwaters. A series of vertical poles are driven into the bottom in rows and horizontal bars are connected on the top of the poles. Oyster shell rens made of 5-6 empty cleaned oyster shells strung in 5 mm thick nylon rope and positioned 10 cm apart are suspended from the racks.

Stake method

Stake method is adopted if the substratum of the culture site is soft and muddy. Casurina or eucalyptus poles act as stakes and level support to the spat, set on shells. Each stake occupies 0.6 sq.m. A stake with a nail on the top and two nails on the sides, is driven into the ground. The nail holds a shell with spat. To protect the spat against predation, initially the top of the stake with shells is covered with a piece of velon screen. Once oysters attain 25-30 mm the velon screen is removed and oysters are grown on the stakes upto harvestable size.

Raft method

In this system oysters are suspended from floating rafts. Rafts are constructed using bamboo or wooden poles and are floated with empty oil drums or wooden barrels. Once raft is positioned by anchors, shell strings with attached oyster spat are hung from the raft for further growth. An alternative to the raft is the long line method whereby a series of small floats are joined by synthetic ropes and the line is anchored at both ends. The trays or strings are suspended from the rope.

Fig. 2. Rack and ren method of oyster culture.

Foulers, predators and diseases

Fouling organisms such as barnacles, ascidians, sponges and algae settle on rearing trays and oysters and compete for food and space. They are periodically cleaned. Wood borers like *Martesia* sp. and *Teredo* spp. damage the wooden farm structures. Crabs, fishes, starfishes and gastropods are the oyster predators. Predatory gastropod *Cymatium* spp. causes 13% mortality of oyster in the farm. Apart from these, diseases caused by Haplosporidians such as *Perkinsus marinus*, *Minchinia* spp. cause considerable large scale mortalities of oysters in temperate waters. Some of the trematodes notably Bucephalids cause castration of gonads.

Fig. 3. Pole culture method.

Harvesting

Oysters reach harvestable size (above 80 mm) within 10-12 months. They are harvested when the condition of meat reaches high value. The condition factor of *C. madrasensis* at Tuticorin reaches maximum of 170 during prespawning periods (February-March and July-August). Harvesting is done manually.

Depuration and shucking

Harvested oysters are kept for 10-12 hours in the tanks under a flow of filtered seawater. As a result the bacterial load of the shellfish is reduced. The depurated oysters are taken for shucking. Shucking is the removal of meat from the oyster. Depurated oysters are kept in a gunny bag and held for 3 minutes in boiling sea water. This treatment makes the meat removed easy with a shucking knife. Shucked meat is washed and dipped for 10 minutes in salt solution containing citric acid. The meat is weighed and packed in polythene bags as 2 kg units. These are quick frozen at -30°C, using horizontal contact plate freezer. The frozen meat is transported to canning factory for canning and marketing. Live oysters could also be transported safely for 25-30 hrs by packing them in wet gunny bags.

Production and economics

Production rates differ according to the culture methods. Through rack and tray method, the estimated production is 120 t, and by rack and string method, it is 80-105 t/ha. The production rate through stake method is 20 t/ha. In rack and tray method the rate of return on investment was 30% and by string method it was estimated as 44.8%.

Production and economics of edible oyster farming by rack and ren method at Dalavapuram in 300 m^2 area

I. Material cost

		Rs.
(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	3,8410
(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

	Rs.
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

Shell-on 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

In an area of 1 ha, 24 units of 300 m^2 each can be accommodated. The cost of materials indicated are based on the present market rates. Production of meat and shell per hectare is estimated as 10.2 tonnes and 81.6 tonnes respectively. There is good demand for live shell-on oysters in the international market and the cost of 100 shell-on oyster is Rs. 25. The international export market value of 1 kg of chilled/frozen oyster meat varies from Rs. 125 to 300. The demand and high price of oyster meat in the international market augur well for the expansion of edible oyster culture in the country.

Utilisation of oyster shell

The empty oyster shells contain 52-55% calcium oxide and are used in the manufacture of calcium carbide, lime and cement. The shells crushed to suitable size are used as poultry grit.

Prospects of oyster culture in India

The experimental work carried out at Athankarai, Pulicat Lake and Tuticorin in Tamil Nadu, Kakinada Bay and Bheemunipatnam in Andhra Pradesh, Goa, Mulky Estuary in Karnataka and Ashtamudi Lake and Dharmadam in Kerala gave highly encouraging results for developing the culture of edible oyster along east and west coasts of India.

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12

TECHNOLOGY OF MUSSEL CULTURE

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Introduction

Culture of edible molluscs is now recognised as an effective way of enhancing food production and sea mussels among all the known cultivable organisms, give the highest production rate for two reasons : (1) they feed directly on the primary producers namely the phytoplankton and (2) it is farmed three-dimensionally in the water column at the farm site. The world production of mussels amounted to 13,37,551 tonnes in 1988 (FAO, 1992) of which 10,86,310 t originated from culture. China ranks first in the production of cultured mussels in the world, followed by Spain, Italy, Netherlands, Denmark and France.

Resources and distribution

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 Chilka Lake, Kakinada, Madras, Pondicherry, Cuddalore and Porto Novo and along the west coast it forms on extensive beds around Quilon, Alleppey, Cochin, Calicut to Kasargod, Mangalore, Karwar, Goa, Bhatia Creek, Malvan and the Gulf of Kutch (CMFRI, 1980). Regular fishery for the green mussel exists in the region from Calicut to Kasargod and for brown mussel from Quilon to Kanyakumari along the Kerala Coast. The total annual production for both the species from traditional fisheries has been estimated at 10,000 t. This annual production of 10,000 t from the natural beds can be taken as the maximum sustainable yield from the available stocks. Being sedentary animals, whose distribution is limited to the intertidal and submerged rocks in the shallow waters, further increase in the yield is possible if suitable substratum is provided for the mussels for growth.

Biology

Mussels are sedentary animals with elongate, equivalved and inequilateral shells. The two valves are hinged at the anterior end with terminal umbo. External colour of the shell is green in *P. viridis* and dark brown in *P. indica*. Interior of the shell is margaritaceous and shining, muscle scar deeply impressed. Foot is finger-shaped, thick and extensible. Byssus threads emanate from the byssus stem and threads are long, thick, strong with a well developed attachment disc at their distal end. The mussels can discard the byssus threads and secrete new ones for enabling it to change its position. Phytoplankton forms the food of mussels and like oysters they are filter feeders.

Growth

P. viridis grows to 63 mm in 6 months, 91.5 mm in one year 117 mm in 2 years, 129 mm in 3 years and 135 mm in 4 years at Kakinada. At Ennore Backwater, green mussels have grown to 64 mm in 8 months. At Kovalam near Madras, mussel seeds of 13.6 mm have grown to 52 mm in 3 months and 25-30 mm to 70-75 mm in 3½ months when grown in ropes suspended from rafts. At Muthukad 26.6 mm green mussels have grown to 52.4 mm in 6 months when grown on poles and 47.9 mm when grown in nylon webbing. At Calicut 23.6 mm mussels have grown to 88.2 mm in 5 months when grown in ropes suspended from rafts and 66.9 mm in the natural bed. In the Binage Bay, Karwar 17.5 mm mussels reached 62.6 mm with an 4½ months in culture rafts. At Ratnagiri 8 mm spat have grown to 61 mm in 7 months. At Goa, in natural bed, mussels have grown to 96 mm, 132 mm and 156 mm in 1-3 years respectively. Cultured mussels reached marketable size of 60-64 mm within 5 months and in 11 months they reached 85 mm.

P. indica of 20 mm have reached 55 mm in one year when grown in ropes suspended from rafts in Vizhinjam Bay. The cultured mussels usually grow faster than those in natural bed and growth is comparatively faster in the open sea when compared to the Vizhinjam Bay.

Condition index

Condition index shows seasonal changes and is usually related to reproductive cycle. Index is always high before spawning. In *P. viridis* the meat is 33 to 40% of the total weight at Calicut in farmed mussels and in natural bed population it ranged from 27.2 to 29.2%. At Vizhinjam, the raft grown *P. indica* had 21.3 to 47.8% of meat in total weight.

Reproduction

In mussels sexes are separate and reproduction and larval development are similar to that of edible oysters. The male gonad is creamy white and in females it is pink or reddish. The mussels attain maturity at very small lengths. The green mussel attains maturity at 15.5 to 28.0 mm. The peak spawning period of the green mussel at Kakinada is from January to May, at Madras and Goa year round, at Calicut August-October and at Ratnagiri June-September and February-March. At Vizhinjam brown mussel spawns from the end of May till September with peak in July-August.

Technology of mussel farming

Seed collection and seeding

The major part of the seed required for farming is collected on ropes suspended from the rafts during the peak spawning period. The spat settled on ropes are allowed to grow to a length of 30-40 mm. These half grown mussels are collected and transplanted to fresh ropes to avoid overcrowding and help further rapid growth and fattening. Seed mussels are also collected from the natural mussel beds during low tide. A well experienced farmer collects upto 100 kg seed in one tide. These seeds are wrapped around the ropes with a loosely woven synthetic netting, which is specially manufactured for Spanish mussel farming. The seeded length of the rope is 8-10 m and these ropes are suspended at rafts 60-70 cm apart from the rafts. In the raft culture, the seeds reach harvestable size of 70-100 mm by 18-24 months in the temperate waters.

Mussel seeds are collected from the intertidal and submerged mussel beds after the peak spawning season (September-November). Normally an experienced person can easily collect 20-30 kg of mussel in one hour. The average seed size for farming is 15-25 mm and 600 g seeds are required for seeding 1 m length of the rope. Synthetic and coir ropes of 15-20 mm diameter are suitable for growing mussels from the rafts. The seeds are placed around the rope and securely wraped with knitted cotton cloth. The seeded ropes are suspended from the rafts, 0.5-1 m apart, with the lower free end of the rope about 2 m above the sea bed. An optimum of 60 ropes, each having 6 m seeded length can be suspended from a raft of 6 x 6 m size. The seed mussels get attached to the ropes by means of freshly secreted byssus threads in two to three days and the cloth disintegrates in seawater within about 10 days. After the suspension of seeded ropes the mussel culture farm needs only minimum attention to see that the rafts are in good shape and the ropes with growing museels are hung properly.

Hatchery production of spat

The basic technology for production of spat of *P. viridis* has been developed by CMFRI at Madras and for *P. indica* at Vizhinjam. At Goa, the National Institute of Oceanography also has achieved spat production in the case of green mussel. So far large scale production of mussel spat in hatchery has not been tried in our country.

Culture methods

Methods currently used for culturing mussels in the tropical and temperate waters fall into four categories : (1) the sea bottom culture, (2) Pole culture, (3) suspended (raft) culture and (4) Long line culture.

Sea bottom culture

This method is widely practiced in Holland, Netherlands, Denmark and Germany. The principle of sea bottom culture is the transfer of young or seed mussels from areas of great abundance, where growth is often poor owing to overcrowding, to areas of good growth and fattening. Government allows farmers to collect mussel seeds from public seed beds during certain specified periods. The wild seeds are gathered by special mechanised mussel boats, equiped with three or four powered dredges. Each dredge can be operated separately and one dredge load will bring 500-600 kg of mussel seeds. One boat can carry 5000-6000 kg mussel seeds. Seeds collected thus are transferred to private culture plots, leased to the individual farmers and allowed to grow at the bottom. The half grown mussels are later transferred to plots in deeper areas for further growth and fattening. Normally the seeds reach the harvestable size of 50-70 mm in 20-36 months.

Pole culture or "Bouchot" culture

Culturing mussels on poles is mainly carried out in the extensive intertidal mud flats along the Atlantic Coast of France. Intially rows of poles called "bouchots" interwoven with branch-wood are placed in the deeper part of the intertidal zone to allow mussel spat to settle during the spawning season. When the spats grow slightly bigger they are transferred to "bouchots" placed in shallow area in the same zone. Now-a-days "bouchot" used for collection of spat, are obsolete and forbidden since they cause silting. At present seed collection is carried on loosely woven cocoa fiber rope, 13 cm diameter and 3 m long, placed on fixed poles in the intertidal area near the natural mussel beds during spawning season. Spat settlement takes place in 2-3 weeks between rope stands. These ropes are removed and wound around oak poles, 15-20 cm thick, 5 m long and driven 2 m into the tidal flat. The mussels attain marketable size on the poles. Periodical thinning of mussels from the poles is necessary to prevent overcrowding. The mussels attain harvestable size of 50-70 mm in 24-36 months.

Mussel culture on ropes suspended from raft

This method has shown the greatest development in recent years and appears to offer the best prospects for future expansion. There are two basic types of suspended culture, fixed and floating rafts. Suspended culture from fixed rafts is usually practiced in bays or sheltered areas, where the depth is less than 4 m with very little tidal range. This method is being followed along the European Coasts of Mediterranean and Atlantic, including Spain, southern France, Yugoslavia and Italy. The fixed mussel raft or park is constructed on top of 200 concrete posts of 15 x 15 cm size and 7 m long, piled in 5 rows of 40 each, at a distance of 5 m. 2 m length of the posts are driven into the bottom, 4 m in water and 1 m above the water level. A framework is constructed on top of these posts using wooden beams of 20 x 10 cm size. Eucalyptus poles are nailed over the framework at an interval of 1-1.5 m for suspending the mussel ropes.

Longline culture

Longline culture of mussel is practised in shallow waters of 10-15 m depth. This method of culture can withstand the severe monsoon conditions in the west coast. A single longline consists of 60 m long horizontal HPD rope of 20-24 mm thickness, anchored at both the ends with 150 kg concrete blocks and a series of 100 lt capacity barrels as floats fixed at 3 m intervals. Vertical lines of 6 m length seeded with mussel spat are hung at a distance of 75 cm between two floats in the main line. A longline unit of 60 x 60 m can accommodate 12 horizontal ropes and 920 to 1,000 vertical seeded ropes. The horizontal lines are interconnected using additional lines.

Mussel farming trials were initiated in the Vizhinjam Bay by following the floating raft culture method in 1973 and later the experiments were shifted to the open sea. In 1975, experiments on culture of green mussel were initiated in the open sea at Calicut and Madras adopting the floating raft culture technique, which continued upto 1980. After successfully developing and demonstrating the technique and production potential at Calicut the programme was shifted to Karwar in 1980 to explore suitable sites for mussel farming, to do further developmental work and demonstrate the production potential along the Karnataka Coast. Concurrent to the above developments, the National Institute of Oceanography developed a research programme on mussel culture in Goa. The Konkan Krishi Vidyapeeth implemented a project on mussel culture at Ratnagiri. Several short term experiments on mussel culture have been carried out by some University departments also.

Production and farming of mussel* P. viridis *by raft method comprising 10 rafts of 8 x 8 m

A commercial unit comprising 10 rafts, each measuring 8 x 8 m is considered. Each raft holds 100 ropes and the seeded portion in each rope is

Plate I A. Mussel raft in the open sea and B. Seed collection from the wild.

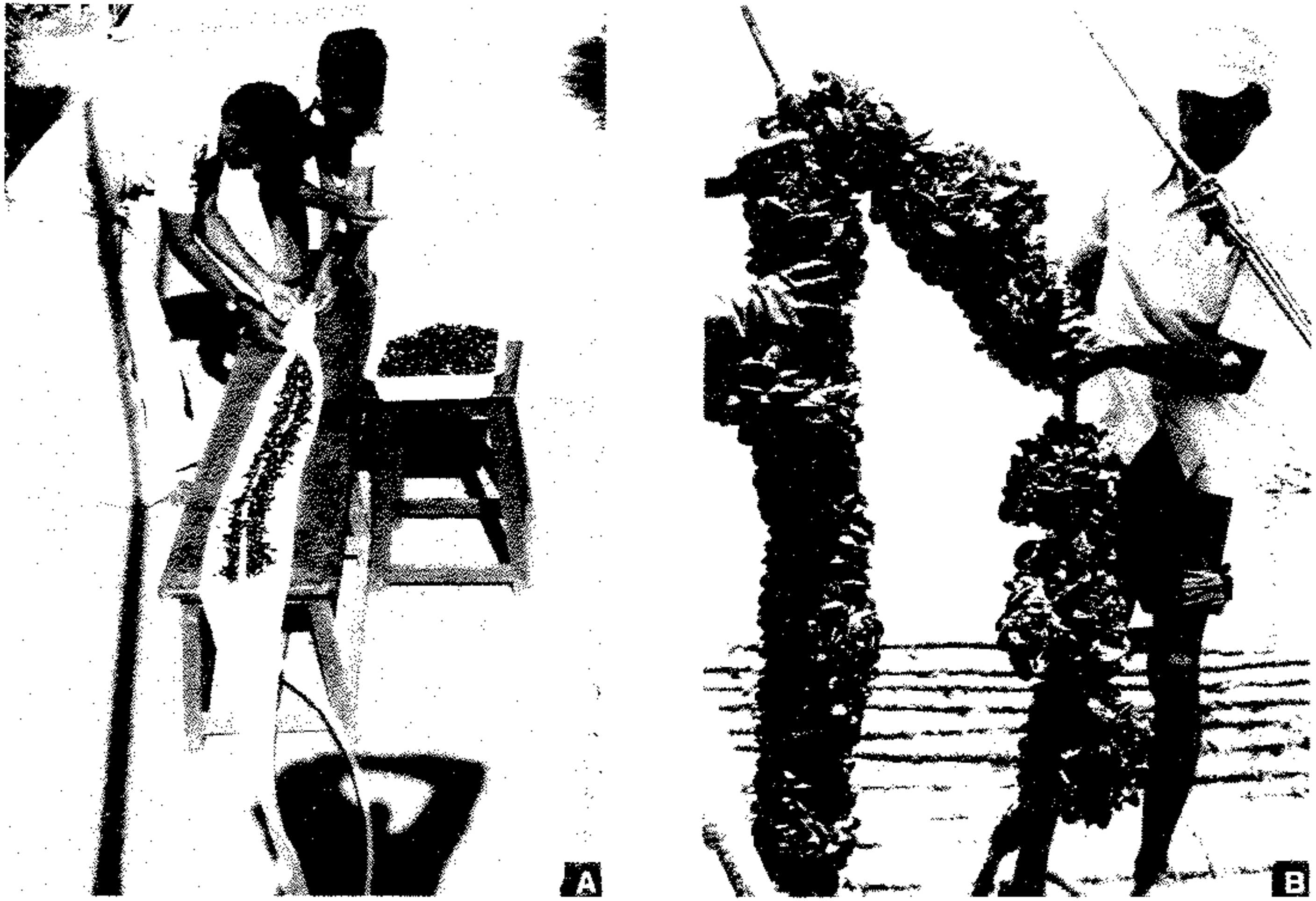

PLATE II A. Seeding of rope and B. Fully grown mussels ready for harvest.

6 m. The duration of the cultue is taken as six months and a single crop is envisaged during the course of a year since the sea conditions are not generally favourable for a second crop. Depreciation was calculated on annual basis and the recurring expenditure for the duration of the crop.

In a three year period, the raft is operational for one-and-half years only; cheaper materials like bamboo/eucalyptus poles, and empty oil barrels instead of specially fabricated MS barrels as floats, would meet the requirement.

The production per raft is 6.18 t. The current market price of the mussel at Calicut is Rs. 4,500/t whole weight.

A.	*Capital expenditure*	Rs.
	FRP boat with outboard motor	80,000
	Cost of 10 rafts	1,00,000
	Total	1,80,000
B.	*Recurring expenditure*	
	Cost of seed	9,000
	Ropes	28,000
	Labour cost	28,000
	Knitted cloth	8,000
	Running cost of boat	9,000
	Salary for manager @ Rs. 2000	12,000
	Watch and Ward @ Rs. 2000	12,000
	Rent for office	6,000
	Contingencies	10,000
	Unforseen	5,000
	Total	1,27,000
C.	*Total investment (A+B)*	3,07,000
D.	*Interest* at 15% for 12 months on A and 7 months for B	38,112
E.	*Production cost*	
	Depreciation on FRP boat @ 12.5%	10,000
	Depreciation on rafts @ 33.3%	33,333
	Recurring expenditure (B)	1,27,000
	Interest (D)	38,112
	Total	2,08,445
F.	*Income*	
	Total mussels harvested from 10 rafts (10 x 6.18 = 61.8 t) Sale proceeds @ 4,500/tonne	2,78,000
G.	*Net profit*	69,555

Production and economics of mussel farming by longline method in 0.36 ha area

Duration of mussel farming is 5-6 months and in the longline method, in an year, two crops can be taken. The growth of mussels in the open sea culture is very rapid. Each mussel gains 11.6 to 12.9 mm in length and 5.9 to 7.3 g in weight per month. A production of 10-12.5 kg marketable size mussels can be obtained from one metre of rope. From a longline unit of 360 m^2 a total production of 54,720 kg shell-on mussels can be obtained of which 40% will be the meat.

The initial investment required for the establishment of a longline unit in an area of 0.36 ha (60 m x 60 m) in open sea works out at Rs. 2.5 lakhs. An entrepreneur has to spend about Rs. 2 lakhs towards operating expenses for a crop. Since it is a labour-intensive technique, about 66.5% of the operating cost is incurred towards wages to the labourers. The net profit to an entrepreneur, venturing into open sea mussel culture, works out to Rs. 2.2 lakhs per crop. At the existing price of Rs. 10 per kg, the break-even production required to cover all the costs works out to 33 t of mussels as against the expected production of 55 t per crop. The cost of production of one kg of mussel in open sea culture works out to Rs. 6/- at the current level of input cost. Besides generating alternative employment to fishermen, the entrepreneur earns substantial profit by adopting this technique of mussel farming.

Economics of open sea mussel farming (0.36 ha area)

I.	*Initial investment*	Rs.
	Cost of construction of a longline unit (floats, anchors, anchroline, 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 (Annua/crop)*	
	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
	Sub Total	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

The social climate along our country's coast line is very congenial for promoting sea farming of mussel and the fishermen communities can participate in the production programme. If open sea mussel culture is carried out in an area of 0.36 ha by a group of ten fishermen, each one would receive about Rs. 13,300 as wages for the maintenance of installations and obtain a profit share of about Rs. 22,700 per head per annum. The social and economic benefits are very high as the annual per capita earning of a fishermen works out to Rs. 36,000/- including wages. The dwindling catch rates in the capture fisheries and the declining employment opportunities have resulted in diminishing annual and per capita income to traditional fishermen. At this juncture mussel farming offers a sustainable and viable economic activity to the coastal rural communities.

Purification of mussels

Mussel is a sedentary bivalve growing attached to rocks or any other hard substratum in coastal waters by means of self secreted byssus threads. They are filter feeders and therefore at any given time their stomachs are likely to be loaded with mud/sand particles and bacteria. Hence depuration of mussels is very important. Legislation regarding sanitary requirements in marketing mussels can be classified into two groups. In most countries mussels can be marketed only when originating from clean waters, where regular analysis ensures that quality is maintained. However, in southern Europe (Spain and Italy) all mussels must be depurated, wherever they originate from. As a result there is less stringent enforcement as to water quality, where the mussels are grown.

It is rather easy to purify mussels of bacterial pollution, because they cleanse themselves of this type of pollution bacteria if kept in clean filtered sea water for 24-48 hours. This treatment can also clean the mussels of mud and sand particles in the stomach. The depuration process consists of three aspects : (1) pumping clear sea water into large storage tanks (2) sterilization of water using 2-3 ppm chlorine or 1-2 mg ozone/litre and (3) keeping mussels in sterilized water for 24-48 hours. Recently ozone is widely used for sterilization of water, as it is a powerful oxidising agent capable of killing bacteria and viruses rapidly.

Prospects

The advantage of mussel culture in our waters when compared to the temperate region is that the rate of production here is very high. In European waters the seeds attain marketable size in a period of 12-36 months. Here it takes only 5-6 months, because of the high productivity of the tropical waters.

The peak spawning season of green mussel along the west coast of India is from August to October and along the east coast it is May-July. Seed collection and seeding can be made during this period. The crop will be ready within 5-6 months and subsequently due to the monsoon the culture operations cannot be continued. If suitable modifications are made in the floating raft culture system to keep the farm structures in position even in monsoon conditions or by adopting the latest method of long line culture developed for open sea rough conditions, theoretically two crops are possible. The mussel in the farm spawns continuously 2-3 months after their initial seeding and seeds for further farming will be available from the farm itself.

During the peak spawning season profuse settlement of spat takes place in the presently heavily exploited area. While exploiting the larger mussels, these seed mussels which form clusters with the grown-up mussels are also removed. The catches along with the seed are normally brought to the shore, where they are sorted and the seeds are discarded. The seeds thus destroyed will be 20-30 times the number of the marketable mussels. During one season the number of seed thus destroyed can be staggering. If these seeds are utilized for suspended culture there will be multifold increase in the production of mussels.

The immediate need is for a perspective planning for the development of mussel culture as an industry with the full realisation of its potential. Government support and assistance from public financing institutions with an element of risk coverage in the initial stage would help the establishment and growth of the industry. Mussel culture, should at least, to begin with be viewed as social necessity with a bias on nutritional improvement of the people and employment potential. Later, if necessary, it can be oriented for export market.

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13

CLAM CULTURE

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Introduction

Bivalves such as oysters, mussels, clams and cockles are widely distributed both in the tropical and temperate waters. In recent years, they have emerged as a delicacy and luxury food items in Japan, USA and western Europe.

The total world mollusc production through exploitation of the wild stocks was 8,885,01 tonnes in 1992 forming nearly 13% to the total world fish production (Table 1). The total mollusc production through aquaculture was estimated at 3,500,719 t in 1992 (Table 2). Due to depletion of the intensely exploited wild stocks, there is increased demand for farm grown products.

Table 1. *Mollusc production by harvest of wild stocks in 1992 (FAO, 1992)*

Group	Production (t)
Freshwater molluscs	303,491
Abalones, conchs, etc.	71,578
Oysters	1,067,403
Mussels	1,337,551
Scallops, pectens	1,044,417
Clams, cockles, etc.	1,696,468
Squid, octopus, etc.	2,758,304
Miscellaneous marine molluscs	605,789
Total	8,885,001

The world landings of clams/cockles have been increasing steadily for the past few years totalling 1,696,468 t in 1992 forming nearly 19.1% of the total mollusc production of 8,885,001 t. The clam production through aquaculture in 1992 was 766,657 t forming 22% of the total mollusc production of 3,500,719 t through aquaculture (Table 2).

The major molluscs producers include China, Japan, Korean Republic, France, Spain, USA, Italy, Malaysia, Netherlands and other Asian countries (Table 3). The major clam producing countries include China, Japan, Malaysia, Korean Republic and Thailand.

Table 2. *Aquaculture production in 1992 (FAO, 1992)*

Group	Production (t)
Mussels	10,85,223
Oysters	9,52,196
Clams	7,66,657
Scallops	5,49,613
Other molluscs	1,47,030
Total	35,00,719

The clam meat is generally processed and marketed in frozen and canned forms. A variety of valued added canned clam meat products find ready market. The global clam meat exports in 1992 was 50,955 t, valued at US $ 1,06,774.

Table 3. *Top ten molluscs producing countries through aquaculture in 1992 (FAO 1992)*

Country	Production (t)
China	15,97,467
Japan	4,54,342
Korean Rep.	3,38,846
France	1,97,854
Spain	1,45,340
USA	1,23,910
Italy	1,10,700
Other Asian countries	62,938
Malaysia	57,088
Netherlands	52,600

Resources and distribution

A number of clam species belonging to the families Arcidae, Veneridae, Corbiculidae, Tridacnidae, Solenidae, Mesodesmatidae, Tellinidae and Donacidae are exploited along the Indian

Coast. The cultivable species belong to the first four above mentioned families.

Arcidae : The arcid clams are called blood clams as their blood is red in colour due to the presence of haemoglobin. A single species *Anadara granosa* is important. It occurs all along the Indian Coast in soft muddy substratum and forms a fishery of some magnitude in the Kakinada Bay.

Veneridae : The venerid clams are the most sought after in the clam fisheries in India and three genera namely *Meretrix, Paphia* and *Katelysia* are important.

