PERSPECTIVES IN MARICULTURE

Editors

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Integrated coastal mariculture, seafarming and stock proposal of a project concept