Along the Maharashtra Coast, *Meretrix meretrix, Katelysia opima* and *Paphia laterisulca* are the dominant species. In Goa, *M. casta* forms a fishery. Along the Karnataka Coast, there are 14 estuaries with varying abundance of clams. *M.*

TABLE 4. *Clam production at different centres (Narasimham, 1991)*

State	Place	Production (t/year) *Species-wise	Total (t)	Source
Maharashtra	Thane to Ratnagiri	Mm & Ko 70% Pl, Km & Dc rest	1,100	Ranade (1964)
	Gav-Khadi	Sk	3	Rao *et al.* (1964)
Goa	Goa	Vc 500, Mc 315	887	Parulekar *et al.* (1973); Ansari *et al.* (1981)
	Kalinadi	Vc 525, Mm 20	545	Rao *et al.* (1989)
	Aghnashini	Mc 500, Mm 250, Vc 5	755	"
	Uppunda	Mc 10, Ko 64, Pm 80	155	"
Karnataka	Coondapur	Mc 50, Mm 40, Ko 5, Pm 500, Vc 8	603	"
	Sita	Mc 230, Mm 5, Ko 5	245	"
	Swarna	Vc 15	15	"
	Udayavara	Mc 215, Pm 5, Vc 5	225	"
	Mulky	Mc 1814, Pm 578	2392	"
	Gurpur	Mc 300, Pm 600, Vc 375	1275	"
Kerala	Nethravali	Mc 233, Vc 149	382	"
	Vembanad Lake	Vc 21490	21490**	Achari (1988 b)
	Ashtamudi	Ko 5552, Vc 6000	11437	Appukuttan *et al.* (1988)
Tamil Nadu	Vellar Estuary	Mc over 87%	985	Sreenivasan (1985)
	Pulicat Lake	Mc 102	102	Thangavelu and Sanjeevaraj (1988)
	Kakinada Bay	Ag 2000, Mm 400, Ko 40, Pm 30, Dc 30	2,500	Narasimham (1973) Silas *et al.* (1982)
	Godavari Estuary	Mm 250	250	Narasimham (unpublished)
	Bihmunipatnam Backwater	Mc 66	66	Rao *et al.* (1980)
		Total	45,412	

* Mm - *Meretrix meretrix*, Mc - *M. casta*, Ko - *Katelysia opima*, Km - *K. marmorata*, Pm - *Paphia malabarica*, Pl - *P. laterisulca*, Dc - *Donax cuneatus*, Sk - *Solen kempi*, Vc - *Villorita cyprinoides*, Ag - *Anadara granosa*

** Average for 1974-85

casta is found in all the estuaries, *M. meretrix* in the Kalinadi and Coondapur Estuaries , *Paphia malabarica* in the Mulky, Gurpur, Udyavara and Coondapur Estuaries are found. *Katelysia opima* is found in Coondapur, Uppunda and Sita Estuaries. Along the Kerala Coast, *P. malabarica* forms a fishery in Koduvally, Azhikkal, Karyamgod and Chittari Estuaries and Ashtamudi Lake. Other venerid clams form fisheries in several estuaries in Kerala State. Along the east coast, *M. casta* occurs at several places and forms a fishery at Vellar Estuary, Pulicat Lake and Bhimunipatnam Backwater. *K. opima, P. malabarica* and *M. meretrix* contribute to the clam fisheries in the Kakinada Bay. Along the Orissa Coast *Meretrix* sp. occurs in the Chilka Lake and Sonapur Backwaters.

Corbiculidae : The black clam *Villorita cyprinoides* is the major resource in Vembanad Lake and is also exploited in several backwaters, lakes and estuaries of Kerala. It also contributes to the fisheries in Goa and in the Nethravathi, Gurpur, Udyavara, Swarna and Coondapur Estuaries in Karnataka.

Tridacnidae : It is represented in India by *Tridacna maxima, T. crocea, T. squamosa* and *Hippopus hippopus* and occur in the Andaman and Lakshadweep Islands.

In India, the production of clams and the species breakup through harvest of the wild populations is not regularly monitored. However, based on the surveys conducted at important production centres, Narasimham (1991) summarised that about 45,412 t are landed annully (Table 4).

Of the estimated annual production of 45,412 t of calms, the black clam *Villorita cyprinoides* with a catch of 29,077 t forming 64%, is the mainstay of the clam fisheries. Major production centres are the Vembanad and Ashtamudi Lakes.

The venerid clams with an estimated annual production of 14,052 t, form 30.9% of the total landings. These clams are widely distributed and form fishery in all maritime States where clams are currently exploited. In this group, *K. opima* is most important with 5,552 t followed by *M. casta* (4,642 t), *P. malabarica* (1,793 t) and *M. meretrix* (965 t).

The blood clam *A. granosa* accounts for 2,000 t/year and 4.4% of the clam landings.

Of all the maritime States, Kerala leads in clam production with a catch of 32,927 t which accounts for 72.5% of the total clam landings (Table 4). The annual clam landings of the Karnataka State was estimated at 6,592 t (Rao *et al.*,1989) although considerable fluctuations in the landings have been recorded. The clam production in Goa has been estimated at 887 t/year and that of Maharastra at 1,100 t/year.

Along the east coast of India, the clam resources are smaller. In Tamil Nadu, the Vellar Estuary and the Pulicat Lake together contribute to 1,087 t ; while in Andhra Pradesh, the clam production was estimated at 2,816 t (Table 4).

TABLE 5. *Pattern of clam meat export from India (MPEDA, 1993) Quantity (tonnes) Value (Rs. '000)*

Production		1989	1990	1991	1992	1993
Frozen boiled clams	Q	329	414	1,234	940	776
	V	5,369	7,558	37,392	31,028	23,541
Clam meat pickle	Q	-	-	-	37	NEG
	V	-	-	-	2,025	15
Dehydrated clam meat	Q	42	107	164	129	124
	V	933	2,546	4,789	3,855	5,669
Total	Q	371	521	1,396	1,106	900
	V	6,302	10,104	42,181	36,908	29,225

There is no information from Gujarat, Orissa and the West Bengal. It may be due to absence of exploitation rather than the non-availability of the resources.

Distinctive characters of cultivable species

Anadara granosa : Shell thick, inflated and dark brown in colour. This species differs from other clams in having taxodont dentition (small teeth in a single straight series) and about 20 elevated ribs bearing rectangular nodules (Fig. 1).

In Venerid clams, the hinge usually bears three cardinal teeth and a single anterior lateral tooth on the left valve and a corresponding depression on the right valve. Two adductor muscle impressions, slightly unequal in size are present.

Paphia malabarica : Shell slightly inflated, surface concentrically grooved. Pallial sinus is 'U'shaped

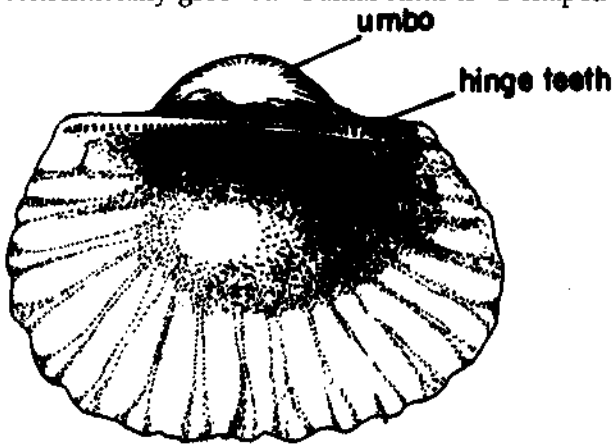

Fig. 1. Inner view of the right valve of *Anadara granosa.*

and very deep. Lunule relatively short. Shell length only one and one third times longer than height. Hinge area short with narrowly diverging teeth. Shell yellowish brown in colour, indistinctly rayed with greyish brown bands or mottled with brownish angular markings (Fig. 2).

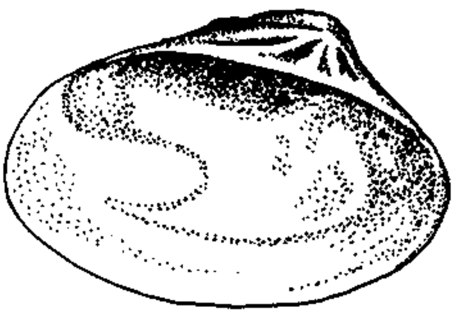

Fig. 2. Inner view of the left valve of *Paphia malabarica.*

Meretrix casta : Shell thick, smooth, devoid of any sculpture and triangularly ovate. Outer surface pale yellowish brown, tinted with dark grey posteriorly and very faintly rayed with greyish radial lines (Fig. 3).

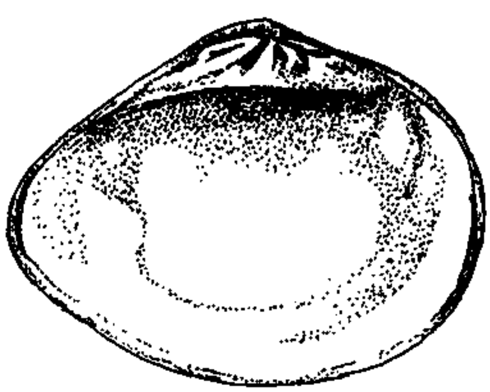

Fig. 3. Inner view of the left valve of *Meretrix casta.*

M. meretrix : Differs from *M. casta* in having less elongated lateral tooth and more ovate shell, grows to a larger size (Fig. 4).

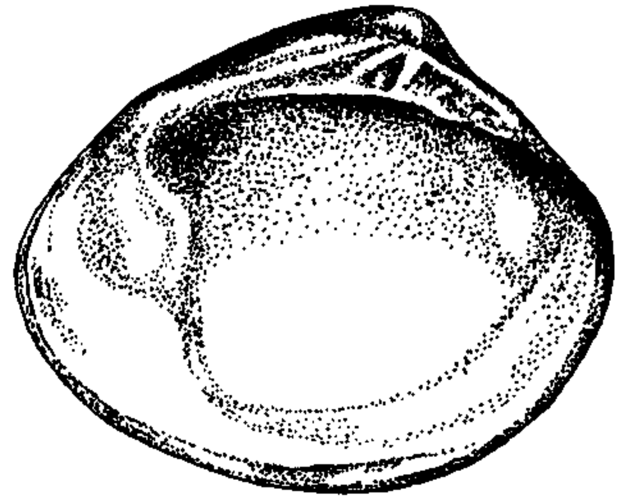

Fig. 4. Inner view of the left valve of *Meretrix meretrix.*

Katelysia opima : Shell thick, inflated, smooth, triangularly ovate. Pallial line deeply sinuate. Apex of pallial sinus bluntly angular. Lunule distinct, flattened and rather broad. Area behind umbones well defined, flattened and greatly elongated reaching almost upto hind margin of shell. Outer surface of shell polished, pale yellowish brown or straw coloured, variously mottled and rayed with purplish grey markings (Fig. 5).

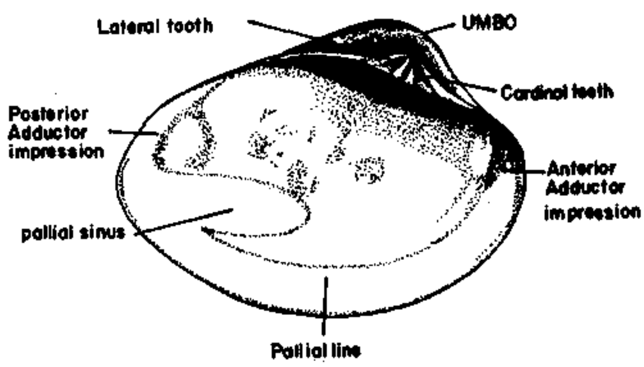

Fig. 5. Inner view of the left valve of *Katelysia opima.*

Villorita cyprinoides : Shell thick, ovately triangular with strong concentric ridges; ridges more strongly developed in anterior half. Umbones prominent, well elevated, hinge margin short and thick, always with three oblique cardinal teeth of which anterior in right valve and posterior in left valve obsolete. Pallial sinus small, lunule narrow and ligament large. Periostracum dark olive brown to blackish brown (Fig. 6).

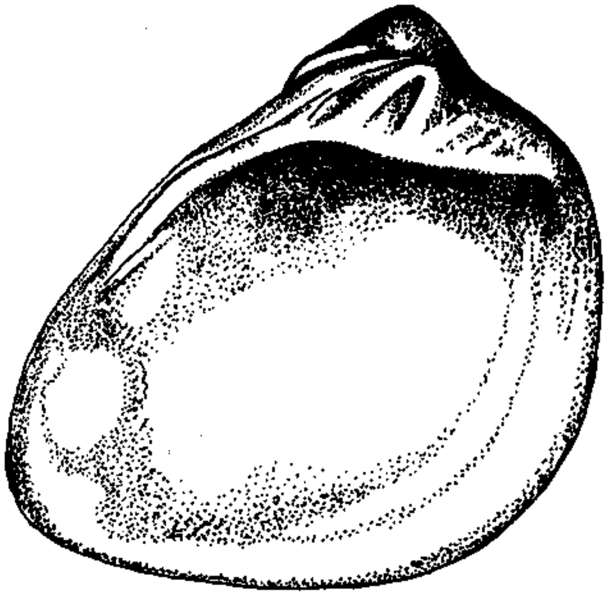

Fig. 6. Inner view of the left valve of *Villorita cyprinoides*.

The Tridacnid clams have large massive shells with broad radial ribs, sometimes bearing large fluted scales. Edges of valves usually scalloped.

Tridacna crocea (Crocus or Boring clam) : Smallest of giant clams, grows upto 15 cm. Large, thick, triangularly ovate shell with large byssal gape, 6-10 broad flattened ribs with concentric ridges. Shell greyish white, flushed with yellow or pinkish orange (Fig. 7).

Fig. 7. External view of the shell of *Tridacna crocea*.

T. maxima (Rugose giant clam) : Shell strongly inequilateral. Resembles *T. crocea*, but its 6-12 broad radial ribs have much more strongly developed concentric scales. Large byssal gape with distinct plicae at edges. Ventral margin of valve often deeply scalloped. Shell greyish white, sometimes tinged with yellow or pinkish orange. Grows to about 35 cm (Fig. 8).

Fig. 8. External view of the shell of *Tridacna maxima*.

T. squamosa (Fluted or scaly clam) : Large, thick, strongly inflated shell with small or medium sized byssal gap. 4-12 strongly convex ribs with riblets in interspaces. Broad, sometimes long fluted scales on ribs which may project beyond ventral margin considerably. Greyish white, sometimes finged with yellow. Grows to 40 cm (Fig. 9).

Fig. 9. External view of the shell of *Tridacna squamosa*.

Hippopus hippopus (Horse' hoof, Bear paw or Strawberry clam) : Large thick elongated lozenge shaped shell with tightly closed byssal area. 13-14 convex radial ribs with tube-like spines. Greyish white with yellowish orange tinges. Often

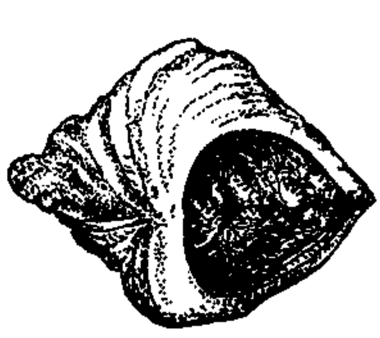

Fig. 10. External view of the shell of *Hippopus hippopus*.

dark red patches on ribs arranged in irregular concentric bands. Grows to 40 cm (Fig. 10).

Clam Culture - Global Scenaria

Clams are bivalves which burrow into the substratum with the help of a usually well developed foot. A few clam species are also known to attach to hard substrates with byssus threads.

Among bivalves, clams are by far, the most abundant and widely distributed resource. They are commercially important and fished in fairly large quantities in several countries. In India, clams form subsistence fisheries all along the coast. Clam meat is nutritious and is a cheap source of protein rich seafood. Clam culture is practised in several countries such as Taiwan, Thailand, Malaysia, Indonesia, Singapore, U.K., Australia. However, it is not as advanced an art as is the case with oysters or mussels. In clam culture, the seed is generally collected from natural grounds and replanted in areas with a suitable substratum, but where seed is not abundant. They are then allowed to grow to market size.

Selection of site

Clams are cultured on the bottom and therefore site selection depends on the substrate. 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. About 1-2 hrs exposure at low tide is desirable as it is easy to remove the predators.

Too long an exposure results in poor growth due to reduced feeding and in summer there may be mortality due to desiccation. Farms located further in subtidal area have the disadvantage when predators are to be eradicated.

The type of substratum preferred varies with the species. For example, *M. casta* thrives well on sandy bottom, while *A. granosa* prefers mud flats. Also the salinity range tolerated differs between species. While *V. cyprinoides* prefers low saline waters few species tolerate prolonged low saline conditions which are generally prevalent in areas subjected to heavy rains and freshwater drain from the land. Clam farms are located in areas where there is little wave action. Areas prone to frequent changes of contour and vulnerable to pollution are avoided.

Hatchery production of spat

Mature clams of 35-45 mm shell length are used as brood stock. The brood stock is conditioned in unfiltered seawater of 25 ppt and at 22-24°C and then transferred to spawning troughs. Spawning is induced by thermal cycling; the spawning trough is part filled with cooler water to a depth of 10 cm and a small amount of cultured microalgae (*Isochrysis galbana*) to stimulate the clams to extend their siphons and start pumping activity. After 15-30 minutes, the water is drained and replaced with water at 28-30°C, again with small addition of algae. This water is drained after a similar period of time and replaced with cooler water and the procedure is repeated. The number of cycles which are necessary to induce spawning depends on the readiness of the clams to spawn.

Eggs are separated through a 60 µm nylon mesh seive and transferred to filtered seawater at 25°C. The larvae are grown in flat bottomed vessels, or in conically based fibreglass tanks fitted with bottom drains, at 15,000-20,000/lt, but optimum density for good growth is 10,000/lt.

Good aeration at the rate of 200 lt/hr depending on the size of the container and filtered and sterilized seawater of 25 ppt and 24-26°C provides optimum conditions for larval growth. Unicellular alga such as *Chaetoceros calcitrans*, *Isochrysis galbana*, *Tetraselmis suecica* and *Thalossiosira pseudonana* are suitable food species. Diets of mixed algae are beneficial. A suitable diet for "D-shelled" larvae is a mixture of *Chaetoceros* and *Isochrysis*, the most suitable cell densities are 125 cells/µl respectively.

Air-lift downwelling recirculation systems of 100 lt capacity are generally used for growing 0.5 million spat to a size retained on 440/µm mesh size.

Nursery rearing

Nursery upwelling systems are generally used in several European countries for spat rearing.

The upwelling system used at the Fisheries Laboratory at Conwy for *Mercenaria mercenaria, Tapes decussatus* and *T. philippinarum* is shown in Fig. 11.

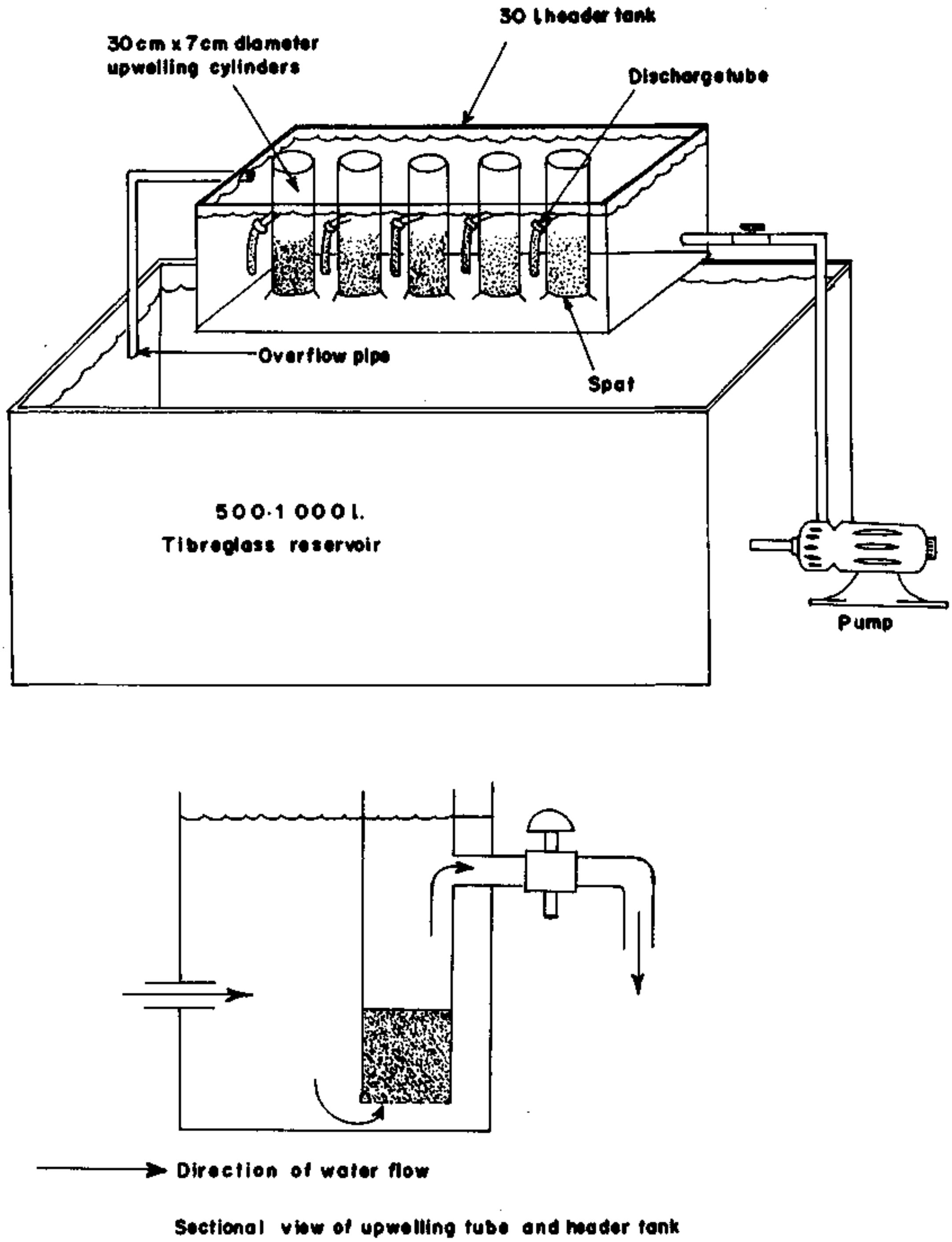

Fig. 11. A nursery upwelling system used in the Fisheries Laboratory at Conwy (Utting and Spencer, 1991).

Water flow is induced through cylinders (30 cm x 7 cm diameter) placed in a 30 lt header tank, by creating a difference in the head of the water. The header tank is placed over the 500-1000 lt fibreglass reservoir tank. Valves are fitted to the overflow of the upwelling cylinders, since spat growth is strongly influenced by water flow rate. Flow rates of 20-50 ml/minute per gram is used.

Seawater, coarsely filtered through a 45 µm mesh is used so that the spat are benefitted from the presence of naturally occurring algae, in addition to those offered as food.

Nursery upwelling systems need relatively large volume, since only small biomasses of spat can be grown successfully per unit volume of water.

Grow out culture and production

The ground is levelled and cleaned of predators such as boring gastropods, starfishes, crabs and skates. Bamboo poles are planted on the boundary of the farm as markers. The movements of the clams are limited and in many areas fencing is not necessary. Synthetic fibre net pens are erected to protect clams against strong water currents in the USA, bamboo stakes with nylon netting are used in Taiwan.

At high tide, seed measuring 10 - 25 mm in length are taken in a boat and planted in the farm, taking care to get even dispersal as far as possible. Uneven distribution is set right at the next low tide. In Malaysia, *A. granosa* is stocked at 1000-2000/m^2 and thinned more than once to achieve final density of 300-600/m^2. The stocking density varies with the species and a stocking density of 400/m^2 for 10 mm seed and 300/m^2 for 20 mm seed is usually optimum.

After seeding the farm, 10 mm mesh synthetic netting is laid and held in position by stakes driven into the substratum at the periphery of the farm, to offer protection to the young clams. Except for watch and ward and eradication of predators, no other maintenance job is necessary during the grow out phase. The clams are harvested after 5 or 6 months either by hand picking or by hand operated dredge.

In Malaysia, wild seeds of *A. granosa* are stocked/ranched in pre-prepared coastal mud flats, generally bound by natural landmarks and where these are lacking, are marked by other means. The stocking/seeding density is between 2-6.5 kg seed/m^2. An average production of 40 t/ha is obtained.

In Thailand also the same method is followed for *A. granosa* and 50 cm long bamboo stakes are used to fence the intertidal mud flats to prevent escape of clam from the culture beds. Clam seeds are also sown in the central elevated areas of shrimp ponds and fenced with bamboo stakes. The seeds used here are larger than those used for the intertidal flats. These methods yield 31-109 t/ha annually.

In China, *Sinonovacula constricta* (razor clam), *Arca (Anadara) granosa* and *Tapes philippinarum* (small-necked clam) are cultivated. Seed clams (1 cm long) of *S. constricta* are collected and sown into rearing beds during January, at 9-18 x 10^6 clam seeds/ha. The average yield is 15-22 t/ha after 6-7 months. *A. granosa* seed are also raised from natural spat and reared in enclosed waterpools. They are thinned several times, transplanted to rearing grounds in the lower tidal zone. It takes 2-3 years to reach marketable size of 2 cm and yield is 22.5-60 t/ha. The small necked clam is also cultivated on pre-prepared culture beds by stocking 1.4 cm seed clams at 1.8 x 10^6 seed/ha. The yield is about 18.7 t/ha, but sometimes as high as 45 t/ha.

Clams are rarely grown in ponds, but in recent yaers, due to adverse impact of the viral diseases in shrimp culture, 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.

Giant clam culture

Giant clams are the only autotropic farm animals known to man. The unique feature of the giant clams is the symbiotic relationship with the dinoflagellate algae, zooxanthellae in their mantle tissue. They retain their filter feeding habit and food is supplemented by the nutrients gained from the photosynthesis of zooxanthellae. They mature as males at two or more years of age and later develop female gonads also. The initial growth of the giant clams is slow and they reach 2-4 cm in shell length after a year. Thereafter growth is rapid in larger species. Estimations of the life spans of giant clams have been speculative and some of them do live for a few decades.

In giant clam culture, four phases are involved.

(a) *Hatchery phase* - rearing the larvae from eggs in indoor or outdoor tanks.

Six out of the eight known species of giant clams have been successfully spawned in the Philippines by injecting serotonin into the gonad of mature clams and also by introduction of macerated gonad materials into the mantle cavity through the exhalent siphon.

The development stages are similar to those in other clams and settlement takes place in about 7-10 days after spawning. *Isochrysis galbana* is given as food. The spats attach with the byssus, but they may break the attachment and creep along the substrate. At this stage the symbiosis with zooxanthellae is established. The larval rearing is done in both indoor and outdoor tanks.

(b) *Nursery phase* - rearing juvenile clams in onshore tanks for metamorphosis (0.2 mm) to about nine months of age and 20 + mm shell length (seed clams).

The tanks are provided with flow of raw seawater. The clams acquire the zooxanthellae from seawater in about 3 weeks after fertilization and they become increasingly autotrophic.

(c) *Ocean nursery phase* - rearing juvenile clams in protective containers in the field from about 20 mm shell length to 200 + mm shell length.

(d) *Grow out phase* - rearing clams of 200 + mm shell length, without protection in the field to market.

T. gigas the largest among the giant clams, grows to 18.6 mm (total wt. 0.55 g) in 0.83 years, 121.1 mm (193.8 g) in 2 years, 206.4 mm (923.3 g) in 2.66 years and 221.3 mm (1.15 kg) in 3 years. The wet meat forms 12% of the total weight in 18.6 mm clams and it increases to 26 % in 221.3 mm clams. A production of 29 t of wet meat/ ha has been estimated in *T. gigas* culture for three year old clams. The field culture techniques, survival and production for various giant clam species are still in experimental stage.

Clam culture in India

The Central Marine Fisheries Research Institute has developed the technology for culture of the blood clam *Anadara granosa* in the Kakinada Bay. Although complete package of technology including seed production under controlled conditions has been developed in the country for the blood clam *A. granosa* and the venerid clam *P. malabarica*, it is yet to be commercialised.

Site selection

The criteria to be adopted are the same as given for clam culture in an earlier section.

Hatchery production of seed

Hatchery production of seed technology has been developed for *A. granosa*, *M. meretrix*, *M. casta* and *P. malabarica*.

In clams, spawning occurs both at elevated water temperature of about 34°C and also at the lower temperature of about 24°C on transfer to the conditioning room, after the thermal shock. Spat settlement takes place between 7th and 26th day after spawning in different clam species studied. The clam spats attains 2-3 cm in length in the hatchery in two months after fertilization and are transferred to the nursery. A survival rate of 15-20% in spat production in the hatchery is considered as satisfactory. In the hatchery the microalga *Isochrysis galbana* is given as food to the larvae and mixed microalgae, reared in outdoor tanks as food to the spat.

Nursery rearing

The 2-3 mm hatchery produced clam seed are transferred to 40 x 40 x 10 cm box type cages. These cages are covered with fine velon screen mesh and for additional protection against damage by crabs and fishes, a 10 cm mesh nylon fish net is stitched over the cage. The cages are suspended from racks in shallow calm waters. They are periodically cleaned of silt, predators and foulers which enter the cages as larvae. In 6-8 weeks, the clams grow to about 10 mm in length and are ready for planting on the grow-out grounds.

Recently rearing of the hatchery produced spat of *P. malabarica* (2-3 mm length) in 25 x 25 mm nylon bags of 1-2 mm mesh at a density of 1000 spat/bag and suspended from a rack in the Tuticorin Bay gave highly encouraging results. This method is cost effective when compared to rearing in cages (Shri D. Sivalingam, Pers. comm.).

Grow out and production

In the blood clam *A. granosa* culture at Kakinada, seed clams of 21.8 to 25.1 mm average length (5.53 - 7.08 g average wt) were stocked at 240-175/m^2. They attained 39.2 to 42.7 mm average length and 25.53 to 32.9 g average weight at harvest. The retrieval is 83.4% to 88.6% when pen enclosures are used and 41.5% without pen. Production rates of 39.0-41.6 t/ha/5.5 months are obtained when pen culture is practised and 21 t/ha/6 months when pen is not used. Thus both retrieval and production rates are reduced by about 50% in the blood clam culture if pen is not used. At a stocking density of 300/m^2 the production is estimated at 70 t/ha with pen enclosure.

In the Mulky Estuary in Karnataka, in experimental culture, *M. meretrix* has grown from 23.6 mm average length to 37.5 mm in 4 months and the survival rate is 75.5%. In the Vellar Estuary, *M. casta* has grown from 7.3 mm to 40.6 mm length in one year.

In a ranching experiment in Ashtamudi Lake in Kerala, *P. malabarica* seeds of 11.5 mm average length and 0.27 g average weight were stocked at 3566 nos./m^2. They attained an average length of 31.58 mm and 8.54 g average weight at harvest after 3.5 to 5.5 months. The retrieval was 7.5%. At Munambam, *P. malabarica* seed of 2.4 mm average length and 0.2 g average weight was stocked at 1500 nos./ m^2. After 4.5 months, they attained 34.6 mm average length and 9.05 g average weight. The retrieval was 17.64%. The production works out to be 1.5 to 2 kg/m^2.

Depuration, processing, byproducts and utilization

Depuration

Clams like other filter feeding bivalves, accumulate pathogenic organisms in their body. By depuration the bacterial load is brought down to permissible levels; also faeces, sand particles and silt are removed from the alimentary canal. Clams are depurated in the same way as other bivalves.

They are placed for 24 hrs in cleaning tanks under a flow of filtered seawater. About 10-20% of the seawater is continuously replaced. At the end of 12 hrs the water in the tank is drained and the clams are cleaned by a strong jet of water to remove the accumulated faeces. They are further held in filtered seawater for 12 hrs and for about one hr in 3 ppm chlorinated seawater, washed once again in filtered seawater before processing. In several countries, they are eaten raw and also steamed and eaten.

Processing

The various techniques followed in processing the clam meat are similar to those used for other bivalve molluscs. The clam meat is frozen as blocks or individual quick frozen, canned and smoked. Other products are clam juice, clam stripes, clam streaks, stuffed clams, clam pickle and chowder.

The adductor muscle is the valued part of the giant clam. In a 20 cm clam, it weighs about 500 g. Except the liver all parts of the soft body of the giant clams are eaten. The mantle of the giant clam is used to make the Japanese salads, spaghetti, marinara, clam crackers and minced clam.

Byproducts and utilization

In clam culture, shell is the byproduct. It is used in the manufacture of cement, calcium carbide, sand-lime bricks and lime. The shell lime is used for manuring coffee plantations, as a mortar in building constructions, in the treatment of effluents, as a pesticide by mixing with copper sulphate and in glass, rayon, polyfibre, paper and sugar industries. The shells of several clams have ornamental value and are used in making curios.

Truck loads of blood clam shells are transported from Kakinada to southern districts of Tamil Nadu for use in the shell craft industry.

Giant clam shells currently find a ready market as decorative objects, ash trays, salad bowls and wash-basins. *T. squamosa* shells are most valued in this trade. Philippines is the centre for shell craft industry.

Export market for clams

The pattern of clam meat export from India is given in Table 5. The export demand for clam meat has been increasing over the past few years, particularly from Japan, western Europe and USA. The clam meat export from India has increased from meagre 371 t in 1989 to 900 t in 1993. In terms of value, almost fivefold increase has been recorded at Rs. 63.02 lakhs in 1989 to Rs. 292.25 lakhs in 1993.

Economics of clam culture

The economics of the on-bottom blood clam (*A. granosa*) culture are given here. The area of the farm is 10 ha and the duration of culture is 6 months. The stocking density of the seeds at 300/m^2 was considered as the optimum and at this density production of 70 t/ha is envisaged. There is much demand for the shell of this species in the shell-craft industry and currently it fetches Rs.1000/t.

		Rs.
A.	*Capital expenditure*	
	1. FRP boat with outboard motor	80,000
B.	*Operational cost*	
	1. Casuarina poles	2,500
	2. Cost of pen enclosure	10,000
	3. Cost of seed @ Rs.55/1000	16,50,000
	4. Running expenditure of boat	6,000
	5. Labour cost	6,000
	6. Harvesting, depuration & shucking of meat charges	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*	
	Shell-on weight of harvested clams 700 t	
	Wet meat weight 105 t	
	Shell weight 525 t	
	Sale of 105 t meat @ Rs. 25,000	26,25,000
	Sale of 525 t shell @ Rs. 1,000	5,25,000
	Total	31,50,000
F.	*Profit* (Rs.31,50,000 - Rs.17,74,500)	**13,75,500**

Net profit on investment works out to 77.5%.

Prospects and constraints

The prospects for developing clam culture in India on commercial lines are very bright and the advantages are given below.

1. Clams feed low in the food web on detritus and phytoplankton and give high production per unit area. They are efficient converters of primary production into nutritious sea-food, suitable for human consumption.
2. Clam culture is essentially a relaying practice of collecting the seed from high density areas and stocking them in suitable grow out areas. The farm management involves periodic site inspection and eradication of predators; the technology is simple and easy for adoption by the farmers.
3. On-bottom clam culture does not involve high labour or cost input.
4. Clam culture can easily be blended with capture fisheries and can be taken up as an income and employment generation programme in rural areas.
5. In the export market there is demand for some species of clams only. From India there

is insatiable demand for the frozen meat of *P. malabarica*. There are large tracts of derelict water bodies such as the Kakinada Bay and they can be utilized for the culture of this species.

6. In clam culture fertilisers and feeds are not used and it is eco-friendly. Clams are good biological filters and the introduction of clams in areas of high eutrophication such as shrimp ponds helps to reduce the pollution due to high load of suspended matter.

7. After the outbreak of shrimp disease in Taiwan, the farmers have switched over to culture of the clam *Mercenaria lusoria* in shrimp ponds for export to Japan. Similar practice can be followed in Andhra Pradesh and Tamil Nadu. Also fattening of the clams in shrimp ponds as followed in Thailand deserves merit.

Constraints

1. The major constraint for the large scale propagation of clam culture in the country is the absence of laws to allot water bodies to prospective farmers.

2. Mapping of sites suitable for clam culture, based on species-site interaction are needed for developing culture.

3. Consumption of clams is still localised, close to the production centres and only a small segment of the population take them as food. They still remain as non-conventional food. Vigorous extension drive is needed to make them popular.

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14

SHRIMP HATCHERY

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Introduction

Successful spawning of *Penaeus japonicus* under controlled conditions and their subsequent rearing upto the juvenile stage by Hudinaga (1942) and his team paved way for the large scale hatchery production of shrimp seed for aquaculture.

Hatchery systems

There are two basic hatchery techniques for the mass rearing of larvae of shrimps : Japenese technique and Galveston technique. These techniques have been appropriately modified to suit the different geographical and climatic conditions. Thus many gradations between these two techniques have been noticed in different parts of the world. In some cases, combination of these two techniques have also been followed (integrated system).

The Japanese technique

The well known Japanese system for the mass production of postlarvae of penaeid shrimps is also known as community culture system or fertilized system or large tank hatchery system or Taiwanese system.

In this system, the spawning, hatching, larval and postlarval rearing upto the fry stage are carried out in the same tank (Hudinaga and Kittaka, 1967; Hudinaga, 1969, Shigueno, 1975; Yang, 1975; Muthu, 1980). By fertilizing the water in the tank, phytoplankton and zooplankton organisms which form the food of larvae are also raised along with the larvae in the same tank.

The hatchery tanks are large and vary in size from 60-200 tonnes of water capacity and above. The tanks may be rectangular, square or round in shape having a depth of 1.5 to 2 m. They may be indoor - with transparent roof or outdoor depending on the prevailing weather conditions. Tanks are provided with good aeration systems.

Before starting the larval rearing operations, tanks are cleaned and sun dried. Then the tanks are filled with fresh filtered sea water upto 1/5 of the tank capacity. Vigorous aeration is provided and the water is agitated slowly by rotating vanes attached to an electric motor.

Spawners are then introduced into the tank. In case of infection, spawners may be treated first with 3 ppm $KMnO_4$ or any other chemicals in prescribed strength. They are introduced into the tank in cage nets (@ 1 spawner per m^3 of tank capacity). After spawning, the spawners are removed along with the cage nets. The eggs released, hatch out within 12-18 hrs depending on the water temperature.

After the eggs hatch out to nauplii, the tank water is fertilized with nitrates (KNO_3, 2 ppm) and phosphate ($KHPO_4$, 0.2 ppm). Fertilization helps the growth of naturally occurring diatoms on which the protozoea feed. The water is fertilized daily to maintain a good growth of diatoms (5000 to 20,000 cells/ml). By the time protozoea develop to mysis stage, a good population of zooplankton organisms will also be developed in the tank. Thus a feeding environment very similar to the condition obtained in the sea is created. Anaerobic decay of the dead organisms is prevented by vigorously aerating the water.

From the first day of mysis to the fourth day of postlarvae, fresh, sediment free and clean filtered sea water is pumped into the tank every day until the water level in the tank is increased to the maximum tank capacity. Supplementary feed in the form of *Artemia* nauplii or minced and washed clam meat or formulated feed of appropriate particle size are also provided for postlarval stages.

Although it is difficult to maintain a constant initial stocking density of nauplii in this system, generally the density will be around 100 no/lt. Postlarvae are reared upto PL 25-30 in the same tank within a period of 35-40 days. Final production of PL 25-30 will be within the range of 5-25/l *i.e.* on an average of 10,00,000 PL 25-30 will be obtained from a larval rearing tank of 200 t capacity during a single hatchery run.

Modifications in the feeding pattern has been introduced into this practice by several workers. In Taiwan, Liao and Huang (1972) used oyster larvae produced by artificial fertilization as food when the phytoplankton bloom did not develop well. Yeast @ 2 gm/t per day was used along with mixed diatom to feed protozoea and mysis stages in Philippines. The rotifer *Brachionus* sp. cultured separately is also used at a concentration of 10-25 cells/ml for the mysis and early postlarval stages.

The low maintenance cost, the less requirement of technical expertise to run the hatchery compared to the Galveston system as well as the use of the same tank for rearing larvae through various stages upto the seed size when they could be transferred to the farm are the advantages of this system. The disadvantages are the high initial cost of construction; the lack of control over the intensity of the phytoplankton bloom and the frequent growth of undesirable species of organisms such as dinoflagellates and *Noctiluca* which lead to mass mortality of larvae. As the larvae do not hunt for food, but filter the food particles within their reach in the medium a good amount of food will remain unutilized by the larvae due to relatively low density of the larval population.

The Galveston system

Galveston system is otherwise known as closed system or unfertilized system or feeding system or small hatchery system. This system has been developed by the scientists of the Galveston Laboratory in USA (Cook and Murphy, 1966, 1969; Mock and Murphy, 1971; Mock and Neal, 1974; Salser and Mock, 1974). This system is more sophisticated and consists of a number of independant processes - mass production and storage of pure algal culture, mass production of freshly hatched *Artemia* nauplii and larval rearing operations - which involve higher technical skill. The use of desirable species of food organisms and the greater control over the water quality facilities by use of small containers make this method more dependable.

Cook (1969) originally used a small fibreglass tank of 946 lt capacity for spawning and a 19 lt polyurethene carbuoy for rearing nauplii to postlarval stage. The phytoplankton added for feeding the larvae, are prevented from settling to the bottom of the larval rearing carbuoy by providing adequate aeration. Half the volume of water in the carbuoy is replaced every day with fresh filtered seawater, which in effect prevents the accumulation of metabolites in the medium. He stocked 266 nauplii/lt and produced 133 PL/lt using this system.

Later Cook and Murphy (1969) used 1890 lt cylindrical polyethylene containers, connected to a sea water recirculation system with crushed oyster-shell filter beds, for both spawning and larval rearing. The recirculation of water is stopped as soon as pure cultures of desirable species of diatoms and unicellular algae are added to the tank water for feeding protozoea stage. Concentration of phytoplankton is maintained at a cell density of 10,000-15,000 cells/ml. Freshly hatched artemia nauplii are given at the rate of 3-5/ml of water for feeding the larvae from mysis stage onwards.

This system has been further improved by Salser and Mock (1974) by introducing cylindro-conical fibreglass tanks of 2 m^3 capacity for rearing larvae. The shape of the tank facilitates efficient dispersal of food particles and larvae throughout the water column.

The system has been adopted in a modified form in Tahiti (Aquacop, 1975), in Philippines (Platen, 1978) and in UK (Beard *et al.*, 1977). Algae in higher concentrations (30,000-1,00,000 cells/ml) are maintained separately and used for feeding protozoea larvae. *Brachionus* culture maintained separately is also used to feed protozoea. The concentration of *Brachionus* in the larval rearing tanks are maintained at 5-10 rotifers/ml. From postlarvae I onwards, freshly hatched *Artemia* nauplii are used as food; the density being maintained at 5 no/ml of rearing medium.

Nauplii are stocked at the rate of 100-200 no/lt and they are reared upto PL 5 in the larval rearing tanks. Survival from nauplius to PL 5 is about 70%. At PL 5 stage they are transferred to nursery tanks.

This system has many advantages. The hatchery can be operated with few spawners. It is easy to maintain and manage the water quality. The amount of water required is small. Water temperature can be controlled easily. Diseases can be checked and prevented by better water management and antibiotic treatment. Food is not wasted. Survival rate is high.

Integrated system

Although the basic hatchery technologies can be broadly brought under two categories, they have been appropriately modified in different countries so as to suit different geographical and climatic conditions. Thus varying degrees of combinations and permutations of these two systems are in vouge in different parts of the world. The larval rearing technology recently developed in Tahiti and New Caledonia has been described by Autrand and Vidal (1995). This system is based on the exclusive use of microparticles as a replacement for algae and avoiding the water renewal upto first postlarva. Better hygenic conditions are provided by keeping the different units of the hatchery separately, by providing biological filter to the larval rearing tanks from first mysis onwards. Pathogenic risks have been reduced to the minimum by adopting minimum prophylactic treatments, using microparticles and *Artemia* nauplii feed and allotting sufficient dry-out period. Similarly two low cost modified systems have been developed and put to use in the production of shrimp seeds in India *viz.*, Kerala Fisheries Technology (KFT) (Alikunhi *et al.*, 1980) and Central Marine Fisheries Research Institute (CMFRI) technology (Silas *et al.*, 1985).

Kerala Fisheries Technology

Azhicode Hatchery utilising the Kerala Fisheries Technology, is using shrimp meat suspension for feeding the various larval stages of shrimp. 6 to 60 t outdoor pools or concrete tanks of 75 to 100 cm height are used for larval rearing. Cleaned and sun dried tanks are filled to 1/5th of its capacity with filtered seawater. Wild spawners either *P. indicus* or *P. monodon* are introduced into the tank at the rate of one spawner/tonne of water. Spawner is removed after spawning and water level is raised to 1/2 and aeration continued.

Shrimp meat suspension made out of juvenile *M. dobsoni* or squilla meat is fed to the larvae. Mysids and *Acetes* are also used for making meat suspension. The approximate weights of meat feed for (1000 larvae/day) different larval stages are given below.

	M. dobsoni	*Squilla*
Protozoea I	0.5 g	1.0 g
Protozoea II & III	0.75 g	1.5 g
Mysis I	1.0 g	1.75 g
Mysis II	1.25 g	1.75 g
Mysis III	1.5 g	2.00 g
PL 1	2.00 g	3.00 g

From mysis I stage onwards 1/3rd of tank water is exchanged daily. Depending on the phytoplankton bloom developed in the larval rearing tanks, water exchange is regulated. The larval rearing tanks are generally stocked with 100-250 nauplii/l. They are reared upto postlarva 10 in the same tank at the survival rate of 75%.

CMFRI Technology

A low cost technology for hatchery production of shrimp seeds suitable to Indian conditions has been developed by the Central Marine Fisheries Research Institute (CMFRI) for the white prawn *Penaeus indicus*. The same technology has been successfully scaled up for the large scale production of PL 15-20 of other commercially important penaeid prawns of India especially *P. monodon*, *P. semisulcatus* and *P. canaliculatus*. Further, using this technology CMFRI has established a hatchery for *P. indicus* (with a capacity to produce 1 million seeds per run) for MATSYAFED at Cannanore. An experimental hatchery for *P. semisulcatus* with a capacity to produce 1 million seeds per year has been established at Mandapam Camp of CMFRI.

The cost of production of postlarvae 15-20 has been made minimum, as this technology mainly makes use of the available natural conditions of the Indian Coast, such as good sun light, ideal temperature, sea water of above 30 ppt salinity and locally available candidate species. It was found that the protozoea and mysis stage larvae of all the commercially important Indian penaeid prawns could be reared successfully by feeding them exclusively with the diatom *Chaetoceros* which can be easily developed and maintained in fibreglass tanks in indoor hatcheries, with translucent roofing - a major factor, which helped to make this technology a low cost one.

This technology (developed for *P. indicus* and adaptible for other commercially important penaeid shrimps), is infact site specific and consists of a package of practices involving the following components : (i) Inducing brood stock prawns to mature in captivity in a predictable manner, (ii) spawning of viable eggs with good hatching rate, (iii) hatchery rearing of the nauplii to the postlarval stage with appreciable rate of survival, (iv) production of large scale mixed culture of diatoms to feed larvae and (v) preparation of dry particulate diet for feeding postlarvae.

Site selection is of prime importance for the successful functioning of a hatchery and the following important criteria may be strictly adhered to : (i) areas subjected to sea erosion, soil erosion and natural calamities should be avoided, (ii) sea water should be of good quality. For this the site should be far away from river mouths so that the sea water is not diluted by the freshwater discharge. Flood water from the rivers also brings in a lot of silt and detritus adding to the turbidity of the water, (iii) hatchery should not be located near sources of thermal, sewage or industrial pollution, (iv) the sea bottom near the site can be sandy or rocky, not clayey and (v) uninterrupted electricity and freshwater should be available in the vicinity.

Broodstock maintenance

It is essential to have a broodstock facility for the uninterrupted production of seed particularly for large hatcheries and for hatcheries producing non-native species. The brood stock tanks are preferably circular with central drain having a capacity of 10-15 t with a water depth not less than one metre. The tanks are provided with recirculation facility, biological filter, provision to get good quality filtered sea water and continuous aeration. The tanks may be housed in a dark room with facilities to control photoperiodicity. For broodstock maintenance adults of males and females may be collected from the wild. The animals having proper weight and without injury, may be transported to the hatchery without stress. These animals are disinfected using formalin; acclimatised and then transferred to the broodstock tanks. Male : female ratio being 1:1 to 1:2. Depending on the species, the stocking density can be 5 to 7 animals/m^2. These animals are subjected to unilateral eyestalk ablation and fed *ad libitum*. Clams, shrimps and polychaetes of marine origin are found to be ideal food for the broodstock shrimps. The success of maturation is directly dependent on the water quality management; clear sea water, conforming to the following hydrological parameters are conducive for maturation.

Parameter	*Permissible range*
Salinity	29 to 34 ppt
Temperature	28 to 30°C
pH	8 to 8.2
Dissolved oxygen	4 to 5.5 ml/lt

The pH of the seawater in the pool is maintained between 8 to 8.2 by addition of sodium carbonate. The unused food and faecal matter are siphoned out every morning. The water in the maturation tank is totally replaced before introducing a fresh batch of ablated females.

The experiments carried out recently on the induced maturation of *P. indicus* and *P. semisulcatus* in captivity has revealed that shrimps can be induced to mature and spawn in captivity by controlling pH of water photoperiod and providing proper food. The advantage of this method of rematuration over eye-stalk ablation is that the quality and quantity of eggs and larvae produced in successive spawning do not show any deterioration (Maheswarudu, Per. Comm.).

Spawning : Impregnated females with fully mature ovary are maintained individually in 250 lt capacity spawning tanks containing 200 lt of sea water of 30-34 ppt salinity filtered through

50 micron mesh bolting cloth. Spawners are transferred to the spawning tank in the evening. Disodium salt of EDTA is added to the water @ 0.1 g/100 lt of water. The ideal temperature range is 27-30°C and pH 8.0-8.2. A mild aeration is provided and the tank is covered with black lid to protect the female from strong light and to prevent it from jumping out of the tank. Spawning usually takes place during right between 2000 and 0200 hrs. Females, after spawning, are removed from the tank at 0600 hrs. Continuous increased aeration is maintained in the tank. Depending on temperature, hatching takes place within 1200-1800 hrs. and by afternoon all the eggs hatch out to nauplii. Aeration is stopped and nauplii are allowed to congregate at the surface. Dead and unhatched eggs that sink to the bottom are siphoned out along with bottom sediments. Once again aeration is switched on and the water is mixed thoroughly and three, 100 ml samples are taken with beakers and the number of nauplii in the samples counted and the total number of nauplii present in the tank estimated.

Larval rearing : 2 to 5 t capacity cylindro-conical tanks are used for rearing larvae upto postlarva 3-5. Fibreglass tanks or concrete tanks with an inner coating of non-toxic epoxy paint are used for larval rearing. The tanks are first cleaned properly with bleaching powder and then washed thorougholy with freshwater. They are sun-dried for 24 hours. Afterwards, they are once again washed with filtered sea water and then used for larval rearing purpose. To begin with, half of the tank is filled with sea water, filtered through 50 micron mesh bolting cloth. Continuous aeration is provided throughout the larval rearing period. 5-6 hrs after hatching the nauplii are counted and transferred to the larval rearing tank at a stocking density of 75-100 nauplii/lt of water. The difference in the temperature of water in the spawning tank and larval rearing tank must not be more than 1°C. After 36 hrs of hatching, the nauplii will be 5th or 6th stage, depending on the temperature of the medium. At this stage 100 lt of mixed algal culture dominated by *Chaetoceros* sp. or *Skeletonema* sp. are added into the larval rearing tank. Protozoea feed on a variety of diatoms such as *Skeletonema costatum, Thalassiosira* spp. *Dunabella* spp., etc. But it was found that the larvae upto last mysis stage could be reared exclusively on *Chaetoceros* spp.

Concentration of the algal cell in the medium must not be below 20,000 cells/ml. The diatoms thus added will ensure the availability of food in the vicinity of larvae as soon as nauplii metamorphose to first protozoea. From first protozoeal stage onwards 150-200 lt of algal culture are added and the water level is made upto the maximum by adding filtered sea water. From 4th day onwards, daily 1/4th to 1/3rd water from the larval rearing tank is removed and replaced with fresh filtered sea water. Filter bags, with proper mesh size are used while siphoning out water to prevent the escape of larvae from the tanks. If the algal culture used is dominated with *Chaetoceros* spp., no supplementary feed is required until the larvae develop to third mysis stage. Otherwise supplementary feeding with particulate feed or egg prawn custard may be started from first mysis stage onwards. Supplementary feed is provided from third mysis stage onwards along with algal diet. The quantity of algal diet is reduced from first postlarval stage. Larvae are reared upto postlarva 3-5 in the larval rearing tanks and are afterwards transferred to nursery tanks for further rearing.

From 2nd protozoeal stage onwards, daily the sediments from the bottom of the tank are removed. Aeration is stopped allowing larvae to come to the surface before siphoning out the water from the tank or removing the bottom sediments.

The water quality and other conditions conducive for larval rearing are as follows :

Salanity	29-34 ppt
Temperature	26.0 - 32.5°C
pH	8.0 - 8.5
Dissolved oxygen	3.0 - 8.0 ml/litre
Light intensity during day ..	20000 to 125000 lux
Total ammonia	0.1 ppm or below
Nitrite	0.05 ppm or below

Some guidelines on the management of larval rearing tanks of 2 t capacity are given in Table 1. But it must be noted that careful attention to water quality and condition of larvae, the volume of water exchanged and the amount of feed given should be judiciously varied to meet the exigencies of the situation.

TABLE 1. *Management of larval rearing pools*

Day	Stage	Seawater removed	Algal culture added (lt)	Particulate feed (g)	Seawater addition (lt)	Total volume of water made upto (lt)
1	N 2	-	-	-	1000	1000
2	N 5	-	100	-	-	1100
3	PZ 1	-	150-200	-	700-750	2000
4	PZ 2	500	150-250	-	250-350	2000
5	PZ 3	500	150-250	-	250-350	2000
6	M 1	500	150-250	-	250-350	2000
7	M 2	500	150-250	-	250-350	2000
8	M 3	500	150-250	10-15	250-350	2000
9	PL 1	750	100-150	12-15	600-650	2000
10	PL 2	750	100-150	12-25	600-650	2000
11	PL 3	750	100-150	12-25	600-650	2000
12	PL 4	750	100-150	12-25	600-650	2000
13	PL 5	750	100-150	12-25	600-650	2000

Nursery rearing : Postlarvae 3-5 are removed to the nursery for further rearing. The capacity of the nursery tank may be four to five times that of the larval rearing tanks from which the larvae are transferred into nursery. It is better to have rectangular tanks with a depth of 1.2 m. Inside colour of the tank can be grey. In places where good sunlight and less rain are prevalent, it is better to have the nursery tanks in open. As per requirement, temporary covering for these tanks may be provided to cut off excess sunlight and rain. Continuous aeration facility may be provided. If possible these nurseries can be constructed near the larval rearing tanks in such a way that the postlarvae can be directly transferred to the nursery by gravity flow. Postlarvae 3-5 can be reared in nurseries for 15 to 20 days and then transferred to the farms. Larvae can be fed with sufficient quantity of egg-prawn custard. Sediments from the bottom of the tanks are removed atleast twice in a week. As per requirement, daily one fourth or one third water is exchanged. Postlarvae 15-20 are harvested and transported to farms.

Diatom culture

Wherever clear and good quality sea water with temperature between 28° and 30°C and sufficient sunlight for a definite period in an year is available, a mixed culture of diatoms could be develolped and maintained without difficulty. For initiating a mixed diatom culture, fresh unpolluted seawater of 30-34 ppt salinity is filtered through a 50 micron mesh bolting cloth and kept in one or two tonnes capacity fibreglass tanks. The tanks must be white inside and the depth of the water column must not be more than 75 cm. These tanks can be housed in a shed with translucent roofing. Sea water is fertilized with sodium nitrate, potassium orthophosphate, sodium silicate and EDTA disodium salt (12 grams of sodium nitrate and 6 grams each of other chemicals per tonnes of water). The seawater in the tank is well aerated and if the intensity of light during day time varies between 0.2 to 1.2 lakh lux and the temperature between 28° and 34°C, a very good bloom of mixed diatoms develops within 24 to 48 hours. A culture containing 3-4 lakh cells/ml is preferred for feeding the larvae. From this culture it is very easy to maintain batch cultures on the succeeding days for a period of 15 to 20 days. Diatom cultures are started every day using the previous day's culture as inoculum (at the rate of 30-55 lt/m^3 of filtered sea water and fertilized as mentioned above). During prolonged cloudy conditions, maintenance of mixed diatom culture becomes difficult. Therefore it is advisable to have a separate, small, diatom culture unit on the hatchery with air-conditioning and artificial lighting to ensure a steady supply of diatom.

Preparation of prawn-egg custard

Yolk and albumen of hen's egg and meat of small prawns are minced together at a ratio of 1 : 5 by weight and steam-cooked for ten minutes, cooled and kept frozen in a refrigerator. A solid block of this custard, after thawing is made into suitable particle size by passing through proper sieves and fed to the larvae. Custard should not be stored for more than three days.

Hatching of Artemia *eggs*

Artemia cysts are first thoroughly disinfected and partially decapsulated. Cysts are treated with 75 ml bleach (5.25 % active sodium hypochlorite). 75 ml bleach is mixed in 60 lt of freshwater in a bin and 1 kg of cyst is soaked in this for 15 minutes. The treated cysts are collected in a net, washed thoroughly in freshwater and released in hatching tanks containing seawater of 34 ppt and well aerated. Within 24 to 36 hrs they hatch out if the temperature is above 28°C. Freshly hatched out *Artemia* nauplii alone are carefully collected and fed to the larvae.

Larval diseases

Disease in the hatchery is mainly caused by unhygenic conditions and inadequate water exchange. The very serious diseases affecting the larval stages are caused by fungi (*Legenidium, Fusarium*), bacteria (*Vibrio*), filamentous bacteria (*Leucothrix*) and protozoans (*Zoothamnium, Vorticella*). Several antimycotic compounds and antibiotics are available for the treatment of fungal and bacterial diseases. These chemicals should be used with great care as they themselves are toxic to the larvae at higher doses. The best method of controlling the fungal disease is by disinfecting the spawners which are the potential source of infection.

Treating infected larvae is very difficult, often unsuccessful and expensive. The best way is to prevent the diseases. To achieve this, the spawning tanks should preferably be separated from the larval rearing tanks, spawners should be disinfected and good quality filtered or purified seawater should be provided in adequate quantity.

Lightner (1985) has reviewed the diseases of cultured penaeid shrimps and prawns with emphasis on recent discoveries and developments. A list of important larval diseases, their symptoms and treatment are presented below.

	Symptoms	Treatment
Viral diseases		
A. Penaeid baculoviruses	Affects hepatopancreas and anterior midgut of the postlarvae, infects epithelial cells causing high mortality.	None
B. 1 HHN. Infectious hypodermal and hematopoietic necrosis		
Bacterial diseases		
a. Bacterial necrosis	Appears as a localised necrosis or discolouration of any appendage of larval stages.	Prefuran 1 ppm
b. Vibrio infection	Infects haemolymph and midgut. Larvae in acute cases show white turbid liver.	-do-
c. Luminiscent vibriosis	Affects haemolymph, gut, haepatopancreas of larvae. Larvae stop feeding.	-do-
d. Filamentous bacteria	Affects gills, pleopods of larval stages. Gill filaments get attached to body thus chocking the larvae.	KHNO4 25-5 ppm
e. Shell diseases	Affect exoskeleton caused by chitinoverous bacteria.	Formalin 25 ppm
f. Black gill diseases	Affect the gills.	Methelene blue 8-10 ppm
Fungal diseases	Affecting body cavity and appendages of nauplii, protozoea and mysis caused by legenidium leading to heavy mortalities.	Treflin 0.1 ppm
Ecto-commensal infection a. Protozoean infection (*zoothamnium* and *vorticella*)	Infects gills, eyes, and exoskeleton of larvae.	Formalin 10 ppm

General remarks

During 1993-'94 the uncontrolled spread of diseases in the hatcheries and farms due to manmade environmental degradation have forced to close down many hatcheries and farms for a considerable period. To avoid recurrence of such situations, the following suggestions are incorporated in planning for the future. Treatment of many diseases in the hatcheries are not only expensive and futile, but also lead to the distruction of many useful bacteria as well. Hence stress to be given for water quality maintenance and management. The seawater should be properly sand filtered. Broodstock shrimps are one of the main source for disease transmission. Hence proper care has to be taken to disinfect them. In rematuration tank it is better to instal proper recirculation system to reduce the exchange of water to the minimum and maintain a constant pH and salinity regime.

The discharge of water from the hatcheries should be properly treated in biopods.

It is advisable to establish independent and isolated units for broodstock maintenance, spawning and larval rearing, and nursery nearing.

Between successive hatchery runs sufficient time gap has to be provided to clean disinfect and sun dry the rearing tanks.

In case of utmost necessity it is also advised to chlorinate and dechlorinate the seawater before using the same for larval rearing.

Economics of hatchery

An insight into the economics of operation (1994-'95) of two types of hatcheries designed using CMFRI technology are presented below.

A medium scale hatchery designed to produce 16 million seeds/year can be established with an investment of Rs. 45 lakhs. The gross income from this unit by way of sale of seed is Rs. 24 lakhs, with a net profit of Rs. 6 lakhs.

A mini hatchery with a capacity to produce 1.65 million shrimp seeds can be established with an investment of Rs. 3.5 lakhs deriving a gross income of Rs. 1.14 lakhs and a net profit of Rs. 35,000.

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15

LOBSTER FARMING IN INDIA

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Introduction

Spiny or rock lobsters are low volume and high value fisheries which support some of the most valuable marine resource worldwide. India, earns an approximate US $ 15 million each year through export of lobsters, mostly to Southeast Asian countries and Japan, although less than, 3,000 tonnes is landed annually. The potential for increasing the yield from the wild fisheries is limited, as the stock is subjected to extreme fishing pressure and is nearing their long term equilibrium yield. Hence, the most imaginative management strategy seems to be increasing the production through population enhancement and aquaculture. Recent success in rearing the phyllosoma larvae, has significantly improved the chances of captive breeding and seed production in spiny lobsters.

The term "farming" and "fattening" are two distinct operations. Farming is essentially a grow-out operation in which the juveniles are grown for several months to marketable size. Fattening, on the otherhand, refers to short duration culture of undersized size lobsters to a specific acceptable size and hence command better price. In the export market, whole cooked lobsters weighing 175-400 g fetches the highest price, whereas live lobsters should be above 400 g to get the best price. Demand for a certain size group and the price may vary from time to time in the overseas market. Among the whole cooked variety, *Panulirus polyphagus* with its deep red colouration after cooking and the prominent white abdominal band is the most preferred, whereas live lobsters of *P. ornatus* is in maximum demand in the Chinese market. So, the farming or fattening operation should be carried out depending on the overseas demand for the lobsters.

Culturable species and their distribution

Though the lobsters are widely distributed along the Indian Coast, the major fisheries are located on the northwest (Maharashtra and Gujarat), the southwest (Kerala and Tamil Nadu) and on the southeast (Tamil Nadu) coasts. Among the six shallow water species, only three, *Panulirus polyphagus, P. homarus* and *P. ornatus* are exploited in commercial quantities. *P. ornatus* grows fast and attains a maximum size of 3.5 kg and is most suitable for fattening, whereas *P. polyphagus* and *P. homarus* attains sexual maturity early (around 175 g), grows to a maximum of 1.5 kg and are good for whole cooking.

Seed supply

Seed in lobster farming refers to the juveniles used for culture. The lobster farming industry requires, large number of juveniles for the culture operations. Though complete larval development of five temperate species have been studied (Kittaka, 1994), commercial seed production is yet to be perfected. Until then, lobster farmers have to depend upon naturally available juveniles (500-300 g depending upon the species) which form a substantial portion of the commercial fishery. In Gujarat, exclusive fishing of juveniles of *P. polyphagus* is carried out in intertidal areas and sold to lobster farmers. The seeds thus procured are transported carefully and used for stocking in the grow out system. However, the impact of such large scale fishing of juveniles on the recruitment process and on the fishery is not known now.

For the lobster fattening industry, the term seed refers to the lobsters which are just below the commercial size, whether it be for whole cooking or for live transport. In the case of *P. homarus* and *P. polyphagus*, which are suitable for whole cooking, the seed size for fattening would be below the commercial size of 175 g, but above 150 g and for *P. ornatus*, it would be below 400 g, but above 300 g.

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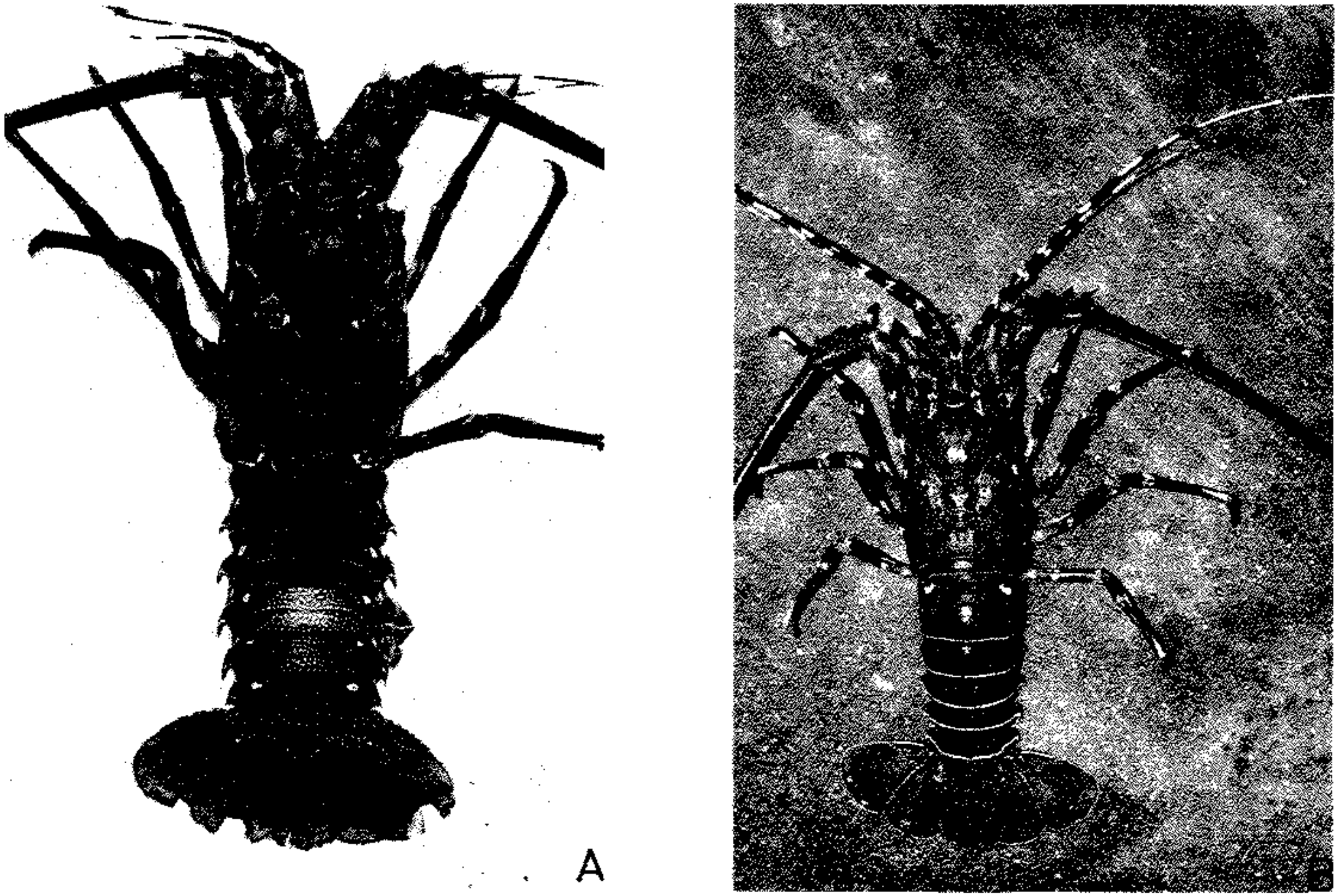

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Plate I A. *Panulirus homarus* (Scalloped spiny lobster) suitable for farming and fattening along the southwest and southeast coast of India and B. *Panulirus polyphagus* (Mud spiny lobster) suitable for farming along the northwest coast of India.

Farming system

Commercial farming of spiny lobsters in India is carried out in Gujarat, where juveniles of *P. polyphagus* are farmed in intertidal pits, until they attain the size of 125-150 g. Experiments carried out in the Central Marine Fisheries Research Institute showed that indoor grow out system is most suited for lobster farming as it is most convenient for management. Farming in grow out ponds have been reported from Taiwan. Experimental culture of lobsters in floating cages was also reported from India, but the commercial feasibility of such operations is not known.

The indoor grow out system consisting of a series of circular or square or rectangular cement tanks, has several advantages, as the different units will be easily accessible for feeding, cleaning and maintenance. The farming or fattening system can be either a flow through model or a semi-closed recirculation system incorporating biological filters. Water reuse system has several advantages as the water quality can be strictly controlled and sudden stress on the farmed animals could be avoided. If flow through systems are used, continuous monitoring of water quality has to be carried out.

Water quality management

Spiny lobsters are susceptible to sudden changes in water quality. The optimal environmental requirements for lobster farming are: temperature (26-33°C), salinity (25-35 ppt depending upon the species), pH (6.8-8.5) and dissolved oxygen (> 3.5 ppm). In recirculation system, ammonia (< 0.1 ppm) and nitrate (< 0.1 ppm) levels have to be closely followed. Sudden fluctuations in water quality normally occur during rainy season and care should be taken to maintain the critical parameters such as salinity and pH to acceptable levels. In flow through systems, continuous circulation of fresh seawater has to be maintained, especially during night when the lobsters feed and undergo moulting. The dissolved oxygen and ammonia may reach critical levels during early morning due to decomposition of unfed feed and excreta in the system.

Farm management

For lobster farming and fattening, stocking may not be possible in a single operation. Stocking will be continuous process as sufficient quantity of seeds may not be available on a single day. Differet sizes have to be separated and after conditioning, can be stocked in separate tanks. The optimum stocking density in indooor grow out system would be 10-15 lobsters/m^2 for farming and 5 numbers/m^2 for fattening. Since spiny lobsters are nocturnal and gregarious in habit, communal shelters have to be provided for faster growth.

Molluscan meat is the most preferred diet of lobsters. However, this could be supplemented with trash-fish and squid head. Since fresh meat is likely to bring in tremendous bacterial load into the system and is difficult to procure for daily feeding, moist compound diets using these fresh ingredients and other raw materials such as rice bran and soyabean could be prepared and stored for daily feeding. Moist feeds with good elasticity and water stability were found to be acceptable for lobsters and this will be especially good for feeding lobsters maintained in recirculation systems.

Growth of tropical lobsters are relatively faster under optimal environmental conditions. Juveniles of *P. homarus* weighing 80-100 g could be grown to 175 g in four months. *P. ornatus* has been estimated to take 7-8 months to attain 400 g in captivity from an initial size of 100 g. Fattening will be much faster. *P. ornatus* weighing 300 g is expected to attain the target size of 400 g in less than 3 months.

Though disease is generally not a serious problem in lobster farming, sudden fluctuation in environmental conditions has been found to bring in a condition called Moult Death Syndrome (MDS). The affected lobsters die either soon after the moulting or within a few days. Nutritional deficiency also is likely to affect the normal moulting and growth of lobsters. Protozoan infestation is also not uncommon and it can be controlled by treatment with 30 ppm formalin for a consecutive three days. Bacterial infection normally occurs through injuries and this can be effectively controlled by oxytetracycline or furazolidone treatment. Good sanitation in the farming system and maintenance of proper water management are essential prerequisites for successful lobster farming.

Stock enhancement through artificial shelters

Population enhancement by attracting spiny lobsters to artificial habitat is a natural form of farming. Cuba and Mexico increased their lobster production severalfold by providing artificial shelters or 'Casitas' in shallow coastal waters. Artificial shelters provide food and shelter and protection from predators to the juvenile and adult lobsters. Studies show that food and shelter are the two important limiting factors which make lobsters susceptible to predatory attacks. Commercial size lobsters can be harvested periodically from these shelters leaving the undersized lobsters back into the sea. The use of appropriately scaled 'Casitas' may be an economical and effective approach for increasing lobster production in our country.

Harvesting and marketing

Harvesting of lobsters from indoor grow-out system is a matter of draining the water and picking up the commercial size for marketing. In fattening cages and pens, harvesting can be done by lifting the cage or the net in the pens and scooping out the lobsters.

The harvested lobsters can be marketed either in whole cooked form or in live condition depending upon the size and species. For whole cooking, live lobsters are dipped in chilled water for few minutes until they die and then immersed in boiling water containing acetic and citric acid for few minutes. After cooking, the material is again kept in chilled water and then cleaned, packed and blast frozen. For live lobster transport, live lobsters are immobilised in chilled water for few minutes and then packed in thermocol boxes with packing material and a coolant. The lobster cartons are then air lifted to the respective destinations.

Future prospects

The technology for lobster farming and fattening has already been developed. High demand for live and whole cooked lobsters in the international market and the high price offered, makes lobster farming an attractive industry. But nonavailability of a perfected hatchery technology and limited availability of juveniles and subadults from the wild are the two major constraints facing lobster farming. Small scale farming or fattening can be carried out utilising the undersized lobsters caught along with the commercial size lobsters. Harvesting of juvenile lobsters for farming should be avoided as we have inadequate information on the impact of fishing of juveniles on the natural recruitment processes and on the fishery. The annual landing of lobsters in the country is already on the decline (Radhakrishnan, 1995), as some of the species have already been overexploited in the absence of strict implementation of a legal minimum size and other management measures. Until a hatchery technology is perfected for commercial seed production, conservation measures have to be implemented to ensure sustenance of fishery as well as farming practices.

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16

CRAB CULTURE AND CRAB FATTENING

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Introduction

Among the commercially important brachyuran crabs, the species of the genus *Scylla*, which are commonly known as mud crabs, green crabs or mangrove crabs, are widely used for aquaculture purpose in the Indo-West Pacific region. In countries like Thailand, Malaysia, Indonesia, Philippines, Singapore and Taiwan, mud crab farming is practised on commercial scale, mainly by the artisanal sector. The farming methods followed and production trends in these countries have been reviewed in detail at the Regional Seminar on 'mud crab culture and trade in the Bay of Bengal region' at Surat Thani, Thailand organised by the Bay of Bengal Programme (BOBP) in 1991 (Anon., 1992). The enthusiasm for mud crab farming is ever on the increase throughout the Indo-Pacific region.

In India, the importance of live mud crabs as an export commodity has opened up great opportunities for crab farming. During the period 1989-'94, the country has exported live mud crabs to the tune of about 630 tonnes valued at Rs. 2.58 million on an average annually. The live crab export recorded a tremendous leap from 36 t in 1987-'88 to 725 t in 1993-'94. 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. Efforts for mud crab farming in the other maritime States are also picking up in recent years.

Mud crabs

According to recent taxonomic studies on the Genus *Scylla*, the existence of atleast two distinct species of mud crabs, namely, *S. tranquebarica* (Fabricius) and *S. serrata* (Forskal) in the Indo-Pacific is established (Kathirvel and Srinivasagam, 1992). Of the two species, *S. tranquebarica* is considered to be synonymous with *S. oceanica*. *S. tranquebarica* attains a larger size than *S. serrata*. These two species are distinguished from colour markings, morphological characters such as spines on the outer border of the carpus of the cheliped, habitat preferences and behaviour. In *S. tranquebarica*, the outer margin of carpus of chelipeds bears two sharp spines, colour of upper surface of carapace light to dark green and all walking and swimming legs with polygonal markings. It is free living and rarely found in burrows. *S. serrata* has one spine on the outer border of the carpus of the cheliped, the other tooth being absent or blunt. Upper surface of carapace is greenish brown to ferrugenous brown in colour; polygonal markings absent on all legs except on the distal part of the swimming legs; lower surface of fixed finger of chelipeds dark to pinkish red in colour. It prefers to live in holes or burrows.

Distribution

Indo-Pacific in distribution, the mud crabs inhabit the marine as well as brackishwater environments. In India, both the species coexist in the inshore sea, estuaries, backwaters, coastal lakes and mangrove swamps of all maritime States on the main land and the creeks and bays of Andaman and Nicobar Islands. They prefer muddy or sandy bottom.

Biology

As in other members of Brachyura, the sexes are separate in mud crabs, the males growing to larger sizes than females. In *S. tranquebarica*, the male attains the maximum size of about 22 cm carapace width (CW) weighing about 2.5 kg and female about 20 cm CW weighing about 1.7 kg. In *S. serrata*, the maximum size attained by male is about 14 cm CW weighing about 1 kg and female about 13 cm weighing about 0.5 kg. Mud crabs are omnivorous and they feed on a wide variety of food items such as shrimps, crabs, bivalve molluscs and fish. The females reach sexual maturity at a size of about 12 cm in *S. tranquebarica* and 8.5 cm in *S. serrata* in the brackishwater or sea. Both the species are continuous breeders, with peak breeding seasons which vary from place to place. Each animal spawns once in two months. After mating and spawning, the fertilized eggs are carried on the pleopods of female for about two weeks. The number of eggs thus carried by the incubating female varies from 0.5 to 0.9 million in *S. serrata* and 1.1 to 7.0 million in *S. tranquebarica*. The egg-bearing females ('berried crabs') migrate from estuarine areas to the inshore sea, mainly during the summer season. The eggs hatch out in the sea and undergo metamorphosis by passing through five zoeal stages and one megalopa stage before developing into the first crab stage. At megalopa stage they migrate to brackishwater areas and spread to different parts of the estuarine systems.

Farming

As mud crabs can tolerate wide range of salinities during their growing phase, brackishwater areas of all salinity gradients are used for crab farming. The most desirable ranges of water quality parameters are : salinity 10-34 ppt, temperature 23-30°C, dissolved oxygen above 3 ppm and pH 8.0-8.5. Commercial mud crab farming is done by two methods. In one method, juvenile crabs are grown to marketable size in earthern ponds for a period of 3-6 months and in the second method the medium sized or large sized crabs, preferably post-moult crabs (soft-shelled crabs or *water crabs*), are reared in cages, pens or ponds for about 20 to 30 days (or even shorter period) till the shells are hardened with additional gain in weight. The former method is generally referred to as "grow-out operation" and the latter "crab fattening".

Grow-out operation

Crab farming in earthern ponds is done either in monoculture or in polyculture with other organisms. Although extensive areas are used for this purpose in some countries, small ponds (0.3 to 0.5 ha) with sandy or sand-covered muddy bottom and a water depth of 1.5 m are ideal and easily manageable for crab farming. A sand bottom inhibits burrowing. Crabs are capable of climbing over the bunds, which is prevented by fixing overhanging fences on dykes. Fencing is done with materials like bamboo sticks, bamboo poles and knotless nets, asbestos sheets, fibreglass panels, etc. The height of the fencing ranges normally between 0.5-1.0 m above the dykes. As the crabs are highly cannibalistic especially on freshly moulted animals, 'refugee cages' made out of hollow bamboo pieces, cement pipes or stones are often placed inside the ponds to minimise mortality. Water exchange is through tidal water, the inflow and outflow of which is regulated through sluice gates. The sluice gates are provided with bamboo screens to prevent the escape of crabs. In regions where tidal influence is less, pumped-in sea water is used for crab farming as done for shrimp.

Pond preparation includes draining of water, baking in sunlight and liming. The seed crabs collected from the wild are stocked in the ponds after acclimatisation. In monoculture, the seed are stocked at the rate of 2 to 5/m^2 depending on size. In polyculture the stocking density is suitably reduced. The animals are fed with bivalve meat or trash fish at a daily ration of 5 to 10 % of body weight. The juvenile crabs of 3-4 cm CW attain marketable size of 200-300 g and 10-12 cm CW in a period of 5-6 months or larger ones of 100-200 g and 9-12 cm CW grown to marketable size of 400-600 g and 14-16 cm CW in 4-6 months. Harvest is done by draining the ponds and using scoop nets and ring nets with baits. Hooks are used to retrieve the crabs from burrows. Harvested crabs are marketed in dead or live condition. Live crabs are also restocked for further growth of fattening in appropriate culture systems.

In the East Asian countries, most of the grow-out operations are part of polyculture systems in which milkfish, penaeid prawns and seaweeds are also produced (Sivasubramaniam and Angell, 1992). In Taiwan, such farms vary in size from 1 to 200 ha. Individual rearing ponds are 0.2 - 1 ha and 1 to 4 ponds make up the average enterprise. Water is drawn from tidal channels in some farms, but many use saline ground-water which may be diluted with fresh well water to obtain the desired rearing salinity of 10-15 ppt. Dykes are protected with bamboo, brick or concrete panels. Stocking densities vary from

5000 to 10,000/ha. Snails at a feeding rate of 10 - 15 g/m^2/day and trash fish at a rate of 4-5 g/m^2/day are given. In polyculture systems, milkfish are stocked at 1000-4000/ha. Crabs are stocked only during early spring and mid-summer. Market size is reached in 3-4 months during the summer and 5-6 months in the winter season, yielding a recovery of 5000-9000 crabs/ha depending on the culture system (whether mono or polyculture). Crabs with 8-9 CW are used for marketing.

In Philippines, mud crabs are only incidental harvests although some farmers take special measures to increase their yield. These include overhanging fences on dykes and soil mounds or tree stumps in the ponds for shelter. Seedlings are usually 2-3 cm CW and are stocked at only 1000/ha. With low level of management procedures the yield of crab averages only about 111 kg together with sizable quantities of milkfish and shrimp. The monoculture operations in Philippines yield 339 kg/ha.

Fattening

Crab fattening is essentially a holding operation during which post-moult or *water crabs* are kept for short periods until they 'flesh out', or immature female crabs are held until their gonads develop and fill the mantle cavity. This type of crab farming has become very popular throughout the Asian countries due to the increasing demand for gravid females and large size hard-shelled ones in seafood restaurants from Hong Kong to Indonesia. In countries like India, newly moulted crabs of sizes above 550 g and about 15 cm CW are obtained alive from commercial catches and subjected to fattening in ponds, cages or pens. The ponds used for this purpose are smaller in size (0.1-0.2 ha) with water holding capacity of 1 to 1.5 m depth. The fattening system has fencing, water exchange facility and other conditions described for the grow-out operations. The stocking density is normally 1 crab/1 to 3 m^2. The fattening period extends for 20-30 days by which time they 'flesh out' fully. The crabs are harvested after the shell becomes sufficiently hard and before next moulting takes place. After the completion of harvest, the ponds are prepared for the next cycle of fattening. Crab fattening/hardening is done profitably by repeated stocking and harvesting. In addition to fattening in ponds, cages made of arecanut palm splits in the size 3 x 3 x 1.5 m, with lid, are also used increasingly in the open backwaters in States like Kerala.

In Taiwan, crab fattening ponds are small, each ranging 50-600 m^2 in size. Most of the culture systems have 5-15 such ponds. They are provided with concrete dykes and water exchange is by tide or through pumping. Female crabs measuring 8-12 cm CW are stocked at the rate of 2-4/m^2 or 1/m^2 during summer. Feeding is done daily with trash fish upto 200 g per crab and live snail at 100 g/m^2. In Thailand, crab fattening in ponds and pens are very popular. Ponds are small averaging about 270 m^2, but an operator may have several such ponds. With a stocking size of about 415 g for the crab, the growing period extends for a month and six crops are taken a year. Crab fattening is considered to be very profitable in the Surat Thani area. In Indonesia, production of gravid females and fattening are practised besides growout operations from seed stock. Females over 150 g are cultured in floating bamboo cages, with 70-110 animals stocked in a 3 m^3 cage. After one month of feeding with trash fish, 70-85 % of them develop ovaries. Fattening is done in ponds or pens and cages in lagoons. The fattening period is 3 or 4 weeks. Some fattening is done in small 0.09 m^2 compartments, each carrying 1 crab. Fattening ponds are 1000 m^2 and equipped with sluice gates, fencing and a central platform. The stocking rate for 150 g crab is 2/m^2 and the holding period is 3-4 weeks. Mortality ranges from 10 to 50 %. In Malaysia, floating cages of about 6 m^3 with a depth of 1 m are used to culture. Netlon is commonly used for mesh. Crabs in size range 7.5-18.0 cm CW are stocked at 10/m^2. Chopped trash fish is given as food. The market size is 300 to 500 g, although the crabs may reach 1 kg in weight.

Economic considerations

Economic analyses of mud crab farming practised in most of the East Asian countries (Anon., 1992; Kathirvel, 1993; Viswakumar, 1993) and in India (Suseelan *et al.*, 1995) have established that crab culture is highly profitable when compared with other forms of aquaculture due to the increasing price of crabs in the international markets. Among the two types of culture, crab fattening is considered to be more remunerative because of the fast turnover, low operating cost, high survival rate and good market demand for the end products. According to Kathirvel (1993), the initial cost for the development of 1 ha crab pond in Philippines is equivalent of about Rs. 25,000/-, while the running expenditure for one crop at Rs. 5000/ha stocking rate for 3 month rearing is the equivalent of about Rs. 24,000/-. The income realised in the first crop is Rs. 57,000/- and the net profit amounts to Rs. 33,000/- excluding the initial cost. Viswakumar (1993) reported that out of the capital investments required for construction of 1 ha farm, cost of pond construction formed about 59 % and perimeter fencing cost formed 28 %. Out of the operating cost, feed represented 37.4 %, labour 26.4 %, seed 10.7 %, depreciation 11.4 % and interest on capital, marketing, fertilizer and maintenance formed the rest. Taking into consideration of the major capital components and input requirements he worked out indicative economics of 1 ha farms, both for grow-out operation from baby crabs (2-3 cm CW) to market size (200 g weight) as well as for crab fattening during a year, which showed a profit of Rs. 27,000/- in the former and Rs. 83,500/- in the latter methods. Suseelan *et al.* (1995) more recently arrived at an annual net profit of Rs. 1,11,550/-for six crops of crab fattening in a 0.1 ha farm in Vypeen, Kerala.

Problems and prospects

When compared with shrimp farming which is now well established throughout the Indo-Pacific, culture of mud crab is only picking up in many countries especially those bordering the bay of Bengal. Even in the Southeast Asian countries where crab farming is traditionally practised, development of this sector is rather slow due to several inherent problems. One of the major constraints faced by the culturists is inadequate supply of stockable crabs as the only source for this at present is the wild stock in most of the countries where crab farming is attempted. It is, therefore, imperative that concerted efforts are needed to develop commercial hatchery for adequate and sustained supply of baby crabs to make mud crab farming an organised industry. As indiscriminate and excessive exploitation of crabs from the wild is bound to affect the natural population, mud crab farming may be popularised in a phased manner with less emphasis for large scale grow-out operations so that the pressure on wild stock can be minimised until the hatchery production of crab seed is established in the country.

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MUDCRAB CULTURE AND HATCHERY

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Introduction

The capture, culture and trade of mudcrab are of increasing importance in the coastal areas of the Indo-Pacific region. Mudcrab is considered as a very expensive sea-food delicacy all-over the world. Widespread interest exists in crab fattening in the countries bordering Bay of Bengal. It is feared that the intensive and indiscriminate fishing of this marine crab and the absence of any management measures may cause a decline in the population. Its reproductive capacity is high. It is possible to culture them in specially designed coastal ponds, pens and cages. Experiments conducted in certain parts of brackishwater regions in India have shown high prospects of commercial culture. The availability of vast stretch of suitable land, tropical climate, local collection of cultivable species and the low cost labour, the potential for development of mudcrab farming in India are considered most favourable. Most of the countries including India have reported on the declining trend in mudcrab resources and stimulated aquaculture ventures in order to increase the production for export market. It is imperative to develop this valuable resource by proper management including the promotion of culture activities. Indiscriminate fishing of juvenile crabs are going on in most of the commercial fishing grounds. These juveniles can be used for further fattening in ponds. The Central Marine Fisheries Research Institute has made pioneering efforts in this aspect of study and accomplished a record of works both in field culture of mudcrab and production of seeds in hatchery system in the early years of 1980. This Institute plays a consultative role to develop and demonstrate new techniques to the interested entrepreneurs. A good number of shrimp farmers have converted their ponds suitably for crab culture and it is profitably practiced in Andhra Pradesh and Tamil Nadu.

Sources of seeds

Among the marine crabs, *Scylla serrata* and *S. oceanica* are the fast growing species and seeds are commonly available in shallow coastal waters, lagoons, brackishwater lakes, estuaries and inter-tidal swampy mangrove areas and become easily vulnerable to overfishing. *S. oceanica* (Pl. I A) is widely preferred as it grows to the biggest size. It is a free swimming animal and do not make holes in bunds or fences. *Portunus pelagicus* is also a cultivable species for farming in coastal ponds. Accidental entry of larvae of this species in shrimp farm has grown to marketable size and an additional production of 500 kg/ha in the same rearing period of four months have been realised in Tuticorin. Live mudcrabs are exported to Singapore and Hongkong and fetches better prices than the swimming crabs *Portunus* spp. The resourceful grounds and seasons for the collection of wild seeds have been identified and reported. Mudcrab culture depends to a large extent on wild seeds supply and thus becomes a limiting factor for the vast expansion of farming in coastal zones. However, a viable technology has been evolved for the production of crab seed in the hatchery at the Central Marine Fisheries Research Institute and the technology can be transferred on commercial scale production of crab seeds for the development of farming.

Methods of culture

Culture is a grow-out operation whereas fattening refers to the holding of growers or *water-crabs* for short duration to acquire maximum biological attributes so as to fetch a better price. This could be carried out in fenced ponds, pen or floating cages. Crab fattening is an advanced technology widely followed in Thailand, Taiwan, Malaysia and Indonesia. In India a good number of potential grounds adjacent to productive

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brackishwater lakes exists for the expansion of this profitable venture and envisage scope for the production in the near future.

Seed stock for crab fattening is collected from commercial fishing centres. The undersized crabs weighing less than 100 g and the newly moulted *water-crab* have a relatively low value in local markets. Such collections from indiscriminate/accidental fishing are gathered and grown further in cages for fattening. Compartmental cages made out of dealwood boxes or iron cages fabricated with nylon mesh were found suitable for fattening of advanced size crabs (Pl. I B, II A). Selective harvesting is arranged according to the size, growth and demand. Fattening of crab is profitable, because of the fast turnover, low operating cost, high survival rate due to control of cannibalism and migration, and good market demand for the end product in export trade. Crab fattening could be carried out on part time basis and needs relatively a low capital. Viable technology is available and the scope for development is promising.

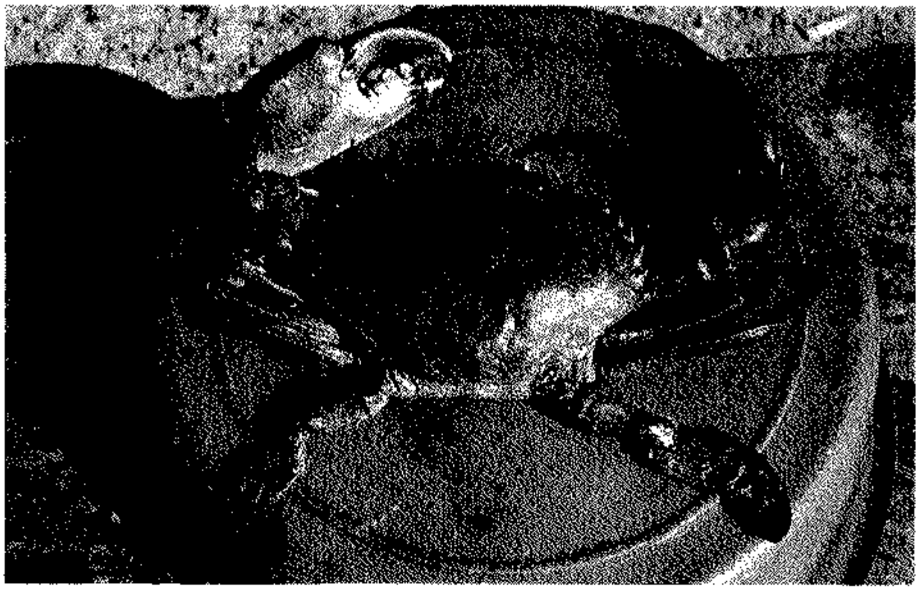
Production of gravid female crab

Mudcrab attains maturity at 90-100 mm carapace width. Females of 7 - 8 cm are gathered from commercial catches and stocked at 1 seed/sq.m for fattening purpose. Fresh bivalve meat facilitates fast development of gonad. Much care is given to feed the stock intensively as high as to 20% of body weight. Salinity is maintained steadily and brackishwater medium in tidal areas are found suitable for operation. Loss of energy by frequent moulting is minimised in such media and the system promotes to gain weight. During fattening the sizewise growth is little, but the end product or the meat value in gravid females with fully developed gonads, command significantly higher prices. Production of gravid females under fattening method created a lucrative market in seafood restaurants in many Southeast Asian Countries. Such an attempt minimises the loss of natural stock of fully matured specimens from the wild and helps the management of stock resources. The holding could be considered almost a maturation process for the matted females. Gravid females should be harvested before they spawn. When male and female of matured size group are stocked together in a pond, that too in water with a salinity around 33 ppt, females may invariably spawn and become ovigerous or berried. Such crabs may not fetch any value in the export trade. Hence, the strategy is to rear the female in brackishwater media of low salinity or in compartmental cages separately without providing a chance to meet the male crab. In fattening process a maximum weight input of 75 to 100 g/month is noticed in crabs of the size group of 9 -13 cm cw. This is the marketing size and crab weighs around 500 g. The trend of growth declines at this phase and so it is desirable to terminate the culture here. The period of culture in fattening system varies according to size at the time of stocking.

Farming techniques

Large scale culture of mudcrab is carried out in coastal ponds as well as by converting shrimp ponds. The intertidal mudflat in the edge of Tuticorin Bay with advantages of tidal range for water movement and circulation is developed into productive culture ponds. Fencing arrangements with palmyrah rachis on dikes are made to control the migration of crab from culture ponds (Pl. II B). Vegetative soil mounds were retained here and there to serve as natural shelter. In order to minimise the mortality of crabs particularly at the time of moulting by mighty predators, "refuge cages" made out of hollow bamboo pieces or stoneware pipes are placed at the floor of ponds and the system promoted the survival rate of the stock. Stocking density is maintained at 5000 - 10000/ha. Seeds are collected from the commercial catches of crab fishing centres such as Punnakayal and Palayakayal. Low cost trash fishes or fish offal are supplied at 10 - 15 % of body weight. Screened water is replenished by tidal exchange. Salinity in the range of 15 - 35 ppt, temperature in 23 - 30°C, oxygen more than 3 ppm and pH around 8.2 are the conducive environmental factors. However, even higher salinity in the range 35 - 45 ppt has never been a hindrance for the survival and growth of mudcrabs in coastal ponds at Tuticorin. The water depth is maintained at 1 m with adequate exchange of tidal fluctuations (Pl. III A).

The growth, survival and production rates differ according to the system of culture. Monoculture with single size stocking, monoculture with



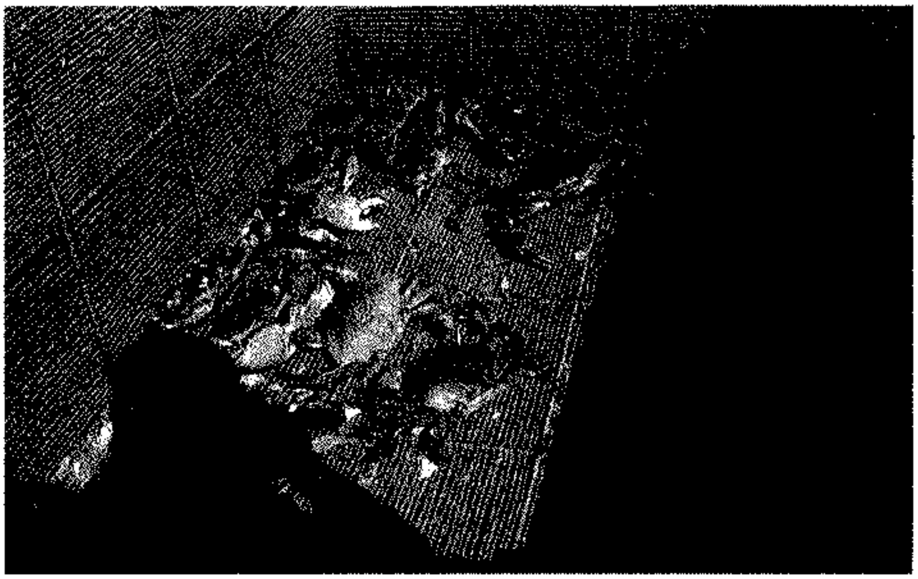


PLATE I A. Mudcrab *Scylla oceanica* and B. Fattening of crabs in cages.

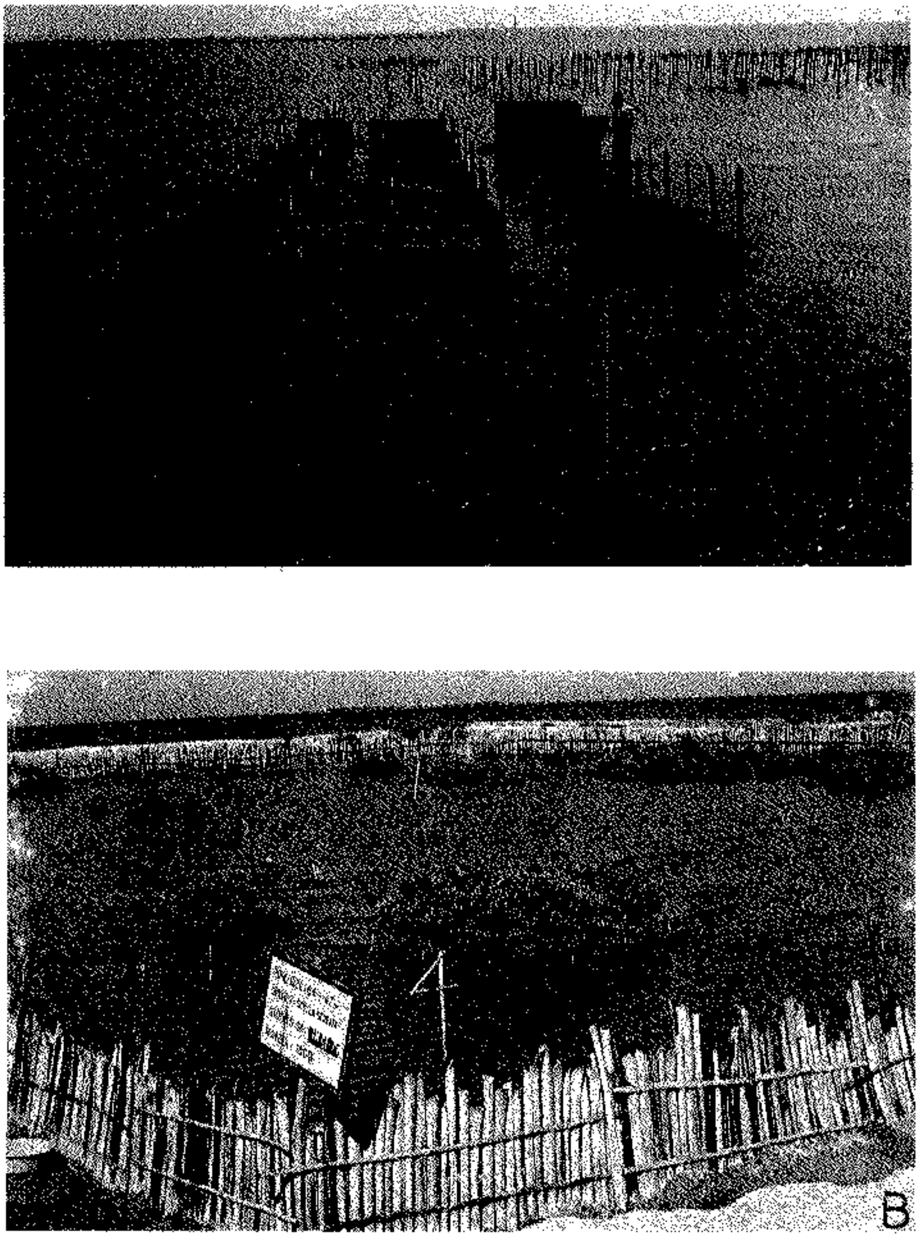


PLATE II A. Collection of fattened crabs in iron-nylon meshed cages and B. Fenced, inter-tidal, coastal, crab culture pond.

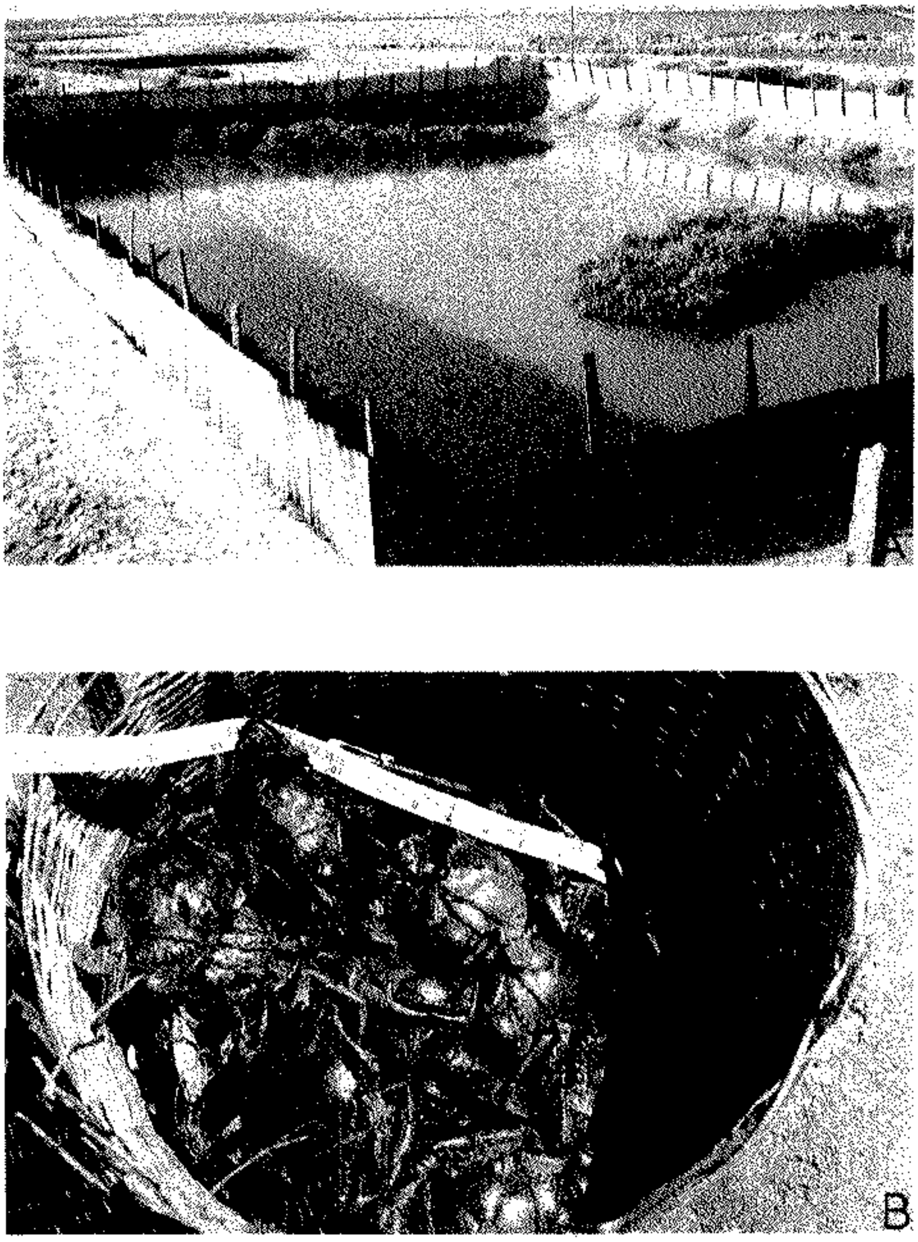
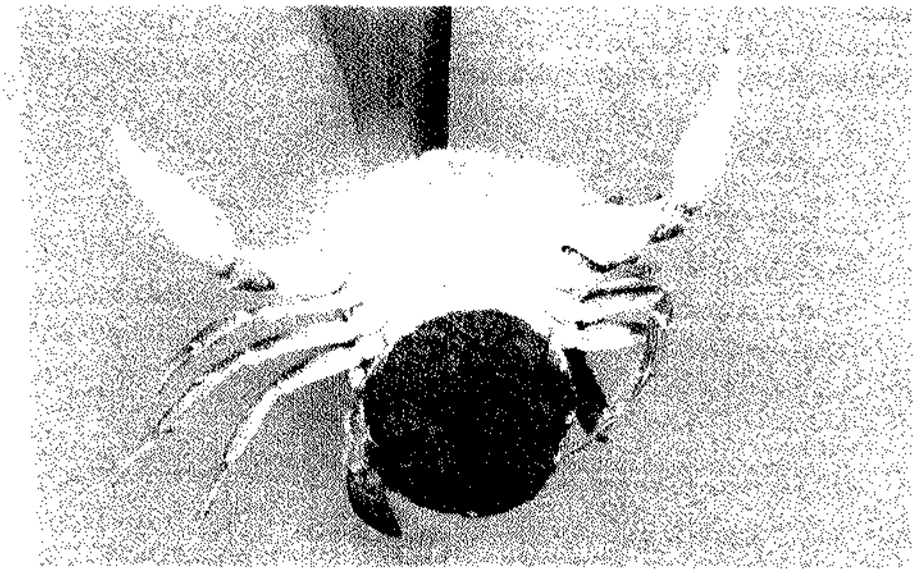


Plate III A. Crab culture pond fenced with light roof sheets and B. Part of selective harvested crabs.



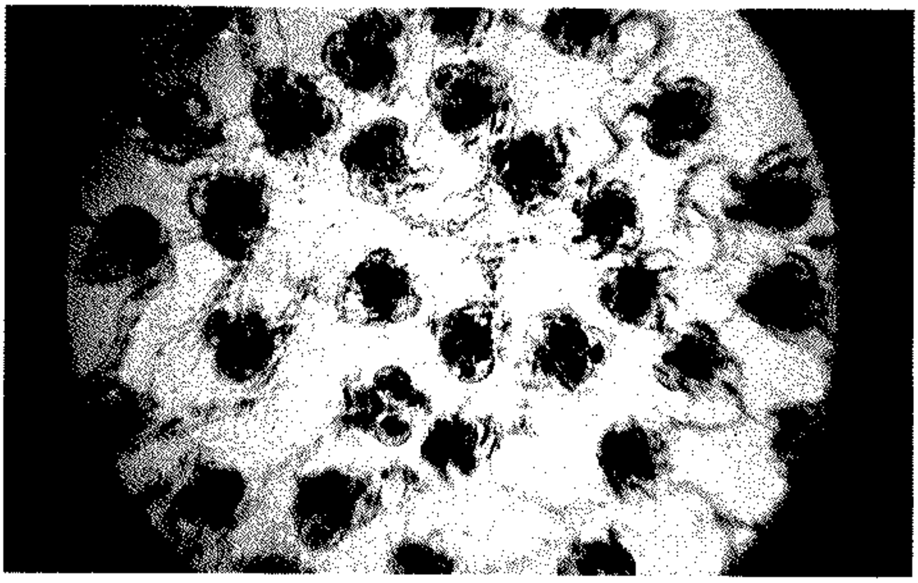


PLATE IV A. Berried mudcrab under incubation and B. Newly hatched zoea I multiple size stocking, polyculture with milkfish and mullets were experimented and attained encouraging production results in the range 2500 - 3000 kg/ha/crop. In polyculture system the unconsumed organic feed materials are decomposed and finally enriched the algal bloom in the culture site. This greenwater with "lab lab" and other algal matter becomes the natural food for milkfish and increased the production. Periodical sampling by cast net and hoopnet is arranged to assess the growth, survival and biomass to design the feeding dose, besides the biological studies. Selective harvesting by hoopnets with baits is preferred in multiple size stocking ponds as it enables the farmer to allow the undersized crabs to grow further. The survival is accounted at 30 - 45 % and envisaged the scope to increase this to 60 - 70 % by adopting management strategies such as frequent water exchange at 30 % of volume in ponds, intensive feeding and increase in shelters and niches in ponds. Total harvesting is arranged by draining the water completely during low tide and crabs are gathered individually by scoopnet. Marketing size crabs should be harvested around newmoon days only. Newly moulted crabs are released back to grow further. Loss of appendages results in the loss of value. Careful handling and arrest of chaelate legs by tying with fibre carefully are necessary before marketing them. The rate of growth varies from 12 - 17 mm/month. The weight input is accelerated in the range 70 - 100 g/month in the crabs of the size group 10 - 11 cm and above. This is the maturity size. Males grow faster than females. In brackishwater media the growth is still faster and the rearing period is shorter. The seed in the size 40 mm/8 g reaches the marketing size of 500 g in about 6 - 7 months and a seed of still advanced sizes (50 - 70 g) attain 400 - 500 g in 4 or 5 months (Pl. III B). In high saline environments it takes additional time to reach this size. *Chanos chanos* is the compatible fish and widely preferred in polyculture trials. It grows to 300 mm in 3 months and attains 700 g in 4 or 5 months. At the stocking density of 3000/ha and survival of 75%, the production potential is 1500 kg/ha and this additional income is realised with little input towards supplementary feed consisting a mixture of rice bran, soya powder, groundnut oil cake, etc. on alternate days. The algal matress of the pond bottom stands as the main nutritive feed for milkfish.

Brood stock development

In tropical waters, spawning occurs throughout the year. Matured crabs and spawner crabs in berried stages are available from the catches of inshore waters from the depth line 5 - 10 m off Kayalpatanam (Pl. IV A). The peak season for such occurrence is March to May and September to October coinciding the hot seasons. Spawners are safely transported in wet condition and can remain active out of seawater for about 6 to 8 hrs. Maturation of ovary and subsequent spawning takes place normally in deep sea, though it spends its life mostly in brackish coastal water zones. However, gonadal maturation and breeding is possible even in coastal ponds under the conducive salinity conditions of 33 - 36 ppt. Mudcrab matures at 100 mm cw when it is about 1 year old. Spawner crab could be developed even from the mating stage itself apart from wild collections. Berried crab reared in good laboratory conditions, may spawn more than once in a period of 5 - 6 months without copulatory ecdysis or further mating. In *Scylla*, there is multiple spawning within a single mature instar. Fecundity is 1.5 to 2 million eggs. Brackishwater is not suitable both for brood management and hatchery operations.

Culture of larvae

During the incubation period, the brood stock are fed with bivalve and crustacean meat for quicker development of ova. Active aeration, cutting of bright light in rearing tanks and adequate water change are the other essential requirements. The incubation period in laboratory conditions varied from 8 - 12 days and the influence of the temperature and salinity has been well recognised for the successful hatching of larvae. Higher the temperature shorter the period of incubation and vice-versa. Lower salinity is detrimental for larval rearing. The temperature at 28 - 31°C and the salinity around 32 ± 2 ppt are found most favourable for the release of viable larvae. Larvae of *Scylla* in tropical waters are considered to be more tolerant of high temperature and salinity than those from other regions. The zoea are liberated from eggs invariably in early morning hours and they are strongly photopositive (Pl. IV B). Mudcrab has a lengthy larval life. There are five zoeal stages taking

15 to 18 days and 1 megalopa stage lasting for 8 - 10 days which leads to first crab instar on 28th - 30th day. Diluted seawater with a salinity range of 21-27 ppt enabled the megalopa for quick metamorphosis into crab stage (Fig. 1). Filtered seawater free from contamination is provided in the hatchery by removing the dead larvae, exuvia, etc. The desired minimum size of the seed for stocking in the pond would be around 20 mm cw and the time taken in this nursery phase is 60 to 70 days. Besides this, water quality management, artificial seaweed are provided in rearing tanks so as to serve as shelters for megalopa which resulted in increased survival of stock. Megalopa are known for cannibalism and this strategy has minimised the loss of stock. Similarly, a sandy substratum is provided in rearing tanks for successful moulting of crab seed. Frequent moultings are observed when the seed stock is maintained at 21 - 27 ppt. Feeding frequency is increased to control the stock. Boiled clam meat or macerated shrimp meat are found to be the best feed at nursery phase.

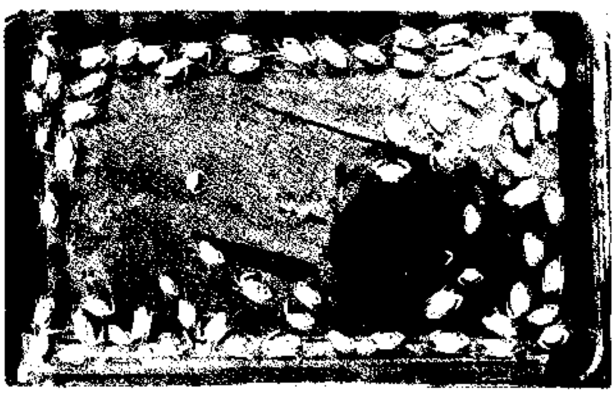


Fig. 1. Part of crab seeds produced in hatchery.

The success of larviculture largely depends upon the designing of the feeding regime. The marine rotifer *Brachionus plicatilis* raised in *Chlorella* culture is found as the best live-feed organism as it contains highly unsaturated fattyacids. *Chlorella* and rotifer cultures are maintained separately to meet the requirements in crab hatchery. A technology to run the *Chlorella* culture at a density of 2000 million cells/ml and rotifers at 70 - 100/ml has been evolved. Active larvae are segregated from the hatching tanks and stocked at 20 - 30/lt in rearing tanks of different volumes and managed as per the following feeding schedule.

Larval stage	Days	Feed
Zoea 1-2	1-8	*Skeletonema*, *Tetraselmis* and *Chlorella* 5000 cell/ml. Rotifer 5-10/ml. Egg yolk at later days.
Zoea 3-4	7-14	Rotifer 20-30/ml, *Artemia* nauplii 10-15/ml. Egg custard, fertilized bivalve eggs. BMC pellets 100 micron.
Zoea 5	15-18	*Artemia* nauplii 50/ml. Decapsulated embryo 20/ml. Minced clam meat. SUTIMAL pellets 150 - 300 micron.
Megalopa	19-30	Adult *Artemia*, copepods, macerated shrimp and clam meat.
Crab seed	28-50	Shrimp meat, copepods, clam and squid meal.

There is ample scope to increase the present rate of survival and production of seed from 15-25% to 60%. High protein micro pellet feed introduced in Japan and Malaysia and similar nutritionally balanced supplementary diet will promote our efforts towards large scale production of crab seeds. Two to three lakh seeds can be attained per run of 2 months.

Suggestions and scopes

Intensive research is needed in the area of nutritional requirements of larvae and water quality managements both in hatchery and farming. Nursery phase rearing of very young seeds has to be improved to attain better survival of seeds. The influence of lunar phase on the moulting behaviour as well as loss or gain in weight in crab are to be studied. The nursery and breeding grounds along the coast have to be protected from exploitation. This will enable a better recruitment which can promote a sustainable yield in the fishery. Seed survey and suitable land survey are equally important for the development of crab farming. The cost economics of this venture has been worked out. With an average production of 2500 kg/ha/crop of 5-6 months, an income of 4-5 lakhs is aimed. Crab culture is more remunerative than shrimp farming and fast return is realised in fattening programmes. The results on the trend of growth and production are encouraging and envisage the scope for development of crab farming in our country. The available published information and the technology evolved in C.M.F.R.Institute both for field culture of crabs and seed production in hatchery will support and promote this new area of mariculture and the farmers have already taken a lead. This Institute has chartered demonstration programmes for crab culture and framed the norms for consultancy services for the interested entrepreneurs. Soon this will occupy a prominent place in the mariculture scenario of India.

Further reading

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18

SEAWEEDS AND THEIR IMPORTANCE

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Introduction

Seaweeds is the name implies to cover the macroscopic plants of the sea except the flowering plants. Most of the seaweeds are attached to rocks and also grow on other plants as epiphytes. Along the coast line of India, seaweeds are abundant where rocky or coral formations occur. This sort of substratum is found in the States of Tamil Nadu and Gujarat and in the vicinity of Bombay, Ratnagiri, Goa, Karwar, Vizhinjam, Varkala, Visakhapatnam and in the Lakshadweep and Andaman-Nicobar Islands. The seaweeds are classified into three important groups namely green, brown and red. Seaweeds contain different vitamins, minerals, trace-elements and proteins. Seaweeds are also a rich source of iodine. As seaweeds are a cheap source of minerals and trace elements, meals prepared from seaweeds can be utilized as supplements to the rations of cattle, poultry and farm animals. From time immemorial seaweeds have been used as manure in the coastal areas. As the minerals and trace elements occur in water solube form, these chemical constituents are readily absorbed by plants when the manure is applied. Deficiency diseases are also controlled by the minerals and trace elements present in them. There are certain medicinal properties for the seaweeds. Seaweeds rich in iodine such as *Asparagopsis taxiformis* and *Sarconema* sp. can also be used for controlling goitre disease caused by enlargement of thyroid gland. Indian marine algae have all the essential amino acids needed in the human diet which are not available in other vegetable food materials. Seaweeds yield the most important products such as agar-agar and algin. They are colloidal carbohydrates present in the cell walls of these algae. Agar-agar is extracted from seaweeds such as *Gelidiella acerosa, Gracilaria edulis, G. folifera, G. corticata* and *G. verrucosa.* Algin is extracted from species of *Sargassum* and *Turbinaria.*

Seaweed culture

In our country there are several factories manufacturing agar-agar and algin (Madurai, Tiruchirapalli, Ahmedabad, Baroda, Hyderabad, etc.). In recent years, many entrepreneurs are enthusiastic to start these industries, as a result of which there will be a great demand and competition for the raw material and a day may come when an acute shortage of raw material (seaweeds) will be felt, as a consequence of which the whole world may find it difficult to prepare certain life saving vaccines, since agar-agar is used as a culture medium for the bacteria and moulds. In order to meet this, a process to augment the supplies of these seaweeds by culture practices has to be developed.

Since 1972, the Central Marine Fisheries Research Institute has been engaged in the cultivation of several economically important seaweeds and the method of cultivation of *G. edulis* a fast growing species with minimum seed material has been standardized. These culture experiments have been done by introducing the fragments of the seed material in the twists of the coir ropes which are fabricated in the form of 5 x 2 m size nets and these coir nets were tied to wooden poles fixed in the coastal waters for further growth. The plants reach harvestable size after a period of 60 days. The yield from a coir net is approximately 30 kg fresh weight in the coastal waters of peninsular India, while the experiments conducted in Minicoy Lagoon (Lakshadweep) using long line coir ropes gave a maximum production value of 31 fold increase over the initial seed material introduced; thus indicating the Minocoy Lagoon to be more productive than main land waters.

The difference between coir net method and coir rope method is that the former gives a very

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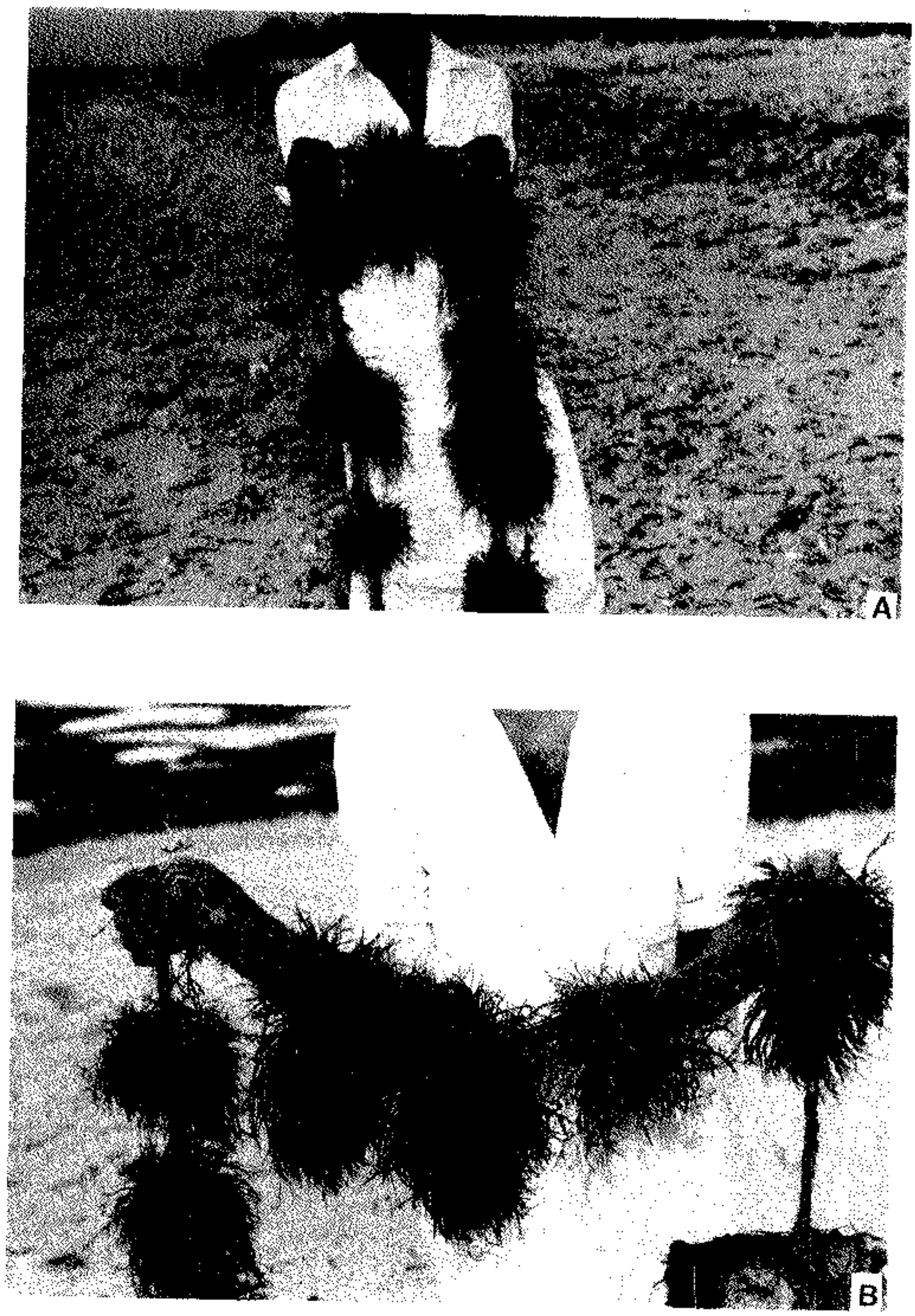

PLATE I. *Gracilaria edulis* on rope: A. after 30 days and B. after 50 days.

PLATE II. *Gracilaria edulis* on rope: A. after 71 days and B. a close up view.

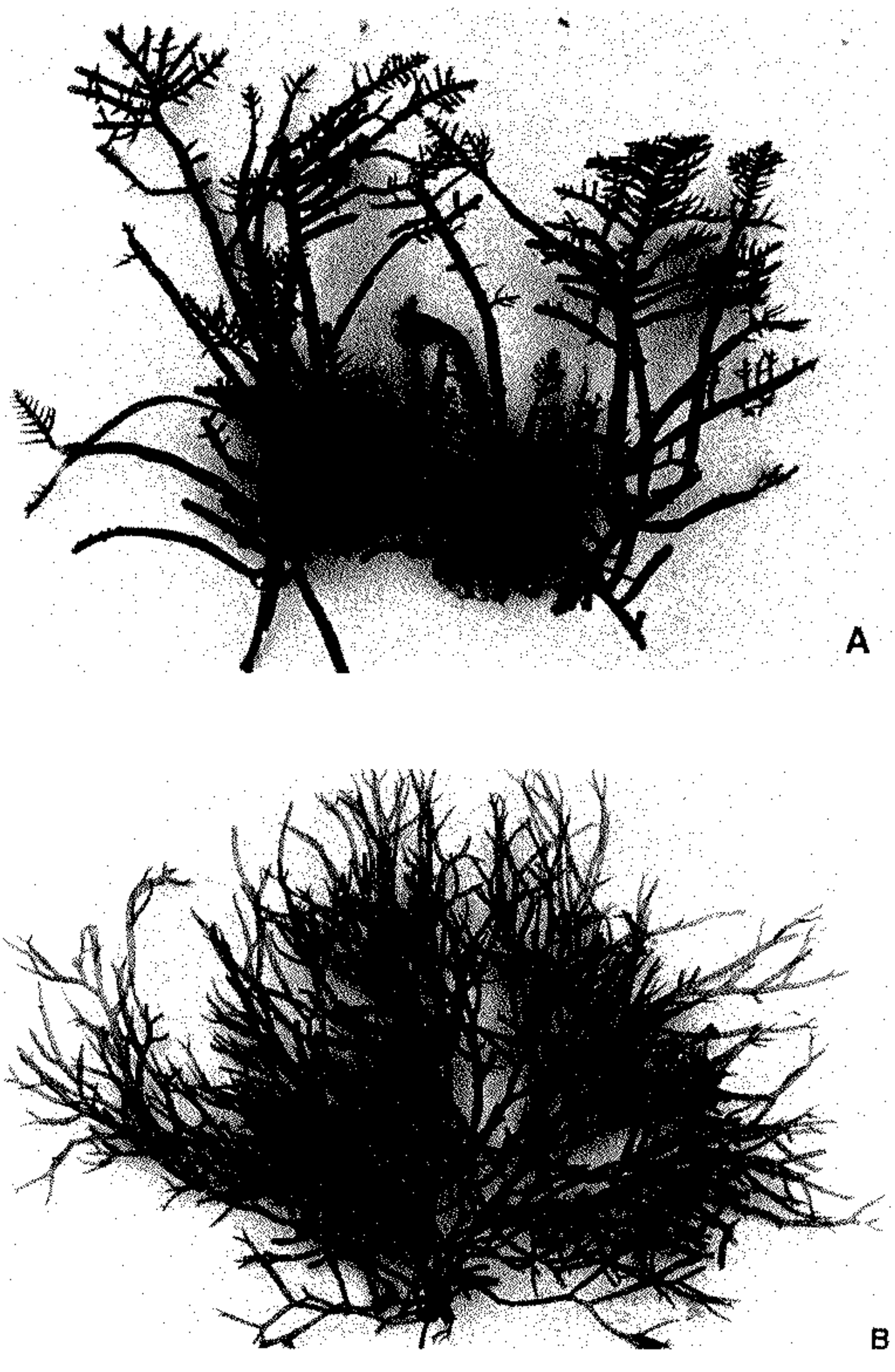

Plate III. Agar yielding seaweeds: A. *Gelidiella acerosa* and B. *Gracilaria edulis*.

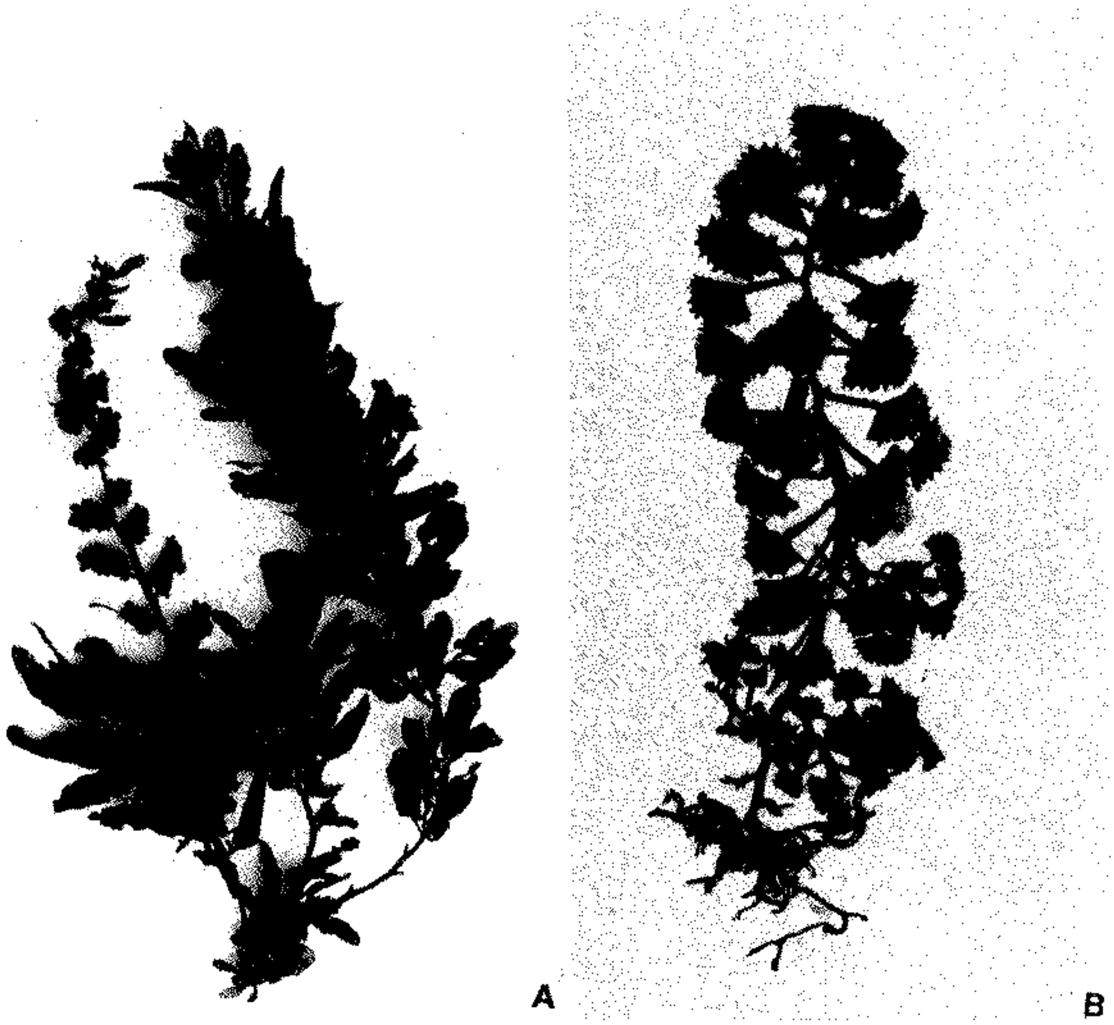

PLATE IV. Algin yielding seaweeds : A. *Sargassum wightii* and B. *Turbinaria conoides*.

good support to the growing plants and it also withstands for 3 harvests, while the latter does not give much support as it is at the mercy of the waves, tides and wind. But the long line rope culture method is suitable for bays and protected areas which has given better results in Minicoy Lagoon than the net method. Further it brings down the operational cost also by this method as the charges for fabrication of the nets and the cost of poles for fixing the nets can be obviated by tying coral stone at either end.

Advantages

1. To augment the supply of seaweeds.
2. A singl species of alga can be maintained in a steady crop.
3. The algae will be uniform in quality.
4. If the cultured alga is utilized by the industry, our natural resources can be used as mother material.
5. A continuous supply of alga can be maintained.
6. By introducing improved techniques and by using modern materials, the yield can be increased and cost of the cultivated seaweeds can be brought down considerably.
7. There is a possibility of improving the quality of the seaweed by adopting scientific breeding and other techniques of crop improvement.
8. The other marine algae which do not grow on our coasts could be introduced for cultivation in our waters, thereby augmenting our resources.

Uses of agar-agar and algin

In general, both agar-agar and algin serve as stabilizers, emulsifiers, thickeners, body-producers and gelling agents. Agar-agar is often used where firm gel is needed and algin for soft and viscous products.

In ice-cream industry, both agar and algin are used as stabilizing agents to give smooth body and texture to the ice-cream and also to prevent the formation of large ice-crystals. Similarly, these two seaweed colloids are employed to prevent adhesion of the sugar coating to the wrappers, in canning industry as coating materials for preserving fish, meat and other products, in the preparation of milk puddings, dental impression materials and agricultural sprays.

There are certain specific uses for each of these two extracts. For instance, agar is used in smoking tobacco and fruit cakes to serve as moisture retaining agent, in confectionery for making gelly candies, in drawing tungsten wires as a lubricant, in hectograph duplicators in photofilms and plates. It is also widely used as microbiological culture medium, therauptic agent in constipation and as a coating material for capsules.

Algin is used for sizing textiles and paper, thickening textiles paints and for boiler water treatment. This is the most useful colloidal carbohydrate in cosmetic industry for preparing creams, beauty milks, mouth washes, hair pomadoes, tooth pastes, etc. It is also used in the preparation of tablets and pills as granulating and binding agents, in rubber industry as a creaming agent to separate the rubber, in the manufacture of lignite briquettes, in liquor clarification, in varnishes, paints, adhesive leather polishing materials, etc. Sodium alginate and other salts are used in the manufacture of seaweed rayon. Alginic acid and its salts are used as blood anticoagulants also.

Along the coast of peninsular India, if seaweed farming is taken up in one hectare area, a return of Rs. 9,000/- is assured in an year for an investment of Rs. 36,000/- assuming the production rate to be 3 fold and that two harvests only can be taken in an year. While in Minicoy Lagoon the input requirement (infrastructure) is less and the production rate high (average of 15 fold) and hence the net profit works out to around Rs. 20,000/- for an investment of Rs. 25,000/- in an year with 3 harvests.

Hence from the above it can be inferred that the culture and utilization of seaweeds can contribute to rural development and thus to economy of the country as a whole.

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LIFE-FEED CULTURE - MICRO ALGAE

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Introduction

Marine micro algae are the floating microscopic plant components of the seawater which forms the basic food of almost all the larval organisms, either crustaceans, molluscs or fishes. They are the primary producers of the sea belonging to various Classes of algae. The important components of micro algae are the diatoms, dinoflagellates, silicoflagellates (phytoflagellates), coccolithophores, blue-green algae and the 'hidden flora' the nanoplankters. Among these, the diatoms and phytoflagellates are significant organisms since they form the primary link in the food chain of the sea. It is known that the success of any hatchery operations depends mainly on the availability of the basic food, the micro algae.

Mass culture of micro-algae has been in prevalence in many research institutions, universities and hatcheries the world over, since the past 50 years. For many years, this has been experimented by Plant Physiologists, Algologists and Bioengineers as an alternate means of producing protein. But in the late 1960s the enthusiasm slowed down when it was found that the process was uneconomical due to technical problems especially in the recovery of the algal product and its subsequent conversion to human food supplement. Recently, there has been renewed interest in producing Single Cell Protein (SCP) by mass culturing the unicellular algae particularly the diatoms and phytoflagellates for feeding the larvae of crustaceans, molluscs, sea-cucumbers and fishes. In recent years, many other potential applications for large scale algal culture have been developed including waste-water treatment, production of extractable commercial chemicals, aquaculture and the bio-conversion of solar energy.

As is well known, the success of any hatchery system either crustaceans, oysters, sea-cucumbers or fishes, entirely depends on the availability of the suitable micro algae. In the natural environment, the larvae feed on any minute plant components which are readily available to them. But in a hatchery, the food which are acceptable to the larvae for their growth and further development have to be identified and isolated. In the early critical stages of the rearing larvae of finfishes and shellfishes, the phytoflagellates (species of *Isochrysis, Pavlova, Dicrateria, Chromulina* and *Tetraselmis*) and other nanoplankters (species of *Chlorella* and *Synechocystis*) form the basic food. But in the postlarval stages of crustaceans and spat juvenile stages of bivalves, the diatoms (species of *Chaetoceros, Skeletonema* and *Thalassiosira*) form the primary food. Hence the culture of micro algae is an essential prerequisite for the rearing operations of economically important cultivable organisms in a hatchery system.

Methodology

Isolation of the required species of micro algae can be done by one of the following methods.

1. *Pipette method* : Large organisms can be pipetted out using a micro-pipette under microscope and transfer to culture tubes having suitable culture media.

2. *Centrifuge* or *washing method* : By repeated centrifuging of the samples in different revolutions and by inoculating the deposits, it is possible to get different organisms.

3. *By exploiting the phototactic movements* : By this method, most of the phytoflagellates can be isolated. Make a dark chamber with a small hole on one side and keep the sample in a beaker nearer to the hole. Place a candle near

to the hole outside. Since the flagellates have a tendency to move towards the light, it is visible after sometimes that these organisms crowded near to the candle light. By pipetting, these organisms can be separated and by tube culture methods, it can be raised to a pure culture.

4. *By agar plating method* : For preparing the agar medium, 1.5 gm of agar is added to 1 litre of suitable culture medium *e.g.* Schreiber's medium, Miquel's medium, TMRL medium and Conway medium or even natural seawater. This agar solution is sterilized in an autoclave for 15 minutes under 60 kg pressure and 100°C temperature. Now this medium is poured in sterilized 15 cm diameter petri-dishes and kept for 24 hrs. For the isolation, the required species can be picked up by platinum needle or loop under microscope and streaked on the surface of agar plate. After inoculation, these petri-dishes are placed in an incubator for 7-8 days providing light (1000 lux) and constant temperature (25°C). Within this time, the required species, if it has grown into a colony, removed by platinum loop under microscope and transferred to culture tubes. Further, from culture tubes to small conical flasks and larger flasks, the algae can be grown on a mass scale.

5. *Serial dilution culture technique* : This method is used mainly for the isolation of phytoflagellates (Sournia, 1971). In this method, mainly 5 dilution steps (the inocula corresponding to 1, 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} or 4 steps - 0.001, 0.01, 0.1 and 1 ml) are involved for the isolation of the required species. For the serial dilution technique, nearly 25 culture tubes (15 ml) are required. After filtering the seawater through 10-20 micron seive, the filtrate has to be inoculated to five series of culture tubes in various concentrations. This has to be kept under sufficient light (1000 lux) with uniform temperature (25°C) conditions. After 15 days, some discolouration can be seen in the culture tubes, due to the growth of micro-algae. Further purification of this culture can be done by sub-culturing it in 500 ml or one litre conical culture flasks. Once the culture is fully purified, it can be transferred into a 3 or 4 litre Hafkin culture flasks and maintained as stock culture.

After the isolation of the required organisms in culture tubes, it may be sub-cultured again in few 50 ml test tubes. These test tubes are the base from which the algal food started producing and from where the continuous supply of non-contaminated algal feed is obtained for the operation of the large-scale culture systems. Once the system is started, the test tube culture can be transferred to small culture flasks and to bigger flasks by adding 3-5 ml of the stock culture. Therefore every two weeks a new set of 10 test tubes for each species should be inoculated from the previous set. The filtration of water and medium enrichment should be done not earlier than 3 days, prior to inoculation.

Culture media

For the successful culturing of the micro algae, either diatoms or nanoplankters, various chemical culture media have been used depending on the type of organisms cultured and their growth phases. Although most algae are photo-autotrophic and can grow in purely inorganic media, many other required organic compounds, the requirements of which may be either absolute or stimulatory. While most of the micro algae can be successfully cultured on synthetic inorganic media, a few genera require organic compounds for their rapid growth and therefore the culture are supplemented with soil extracts, yeast extracts or organic salts. Since the micro algae in any water body require the nutrients such as nitrates and phosphates roughly in a ratio of 10:1 (N:P) for its normal growth and reproduction, the culture media used in the laboratory should have sufficient quantities of these elements besides other growth promoting substances including trace metals, amino acids and vitamins. The absence of one or two growth promoting agents would defenitely reflect on the growth of micro algae especially in a culture system.

For culturing the micro algae, various culture media are in use depending on the organisms involved. Though Erd-Schreiber's and Miquel's media (Miquel, 1892) were found to be very effective for culturing the diatoms and nanoplankters, several other media are also available with the addition of trace metals, vitamins and other organic and inorganic salts.

Since the diatoms require silica for building up the cell walls, the culture media should have a compound of silicate besides the nitrates, phosphates, chlorides and trace metals. Usually for culturing the flagellates, 'Conway' or 'Walne's medium (Walne, 1974) is used in the laboratory for the maintenance of the stock culture as well as mass culture. Since this culture medium has got various chemicals, trace metals and vitamins (B1 and B12), the phytoflagellates such as species of *Isochrysis, Povlova, Dicrateria, Chromulina* and *Tetraselmis* are being cultured by using media alone. However, media like TMRL and PM (Gopinathan, 1982) are also found to be effective for the mass culture of nanoplankton flagellates. Still, the technique of culturing different micro algae requires a clear understanding of their nutritional requirements, especially during the various phases of growth. The important culture media used for the micro algae are given below.

Schreiber's medium

Potassium nitrate	0.1 gm
Sodium orthophosphate	0.02 gm
Soil extract	50 ml
Filtered and sterilized seawater	1 litre

Soil extract is prepared by boiling 1 kg of garden soil in 1 litre of freshwater for one hour. After 24 hrs, clear water is decanted and kept in a bottle. 50 ml of this soil extract can be added to each litre of sterilized seawater. This can be used as a medium while isolating the nanoplankton.

Miquel's medium

A.	Potassium nitrate	20.2 gm
	Distilled water	100 ml
B.	Sodium orthophosphate	4 gm
	Calcium chloride	2 gm
	Ferric chloride	2 gm
	Hydrochloric acid	2 ml
	Distilled water	100 ml

0.55 ml of 'A' and 0.50 ml of 'B' are added to one litre of filtered and sterilized seawater. This medium can be used for culturing various types of micro algae.

'Schreiber's medium (modified for serial dilution culture method)

Potassium nitrate (5 gm in 100 ml of DW)	0.25 ml
Sodium orthphosphate (1 gm in 100 ml)	0.25 ml
EDTA (1.2 gm in 100 ml)	0.15 ml
Vitamin mixture (Thiamine - 200 mg; Biotin - 1 mg; Cyanocobalamine - 1 mg; in 1 litre of DW)	0.50 ml
Soil extract	3 ml
Sterilized seawater	250 ml

The medium is autoclaved at 80°C for 15 minutes, then cooled down to room temperature in running water. If possible add vitamin mixture to the medium after it is cooled.

***TMRL medium** (Tung Kang Marine Res. Lab.)*

Potassium nitrate	10 gm/100 ml of DW
Sodium orthophosphate	1 gm " "
Ferric chloride	0.3 gm " "
Sodium silicate	0.1 gm " "

The chemicals are kept separately in 100 ml reagent bottles. 1 ml each to 1 litre of sterilized seawater is added. This medium can be used for the mass culture of diatoms.

'Conway' or Walne's medium

A.	Potassium nitrate	100 gm
	Sodium orthophosphate	20 gm
	EDTA (Na)	45 gm
	Boric acid	33.4 gm
	Ferric chloride	1.3 gm
	Manganese chloride	0.36 gm
	Dist. water	1 litre
B.	Zinc chloride	4.2 gm
	Cobalt chloride	4.0 gm
	Copper sulphate	4.0 gm
	Ammonium molybdata	1.8 gm
	Dist water	1 litre
C.	Vitamin B1 (Thiamin)	200 mg in 100 ml dist. water
	Vitamin B12 (Cyanocobalamine)	10 mg in 100 ml dist. water

A, B and C (each) in different reagent bottles are prepared. 1 ml of A, 0.5 ml of B and 0.1 ml of C to 1 litre of filtered and sterilized seawater are added.

During the course of the larval rearing of oysters, the flagellates form the basic food upto its spat stage. However, for the better growth of the spat, the food is to be changed from flagellates to a mixture of diatoms and other nanoplankters. For the preparation of mixture of various phytoplankton organisms in the open tanks, using direct sunlight, the following media could be used.

Mixture culture medium

Potassium nitrate	1.2 gm
Sodium orthophosphate	0.66 gm
EDTA (Na)	0.66 gm
Sodium silicate	0.66 gm

The first 3 chemicals are dissolved in 25 ml of DW and sodium silicate alone is dissolved in 25 ml of DW. This is added to 100 litre of fresh unfiltered seawater (fresh seawater is filtered through organdy cloth, 0.33 mm mesh size to remove zooplankton). This water is poured in 3-4 white lined basins or fibre-glass tanks and kept in open sunlight. Within 24 hrs, a slight yellow colouration can be noted. On examination, it can be noticed the growth of mixture of planktonic diatoms and other nanoplankters. If the temperature is very high and sunlight is very bright, only the blooming of *Chaetoceros* spp. could be observed.

Besides the above mentioned laboratory prepared chemicals which serve as nutrients, commercial fertilizers can be used for the mass culture of diatoms and nanoplankters, in open tanks for economy purpose. The media used for the open culture are:

Urea 46	10 mg/l
16-20-0	10 mg/l
20-0-0	100 mg/l

Growth phases of the algal culture

The usual way of the laboratory culture of micro algae is one in which a limited volume of medium containing the necessary inorganic and organic nutrients, is inoculated with a relatively small number of cells and these exposed to suitable conditions of light, temperature and aeration. Increase in cell numbers in such a culture follows a characteristic pattern in which the following phases of growth may usually be recognised.

Lag or induction phase

The cells taken from the stock culture room and inoculated to a new flask have to acclimatise the surroundings or in the new medium. Hence, there will be no cell division for a few hours and this stage is known as lag or induction phase.

Exponential phase

Once the cells are acclimatised to the surroundings, they start multiplication and grow rapidly. It is assumed that within 8-16 hrs, the cell will divide into 2 and further these cells carry on the growth till the culture reached its maximum concentration. This growing phase is known as exponential phase.

Declining phase

Once the cells reaches its maximum concentration, the growth and multiplication of the cells will be arrested and slowly the cells show the symptom of decline. This arrested growth of the cells in the culture is known as declining phase.

Stationary phase

After the arrested growth, the culture will be stationary without any further cell division for a few days. Actually, stationary phase is a prolonged one in the case of flagellates. For this they may develop some cover or cyst or matrix around its body for thriving in the unfavourable conditions. In the stationary phase, if the cells get a new environment, they start further growth and reproduction.

Death phase

After a long period in the stationary phase, the cells lose its viability and start to die and thus the culture becomes useless, either for reculturing or for feeding.

Determination of algal cell densities

Regular counts of the algal cells must be made in order to schedule inoculation of the various culture flasks as well as mass culture containers, to monitor growth of the algal cultures and to determine the quantity of algae to be fed to the rearing larval organisms.

In sampling the mass or tank cultures, a small length of rubber tubing is helpful to work with and to connect it to the mouth piece end of a sterile serological pipette. To get a representative sample, move the pipette around the tank while withdrawing algae upto the mark on the pipette and then place it in a flask. This is how the sample is to be counted.

Since most of the nanoplankters measure less than 10 μ a haemocytometer is used for counting the cells. First of all the sample is treated with a drop of eosin or formalin to kill the cells and stirred well, one drop is taken with sterilized pipette. After placing a cover-slip on the haemocytometer, the pipette is brought to the edge of the haemocytometer to touch it. The sample runs inside the cover slip and thus a thin film of the culture is maintained, and the cells are equally distributed. Since the haemocytometer has got 9 chambers, and 4 sides having 16 divisions and 5 chambers of multiple divisions, it is restricted the counting for at least 4 chambers. The average number of cells in 1 ml is calculated as shown below.

Average counts per chamber x 104 = Total number of cells/ml.

Stock culture maintenance

Stock culture of the micro algae are maintained in a special air conditioned room adjacent to the mass culture room. Stock cultures are kept in 3 or 4 litre Hafkin culture flasks. The autoclaved or boiled seawater after cooling is poured to the Hafkin flasks and required nutrients are added. Walne's medium enriched with vitamins is the quite ideal one to maintain the stock of all the phytoflagellates. About 10 ml of the inoculum in the growing phase is transferred to the culture flasks and the same is placed in front of 2 tube lights (1000 lux). After 8-10 days, when the maximum exponential phase has reached, light is reduced to 1 tube light for further growth. The time required for the maximum cell densities varies depending on the species. However, it was noticed that all the Haptophycean flagellates require 2 weeks for the completion of growth phase before entering into the declining phase. In the stationary phase, the flagellate can be kept for 2 months in the stock culture room, under controlled conditions of light and temperature, with or without aeration. At the time of maximum exponential phase of growth, the colour of the culture turns into dark brown and the cells are found as suspension without movement. The cells of flagellates produce a thick matrix or cyst around it in the stationary phase and when inoculate the same, these cysts break and the flagellates emerge out for its further growth and multiplication. A minimum of 5 Hafkin culture flasks were kept for each species as stock culture.

Mass culture

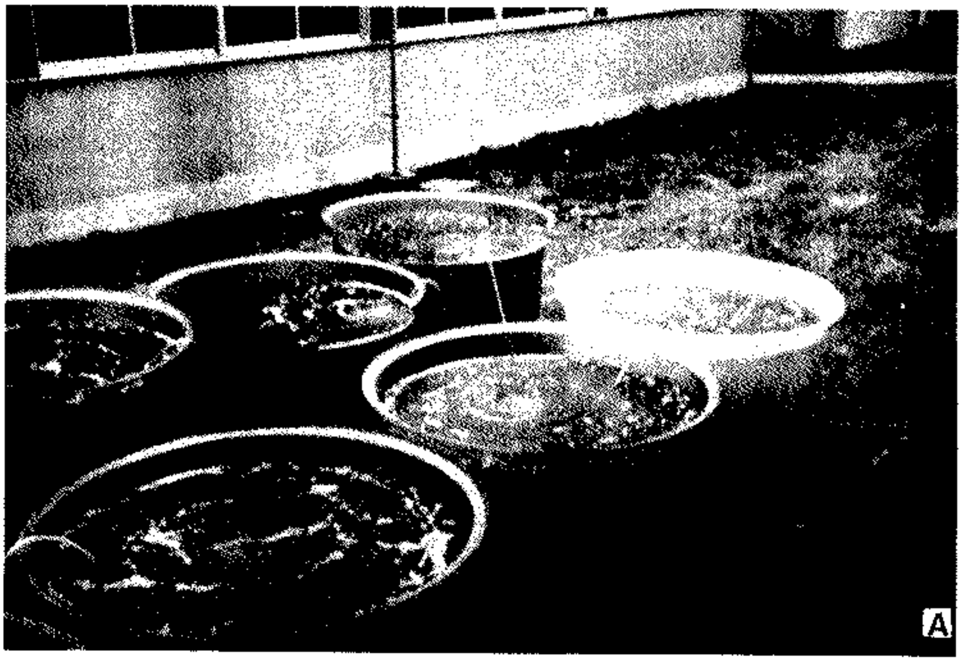
Large scale culture of micro algae, especially nanoplankton flagellates and selected species of diatoms, are necessary for feeding the larval forms in a hatchery. Since the molluscan larvae feed organisms measuring < 10 μ only, these forms are isolated from the seawater, maintained as stock culture and the inoculum, mass culture is done in the laboratory conditions as well as in the outdoor tanks.

The containers for the mass culture of micro algae are of 10 lt capacity polythene bags, 20 lt glass carbuoys, 100 lt persepex tanks and 250 lt cylindrical transparent FRP tanks for the indoor culture. These containers are kept in wooden racks with light and aeration. Fully grown culture from the stock culture room is used as inoculum for the mass culture in these containers. These tanks have the maximum concentration of the cells in the growing phase on the 5-7th day and harvested. After estimating the cell concentration using a haemocytometer, the culture is supplied to the hatchery for the rearing operations of the larval organisms. Leaving 2 lt of the culture, fresh enriched medium is added for further culture in the same container.

Equipments and glasswares

For the identification of the micro algae as well as for the determination of cell concentration

Plate I A. Stock culture maintenance of micro algae and B. Indoor mass culture of micro algae in 20 lt glass carbuoys and 100 lt perspex tanks.



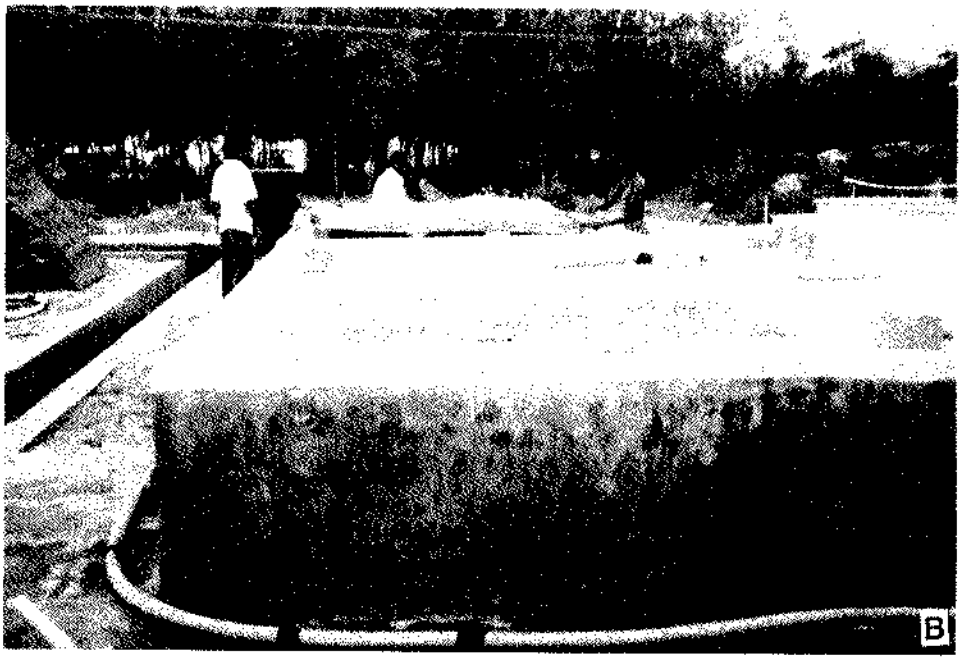


PLATE II A. Outdoor mass culture of micro algae in FRP basins and B. Large-scale culture of *Chaetoceros* in 5 tonne concrete-white tile tanks.

of the culture, a powerful microscope is necessary. Since the flagellates are identified by noting the number of flagellae and other cell characteristics, a phase contrast microscope is advisable.

For the stock culture maintenance, micropipettes, droppers with teat, reagent bottles, culture tubes, conical flasks, Hafkin culture flasks, haemocytometer, etc. are required, in addition to the containers mentioned above.

Sterilization of glass containers

The glasswares used for the isolation, maintenance, laboratory culture and mass culture should be cleaned thoroughly prior to sterilization either by steam or by autoclaving. The cleaning procedures : (1) Treat with conc. hydrochloric acid and keep the same for 30 minutes, (2) Rinse 3 times with hot tap water, (3) Rinse 2 times with cold water, (4) Pour few drops of suitable soapwater (T-poll or Labolene) and rinse 6 times till the froth is completely removed and (5) Rinse 2 time with distilled water. After drying in the sunlight, the glasswares are kept in an oven at 100°C for an hour. The culture tubes, conical flasks and Hafkin culture flasks are to be plugged with cotton before keeping in the oven.

Illumination of algal cultures

One of the most important factors in determining successful culture of micro algae, is the type and quantum of illumination. Most of the flagellates require less light during the stationary and declining phases. Too much of light causes the culture for the early declining. Comparing the low light levels found in natural water, successful cultures of these algae in the hatchery also requires relatively low levels of light to achieve maximum growth and optimum densities of cells.

For maintaining the stock cultures of all micro algae during the declining and stationary phases of growth, one tube light (500 lux) is essential while the mass culture containers require 1000-2000 lux. Twelve hours of light and 12 hrs of darkness is ideal for maintaining the stock as well as mass culture, which can be controlled by auto-timer control switch mechanism.

Temperature control

Normal room temperature (28-30°C) is not ideal for the maintenance and culture of micro algae. Hence air conditioned rooms are used for keeping the stock as well as indoor mass culture of this live feed. Both the rooms should have 23-25°C during day time. Since there is no light during night hours, air conditioners can be switched off for few hours.

Aeration

Similar to light and temperature, aeration is also important for developing and maintaining healthy cultures, as well as enhance the exponential phase of growth of micro algae for few days more. It was noticed that if aeration is given to the mass culture tanks, cultures remain in the growing phase 3-4 days more than the tanks with no aeration. Moreover, aeration is more required during day time when there is light when compared to night. Aeration not only helps the culture, but also keeps the culture always in suspension. Aeration also helps the nutrient salts to distribute uniformly in the medium and supplying of CO_2 required for photosynthesis. Lastly, aeration prevents the settling of the cells at the bottom of the culture tanks, causing eventual death due to the lack of supply of CO_2.

Anti-contamination procedure

In culturing of various species of micro algae, the most important aspect is the cleanliness of all surfaces. Personnel should not work in areas where there is raw ambient seawater prior to working in the algal section. All works with algae should be done with one species at a time. Neither samples from, nor inoculation of culture containers containing different species of algae should not be done at the same time. In addition, personnel should wash their hands after working with one species and before starting to work with another species of algae. Transfer of tube cultures should take place where there is a minimal movement of air to reduce chance of contamination. All glasswares should be sterilized before use.

Further, all stock cultures in Hafkin culture flasks should be checked in a week under microscope using sterilized pipette for contamination. The checking of these cultures is to be combined with the counting procedure on a regular basis.

Harvest

The fully grown culture should be harvested during the exponential phase of the micro algae after determining the cell concentration. If the culture has entered the declining or stationary phase, the metabolites will be very high and the cells may not be in healthy condition. The rearing larval organisms may not show the expected growth if fed with this feed.

Preservation

The maintenance and constant supply of the culture whenever required is a problem in the hatchery especially during adverse weather conditions. In this case, the preservation of the algae either by freezing or by sun-drying is done in the sense that during scarcity of the feed, the rearing operations may be successfully controlled. For the method of freezing, the culture is flocculated either by adding lime or by adjustment of pH using sodium hydroxide. Usually, the addition of alum or lime will not give satisfactory results, but manefestation of pH with sodium hydroxide is the advanced technique conducted in the laboratory. After knowing the quantity of the culture to be flocculated, the volume of sodium hydroxide solution needed to flocculate to get one degree raise in pH is measured. Suppose the pH of the culture is 8.4, by adding sufficient quantity of sodium hydroxide solution raised to 9.4. After vigorous stirring, the culture is left for one hour to settle the algal mass at the bottom. Slowly decanted the clear water and the mass in a plastic bucket is collected. Then the pH of the culture to the original level is brought slowly by adding dilute hydrochloric acid. Now the algae is ready for freezing or sun-drying. The algae is dried by pouring the mass in white enamel trays and keeping the same in the bright sun-light. If the algae dried thoroughly, the powder from the enamel tray is scraped and kept in glass bottles.

Before freezing the algal mass, some protective reagents like Dimethyl sulphoxide or Glycerol (a few drops) are added. The concentrate is then poured into polythene bags after measuring. The polythene bags are labelled and kept in deep-freezers. The frozen algae do not have the same protein content as in the live condition. Whenever adverse condition arise, the frozen food are used for rearing the larval organisms.

Future scope of micro algal culture

The development of mass culture of micro algae offers immense scope and can run concurrently with mariculture programmes. At the same time it offers a challenge for the phycologists. Considerable research is needed for elucidation of the key problem such as the growth kinetics of different species, the period of economically viable harvest, etc. In the matter of waste-water recycling, unicellular algae holds out much promise. Maximisation of solar energy utilization under controlled conditions of temperature, light and aeration, development of viable methods for intensive culture, maintenance, formation of extra-cellular products and their significance are promising lines of investigations.

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CONTINUOUS MASS CULTURE OF LIVE-FEED TO FEED DIFFERENT STAGES OF PRAWN AND FISHES

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Introduction

Live feeds are important in the diets of prawns and fishes in the culture pond, particularly to the larval stages and juveniles of prawns and fishes. The important live feed organisms are *Artemia salina*, rotifer *Brachionus plicalitis* and the freshwater cladoceran *Moina* spp.

Artemia

The dried *Artemia* cyats are introduced into the filtered seawater (salinity 30-35‰) at the rate of 1 gm/lt and provided with aeration and the light which stimulate the embryonic development. The free swiming nauplii are hatched out within 18-36 hrs after hydration in the seawater.

Fig. 1. *Artemia salina.*

The nauplii are collected and introduced into a plastic pool or cement tank at the rate of 1000 nauplii/lt. The salinity of the culture tank raised gradually upto 80% till that time the young ones became adult within 12-14 days.

In the case of heterosex strain, the IInd antennae of the male developed as the hooked claspers to hold on female in the uterus region during copulation and in the female IInd atennae degenerate into sensorid appendages.

Adult *Artemia* measures about 10-12 mm size with elongated body having 11 pairs of thoracic appendages and two eyes in the head region. The eggs are developed in the ovary and transferred to the brood-pouch through oviduct. The male mates with the female and fertilizes the eggs. The unfertilized eggs are disintegrated. The fertilized eggs develop into Nauplii (Ovoviviparous reproduction) in the brood-sac and released into the culture tank every 4-5 days.

In abnormal conditions such as high salitity (above 12‰ and low oxygen level, the eggs developed into dormant cysts due to the secretion of Chorion by the gland in the brood-pouch. The cysts released into the culture medium and adhered on the sides of the tank, can be collected, dried and stored in the closed container or in the saturated high saline water upto 6-8 months for future use.

In the case of parthenogenic strain the embryonic development starts as soon as the egg reached the brood-pouch from the ovary.

The released young ones in the culture tank become adult within 10-12 days. The adult may survive upto 3 months and release 100-180 young ones/batch in every 4-5 days, depending upon the culture environment. The continuous mass culture was maintained with partial water change and harvesting. The single cell algae such as *Chlorella, Tetraselmis*, yeast or bacteria culture are used to feed *Artemia*.

In 1982, the *Artemia* hybrid was developed by crossing low salaine, heterosex Californian strain male and the high saline parthenogenic Bombay strain female. From F1 generation low saline parthenogenic females are isolated and the mass culture is maintained in the seawater after sterilization with formalin to avoid the contamination like rotifers, copepods, etc.

In the heterosex strain, the female releases male about 50% in each batch and the unfertilized eggs are disintegrated so the duration to reach the maximum concentration is longer than the parthenogenic strain. Hence the parthenogenic strains are preferable to culture in the laboratory.

Rotifers

A technique, for continuous mass culture of euryhaline rotifer *Brachionus plicatilis* has been developed and perfected in 1979-80 to feed the early level stages of prawn and fishes.

Stock culture of rotifers collected from the natural environment in the seawater or brackishwater pure culture is obtained by the sub-culture in the laboratory.

Filtered seawater is pumped in to a tank (50 tonne capacity) and fertilized with groundnut-oil cake (250 gms), urea (10 gms) and superphosphate (5 gms). This medium is inoculated with *Chlorella* on the same day at the rate of 5-10 lt/tonne and the rotifers are introduced at the rate of 500 nos/lt on second day. Vigorous aeration is given from the start of the culture.

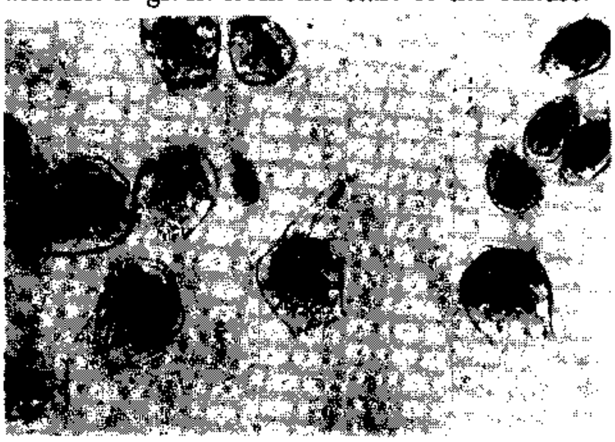

Fig. 2. A group of rotifers *Brachionus plicatilis*.

Rotifers reproduce rapidly by feeding on *Chlorella* bloom. The eggs developed in the ovary and reach the brood-pouch are released as young ones within 8-10 hrs. The young ones become adult in 16-18 hrs and begin to reproduce. The adult bear six eggs at a time and release one by one. So the culture attains the maximum concentration of 4-5x10^5 rotifers/lt in 5-7 days depending upon the culture conditions. They flourish in salinity range from 25 to 40‰ and the temperature between 26-34°C.

Harvesting of rotifers is done with the hand net of 60 micron mesh size in the morning hours when they swarm at the surface. The harvested rotifers are concentrated, washed with filtered seawater and mixed with equal volume of 10% glycerin and frozen into blocks, in a deep-freezer. This ensures a ready supply for use at any time or feed immediately after washing in the seawater.

During unfavourable conditions like the maximum concentration of rotifers, low oxygen level and during the scarcity of feed, the rotifers release the male. By the sexual reproduction it products dormant cyst and the cysts settle at the bottom of the culture tank. This cyst is collected along with the sediments, dried, stored upto 3-4 months for future use or transportation without any risk. The dried cysts hatch out within 36-48 hrs after hydration in the seawater.

The continuous culture is maintained by changing 1/3 volume of water after harvesting and the medium is enriched with organic fertilizer to stimulate the algal bloom.

Cladocerans

A low cost technique for the mass culture of *Moina* spp. (Cladoceran) in fresh water has been developed to feed the prawn postlarvae (PL 5 to PL 20) and the 10-20 days old fish fry in frozen condition.

Fig. 3. A collection of freshwater cladocerans.

The filtered freshwater is pumped into a tank and fertilized with groundnut oil cake

(250 gms), urea (10 gms) and the superphosphate (5 gms). *Chlorella* is inoculated at the rate of 5-10 lt/tonne on the same day and vigorously aerated. The next day the *Moina* from the stock culture in the laboratory is introduced at a stocking rate of 1-5 animal/lt.

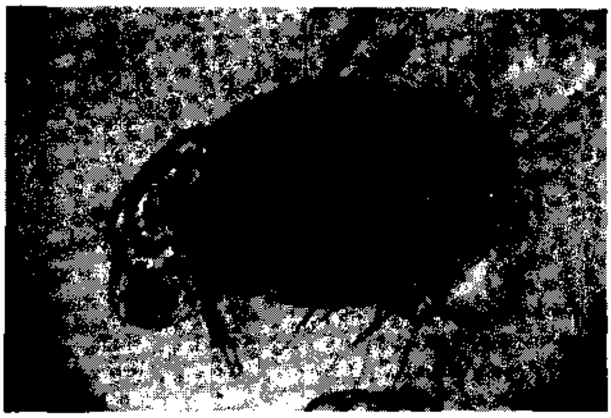

Fig. 4. A cladeoceran *Moina* sp.

The *Moina* population grows rapidly feeding *Chlorella* bloom which multiflies utilizing the fertilizers and the natural sunlight. The temperature ranges between 27°C and 34°C and the pH from 6.8 to 9.5. The adult *Moina* releases 10-12 of young ones daily. The young ones become adult within 20-24 hrs and begins to reproduce from the following day. So the maximum concentration of *Moina* (about 35,000 to 40,000/lt) reaches in 5-7 days depending upon the culture conditions. Thereafter the *Moina* are harvested every day morning or evening when they swarm at the surface. Harvesting is carried out by skimming the surface water with a zooplankton net after stopping the aeration. They are washed in fresh water, mixed with equal volume of 10% glycerin and frozen in a deep-freezer into blocks.

During the unfavourable conditions like high concentration of *Moina*, less oxygen level and the scarcity of feed, the *Moina* releases the male and female young ones. After mating, the female produces 4-6 dormant cysts in the brood-pouch and the released cysts settle at the bottom of the culture tank. The cysts collected alongwith sediments, dried and preserved upto 4-5 months in a closed container to restart or transport to the long distance without any risk. The dried cyst when hydrated with fresh water, the embryonic development starts and hatches out in 24-36 hrs.

In the event of decline in *Moina* population due to the continued harvest, half the volume of water is replaced by fresh water and enriched with organic fertilizer to stimulate *Chlorella* bloom. So, again the *Moina* population coming up within 3-5 days and the continuity of culture is maintained for over 3 months.

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CULTURE OF SEA-CUCUMBER

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Introduction

The sea-cucumbers are entirely marine and distributed from the Arctic to the Antarctic region. They are distributed right from the supralittoral zone to the hadal zone. They inhabit a wide variety of habitats *viz.* rocky, muddy, sandy and coral. Most of them live among corals. They are well distributed on the reefs of the Indo-West Pacific region. Good concentration of them are found in the Philippines. Species belonging to the families Holothuridae and Stichopodidae alone are used for processing since they grow to a large size and the body well is also thick.

In the seas around India more than 200 species are distributed. In the shallow waters 75 species are distributed. In the Indian waters the sea-cucumbers occur chiefly 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* (Pl. I) is the most important species for processing. In recent years *Actinopyga echinites* and *A. miliaris* are exploited in good quantities. *Holothuria spinifera* and *Bohadschia marmorata* are also distributed in small quantities. *Holothuria scabra* and *H. spinifera* are not distributed in the Lakshadweep. In the Lakshadweep *Holothuria nobilis* and *Thelenta ananas* are important species. The other species distributed in the Lakshadweep are *Bohadschia marmorata, Actinopyga mauritiana, A. echinites, A. miliaris, Stichopus variegatus, S. chloronotus* and *Holothuria atra*. In the Andaman and Nicobar Islands the most important species is *H. scabra*. The other species distributed are *Holothuria atra, A. mauritiana, A. echinites, A. miliaris, H. nobilis, Stichopus variegatus* and *S. chloronotus*. *Holothuria spinifera* is not distributed in the Andaman Islands. The record of *Thelenota ananas* from the Andamans needs to be checked. Sea-cucumbers are distributed in the Gulf of Kutch and also along the coast of the main land of India but they are not of commercial value.

The Central Marine Fisheries Research Institute started a Project on the seed production of *Holothuria scabra* in 1987 and they produced seeds for the first time in 1988 by inducing the sea-cucumber to spawn by thermal stimulation (James *et al.*, 1989). Since then seed of *H. scabra* is produced in the hatchery on a number of occasions. James and James (1993) have given prospects for sea-cucumber farming. James (1994 a, 1994 b) reviewed the seed production in Japan and China and also discussed the seed production of sea-cucumbers in India. Finally James *et al.* (1994 a, 1994 b) brought out a handbook on the hatchery techniques and culture.

Morphology and anatomy

Some information on the morphology and anatomy of the most important sea-cucumber *Holothura scabra* from the Gulf of Mannar and Palk Bay is presented here.

External characters

The body is robust, elongated and cylindrical with blunt ends. The mouth is at the antero-ventral and, surrounded by a ring of 20 peltate tentacles, and the anus is at the postero-dorsal end. The dorsal side is convex and the the ventral side flat. The total length ranges from 10-400 mm and the body weight ranges from 25 - 2000 g. The skin in large specimens is thick and slimy. On the dorsal side there are many small often inconspicuous papillae, which are thinly scattered. On the ventral side the tubefeet are densely arranged in an irregular manner. Each dark spot on the ventral side represents one pedicel.

In the live condition, it is grey to black on the dorsal side and white on the ventral side. Generally smaller specimens are totally black and larger specimens have a number of irregular yellow or white transverse bands on the dorsal side. Mouth is oval, situated at the centre of the circlet of tentacles.

Anatomy

At the base of the tentacles there are ten calcareous plates, of these five are radials and five interradials. On either side there are two long structures known as respiratory trees. They open at the posterior end into the cloacal chamber. At the base of the calcareous ring there is a circular ring water canal to which two or three polian vesicles which look like transparent sacs, hang freely into the body cavity. There is also a single stone canal. The intestine is highly coiled and opens into the cloacal chamber. There is a single bunch of gonadial tubules attached to the dorsal mesentery and this opens out through a single gonopore in the mid-dorsal region near the anterior end. There are five longitudinal muscle bands.

Feeding

It is omnivorous in habit. The peltate tentacles surrounding the mouth shovel the sand and mud continuously into the mouth. Nutrition is derived from the organic matter in the mud or sand. An analysis of the contents in the digestive tract has revealed the presence of marine algae, copepods, diatoms and molluscan shells. No food preference is noticed. The small intestine always appears to be relatively empty, whereas the large intestine is distended with a load of bottom material. The feeding seems to be a continuous process.

Reproduction

The sexes are separate and it is not possible to differentiate the males and females externally. Gonad is single, consisting of numerous thin, filamentous tubules united basally into one tuft. It is attached to the left side of the dorsal mesentary and hangs freely in the coelom. The tubules are elongated and branched. From the gonadal base, the gonoduct proceeds in the mesentery and opens to the outside in the mid-dorsal region near the anterior end. In advanced stages of maturity of filaments of the ovary are coloured brown in which the eggs or oocytes are visible as small white spots. The testis consists of long white beaded filaments. The gonoducts released through the gonopore by the ciliary action of the gonoduct. Fertilization is external and the embryo passes through different larval stages before setting down to the bottom as juveniles.

Brood stock maintenance

The brood stock material is procured from the commercial catches meant for processing. This material can be collected only during January to April. Therefore the brood stock material has to be maintained properly so that it can be used for spawning experiments. Sea-cucumbers are kept in one tonne FRP tanks with 800 litres of sea water. Aeration is provided at either side of the tank. In one tonne tank 15-20 individuals are maintained. At the bottom of the tank a layer of mud of 100 mm thickness is provided for the animals as feed. The water is changed completely daily. A feed was prepared with prawn head waste, soyabean powder and rice bran. This has 6.5% protein and the sea-cucumbers accept this food well. Daily 50 g of this feed is put in the one tonne tank as supplementary feed. The brood stock is used for spawning during January to April.

Spawning

Natural spawning

During the breeding season mature animals release the gemetes without external stimuli. During February, March, April, August and December, the sea-cucumbers spawned on changing the water in the brood stock tanks.

Induced spawning

First sea water is heated in GI buckets by using immersion heater. Pure filtered sea water is taken in 100 lt FRP tank and the initial temperature is noted. Then the heated sea water is slowly added to the 100 lt tank. While adding heated water, the sea water in the 100 lt tank is thoroughly mixed to get uniform temperature. When the temperature rises by 5°C, adding of hot water is stopped. The brood stock animals are first washed and then introduced into 100 lt tank. The normal temperature of the sea water in the hatchery is 28-30°C.

Usually the brood stock animals are introduced into the spawning tank around 1000 hrs. First the temperature in the spawning tank falls by 1 or 2°C, since the sea-cucumbers release cold water held inside their bodies. After 2 to 3 hours first the males start reacting by raising the anterior end swaying. The mature males start releasing the sperms in white streams. When once the males start spawning they spawn profusely. This will induce the other males also to spawn. It is better to keep one or two spawning males in the tank and remove the others since they foul the water. Excess sperm suspension is harmful for normal development of embryos. The females release the eggs after one or two hours after the males release the sperms. The females release the eggs in one or two spurts to help in wider distribution of the eggs. The eggs on release first sink to the bottom. They are immediately fertilized by the sperms.

Early embryonic and larval development

First the fertilized eggs are siphoned out into a sieve which is kept partially immersed in a bucket of water. The tank is gently washed with fresh sea water from all sides to collect the eggs into the sieve. Now the eggs are washed well with fresh filtered sea water to remove excess sperms. The contents of the sieve is transferred to a 10 lt beaker upto the mark. Then the water in the beaker is gently stirred to bring in uniform distribution of the eggs. From this 1 ml sample is taken and transferred to the counting chamber. The eggs in the counting chamber are numerically enumerated. This procedure is to be repeated three times to get the average number of eggs in the 1 ml of sea water. The average number multiplied by 10,000 gives the actual number of eggs in 10 lt beaker. The fecundity is five lakhs to one million.

Three to five lakhs of eggs can be stocked in one tonne tank with 800 lt water. Two aerators are provided for one tonne tank. The eggs are round and spherical with diameter 160-190 m. The cleavage is complete and holoblastic. After 40 minutes blastula is formed. First day no feed is given. After 26 hours the embryo hatches out. After 24 hours gastrula is fully formed. The gastrula is motile and oval shaped. After 48 hours early auricularia appears. As days advance the lateral projections become prominent in the auricularia. On the tenth day some of the auricularia transform into doliolaria. After three days pentacula stage is reached. The various types of larvae and different stages of development have been illustrated and described elaborately by James *et al.* (1994 a), and they are again briefly described below.

Auricularia larva

Early auricularia is formed after 48 hours. After five or six days. late auricularia is formed. It is slipper-shaped, transparent and pelagic in habit. It has a pre-oral loop anteriorly and anal loop posteriorly. These bands help in locomotion. The digestive tract consists of mouth, an elongated pharynx and sacciform stomach. The early auricularia larva measures on an average 560 m. The later auricularia has an average length of 1.1 mm. On the tenth day some of the auricularia larvae metamorphose to doliolaria larva.

Doliolaria larva

The doliolaria is barrel-shaped with five bands around the body. These larvae measure 460-620 µ. Rapid changes occur inside the body and all adult features of the holothurian set in. This stage is short and lasts only for two or three days and subsequently transformed into a creeping stage known as pentactula.

Pentactula larva

The pentactula is tubular with five tentacles at the anterior end and with a single tubefoot at the posterior and which helps in the locomotion of the larva. The pentactula creeps over the sides and bottom of the tank. They actively feed on benthic algae and other detritus matter. The pentactula measures 600-700 µ. If they are fed on algal extract some of them reach a length of 10 mm in one month and transform into juveniles.

Larval rearing

Rearing tanks should be clean and free from bacterial settlement. They should be scrubbed well before use and after washing they should be dried. Strict control of rearing density of the larvae is to be observed. If the density of the larvae is more, they will form as a ball and sink resulting in death. Therefore rearing density should be controlled to ensure better survival rate. The desirable density should be controlled to ensure better survival rate. The desirable density

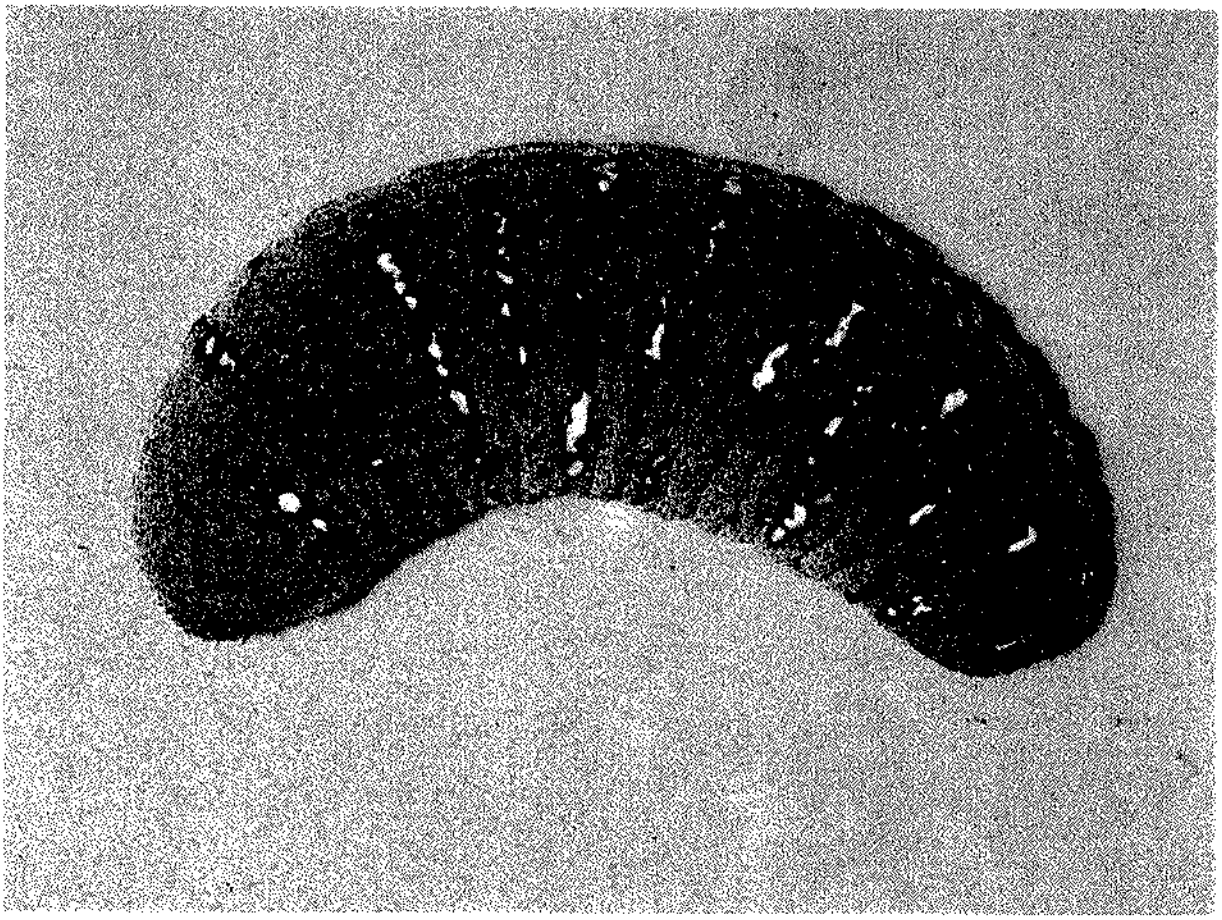

Plate I. *Holothuria scabra*

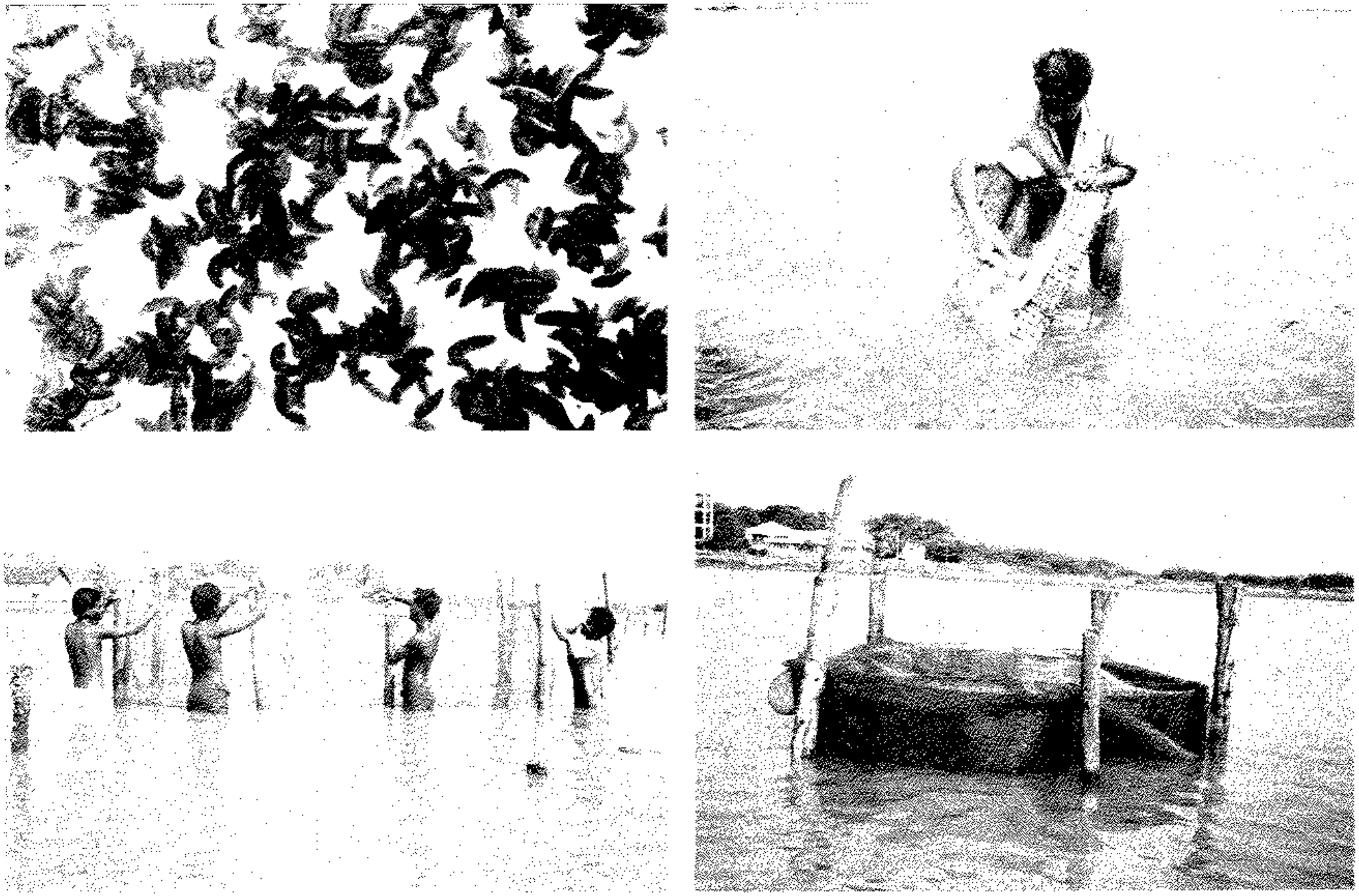

PLATE II A. Sea-cucumber seeds produced at the CMFRI hatchery at Tuticorin, B. Rectangular cage, C. Velon screen cage and D. Netlon cage.

of larvae is 300-700/lt. In one tonne tank with 750 lt of water 3,75,000 larvae can be stored. The number of larvae is estimated by using the same procedure as in the case of egg estimation. Normally the larvae are taken out once in three days so that the tanks can be cleaned thoroughly to avoid infestation of other organisms. On other days the water level is reduced to more than half by keeping the sieve inside the tank. The sediment must be removed to keep the water fresh. An upto date information on the survival rate at each developing stage is necessary.

Larval feeding

Suitable and high quality micro-algae and correct feeding rates are important for successful rearing. As the larvae progress in development the alimentary canal is well formed and the larvae must be given diet immediately. The effectiveness of the various micro-algae were tried. Better growth rate was obtained when fed on the micro-alga *Isochrysis galbana.* With this micro-alga the mortality rate was also found less. The larvae require different quantities of diet during different developmental stages. In general 20,000 to 30,000 cells/ml in the rearing tank water is maintained. The micro alga *Isochrysis galbana* cultured usually has a concentration of 80,000 cells/ml. When the bloom is good it reaches one million mark. Pentactula larvae settle down to the bottom of the tank. *Sargassum* is made into a fine paste and sieved through 40 µ. This settles down to the bottom of the tank. The penctactula larvae feed on the matter settled at the bottom of the tank. The culture of micro-algae for feeding of larvae of marine cultivable crustaceans, molluscs, fishes and holothurians have been elaborately given by Gopinathan in one of the chapters in this Bulletin.

Juvenile rearing

The juveniles when once they settle down to the bottom of the tank need food. They can no longer take planktonic food. If proper food is not available at the bottom of the tank they die. The juveniles are found to thrive and grow well on the algal extract of *Sargassum* spp. The seaweed *Sargassum* sp. is collected from the wild and first they are cut into small pieces. Then they are put in the mixie and made into fine paste by adding sufficient water. The fine paste is mixed with seawater and the same is filtered by using 40 µ seive. This filtrate is now added to the tanks with juveniles. The extract soon settles down to the bottom of the tank and forms a fine film. The juveniles feed well on this extract settle down. In one tonne tank having an area of 2 m^2, 20,000 juveniles can be stocked.

The water in the tank is daily changed and the feed is given in the morning. Once in four days the juveniles are removed by using a siphon. Those which stick to the surface of the tank are gently removed with the help of a fine brush. It is observed that all the juveniles do not grow at the same rate though they belong to the same brood. Some of them grow faster than others and they are known as *shooters.* These are separated with the help of a brush and reared separately in 100 lt tank. When they reach a length of 10 mm, fine mud is also added to the tank. The shooters are regularly removed while rearing the juveniles. When they reach a length of 25 mm, formulated feed is also added to the diet of the juveniles. The fine mud provided for the juveniles is also changed when the juveniles are taken out to clean the tank (Pl. II A).

Farming

The sea-cucumbers are slow growing animals and they live for a number of years. It is expensive to maintain them in the hatchery till they reach marketable size. Therefore they are transferred to the sea when they reach a length of 20 mm. The juveniles were farmed in old one tonne tank, rectangular cage, velon screen cage, netlon cage and cement ring (Pl. II).

Old discarded one tonne tanks are used for farming the juveniles. These tanks are 2 m in length, 1 m in breadth and 50 cm in height. The tanks are taken to a suitable spot and filled with seawater to settle it to the bottom. Then the tank is fixed with the help of four casurina poles to keep it in the same position. Fine mud is provided in the tank to a height of 50 mm for the juveniles to feed and also to take shelter. The tank is covered by velon screen to present the entry of undesirable organisms into the tank.

The rectangular cage (Pl. II B) is made of iron rods of 7 mm diameter. They are 1 m long and 60 cm wide and 15 cm high. They are in the form of rectangular boxes with lid. On the outer side of the cage nylon rope of 2 mm thickness is knotted to the frame. The distance between two knots is 30 mm. The cage is lined with fine velon screen inside to prevent the sand or mud going out. The cage is fixed to the bottom of the sea at a depth of 2 m with the help of four casurina poles.

The velon screen cage (Pl. II C) was 2 m^2 in area. It was made of velon screen of 4 mm mesh to allow the free flow of water. The length and breadth of the cage was 2 m and 1 m respectively. The height of the velon screen cage was 2 m. The cage was fixed at a depth of 2 m on an algal bed. The bottom of the cage also has velon screen for easy and total retrieval of the juveniles. The cage was fixed to the ground by your poles one at each corner of the cage. The cage is further strengthened by four more poles at the middle of four sides to keep the cage in position during high gales. To keep the bottom of the velon screen cage stable four big stones were kept at four corners. After the juveniles were stocked the top is covered by velon screen and stitched so that fish and crabs may not enter the cage. Before stocking the juveniles, sufficient quantities of mud is put inside the cage which serves as food for the juveniles.

Netlon cage (Pl. II D) is cylindrical in shape with an area of 1.65 sq. m. Diameter of the cage is 1.5 m and the height of the same is 1.3 m. The mesh size is 5 mm. The netlon cage is erected in the sea at a depth of 1 m. The cage is fixed to the bottom with the help of four stout casurina poles. The top of the cage is covered by velon screen to prevent entry of other organisms. Every week during low tide two buckets of mud is put into the cage and this serves as food for the juveniles. The juveniles are examined every month to find out the mortality and also the increase in average weight of the juveniles.

Cement rings used in the construction of wells are used to grow the juveniles. The diameter of the cement rings was 75 cm and 122 cm. The cement ring is covered by velon screen.

The space in the rectangular cage is limited and therefore only small number of juveniles can be reared. The netlon material does not last long in the sea. Netlon with mesh 4 mm becoms brittle and does not last for more than three months. Velon screen cages get blocked, because of the small mesh size. Therefore this has to be periodically brushed. Cement rings last for a very long time in the sea, but the number that can be stocked is again limited. Larger rings cannot be handled due to the weight.

Economics

A tentative expenditure both capital and recurring, investments and economics of sea-cucumber culture is given below :

Hatchery seed production

Total number of tanks required	:	6 (1 tonne capacity)
Stocking rate of auricularia larvae	:	3.75 lakhs/1 tonne tank
Total auricularia stocked in one run	:	1 million
Expected percentage production of juveniles (10%)	:	1 lakh
Survival of juvenile at the end of 18 months in the sea	:	40%
Net production of harvestable sea-cucumbers	:	40,000

Capital expenditure

		Rs.
A.	*Building and tanks*	
	Hatchery shed with light roofing (30 m 10 m)	1,00,000
	Room for Generator/Compressor (27 sq. m @ Rs. 500/- per sq. m.)	13,500
	Seawater sump 14 sq. m. @ Rs. 750/- per sq. m	10,500
	Sedimentation tank 8.4 sq. m @ Rs. 750/- per sq. m.	6,300
	Filter bed 4.5 sq. m @ Rs. 750/- per sq. m	3,375
	Pump house 14.6 sq. m @ Rs. 750/- per sq. m.	10,950
	Overhead tank - 10,000 lt capacity	50,000
	Total	1,94,625
B.	*Fibreglass tanks*	
	1 tonne capacity Broodstock/ larval/juvenile FRP tank - 6 nos @ Rs. 5000/-	30,000
	100 lt capacity spawning FRP tank 4 nos @ Rs. 1000/-	4,000
	200 lt capacity mixed culture FRP tank 1 no @ Rs. 1000/-	1,000
	Total	35,000

C. *Major equipments*

10 KVA Generator - 1 no	50,000
Air Compressor - 1 no	10,000
7.5 HP Electric pump - 1 no	15,000
1.0 HP Electric pump - 2 nos	7,000
Microscope, pH meter, Salinometer	15,000
Chemical balance	5,000
Furniture	25,000
ECE Controller, Silica cased impression heater, jumo thermometer	4,000
Air Conditioner - 2 nos	40,000
Total	1,71,000
Total capital cost (A+B+C)	4,00,625

Recurring expenditure

A.	*Interest*	
	On Rs. 4,00,625 @ 15%	60,000
B.	*Depreciation*	
	On building and fibreglass tanks @ 5%	7,000
	On equipment @ 10%	17,000
C.	*Salaries*	
	One Technician @ Rs. 2000/- per month for 18 months	36,000
	Two helpers @ Rs. 500/- per month for 18 months	18,000
D.	*Contingencies*	
	Plastic ware, flexible PVC hoses, glassware bolting silk, etc.	5,000
	Energy cost (Electricity and Diesel)	15,000
	Chemicals	2,000
	Other contingencies	5,000
E.	Maintenance	5,000
F.	Annual lease for land	3,000
	Total recurring expenditure	1,73,000

Realisation of profitability of sea-cucumber produced

Total Sea-cucumber production	40,000 Nos
Cost of each Sea-cucumber	Rs. 20/-
Total amount realised (40,000 x 20)	Rs. 8,00,000
Less: Non-recurring and recurring	
Expenditure (Rs. 4,00,625 + Rs. 1,73,000)	Rs. 5,73,625
Net Profit	Rs. 2,26,375

List of equipments required

Equipment/facility	*Quantity required*
Generator (10 KVA)	1
Air compressor 200 220 1420 RPM 50 HZ SI Rating output 0.75 KW AMP 73	1
Fibreglass rectangular Broodstock/larval juvenile rearing tanks (1000 lt capacity)	6
Fibreglass rectangular (100 lt capacity) spawning tank	4
Fibreglass tank rectangular (200 lt capacity) mixed culture tank	2
Binocular microscope	1
Mixie	1
ECE Controller	1
Jumo thermometer (0-50°C) (For thermal stimulation)	1
Silica cased immersion heater	1
Air-conditioner 2 tonne capacity	2
pH meter	1
Saline-refractometer (Temperature compensated) (0-50°C)	1
Chemical balance	1
Thermometer (0-50°C)	3
Laboratory glassware	
Beaker 10,000 ml	6
Beaker 5,000 ml	6
Beaker 3,000 ml	4
Beaker 1,000 ml	6
Beaker 500 ml	6
Beaker 250 ml	6
Conical flasks 250 ml	5
Oxygen bottles 125 ml	10
Volumetric pipettes (assorted sizes)	10
Burettes (10 ml)	2
Pestridishes (150 mm dia)	2
Embryo cups (50x50 mm)	6
Micro slides with cavity	2
Micro slides (in box)	1
Cover slips (in box)	2
Plankton counting chamber 1 ml capacity	2
Plasticware	
Plastic buckets (15 lt)	6
(5 lt)	6
(3 lt)	6
Basins (20 lt) capacity	6
Polyethylene flexible hoses (20 mm dia)	10 m

PVC Pipes (150 mm dia for sieves)		6
Polythene sheets (for mixed algal culture)		10 m
Bolting silk cloth	40 microns	1 m
	80 microns	1 m
	140 microns	1 m
	180 microns	1 m
	200 microns	1 m
Volen screen	1 mm mesh	30 m
	4 mm mesh	30 m
Tank cover cloth (Black)		30 m
Nylon rope (2 mm)		10 kg
Nylon rope (5 mm)		10 kg
Casurina pole (3 m length)		50 nos
Sea water draining distribution gride made of 50 mm and 25 mm grid PVC Pipelines and valves		as required
Aeration grid made of 25 mm rigid PVC pipelines with copper nozzles, 5 mm polythene tubes, plastic 'T' joints and regulators and diffuser stones		as required

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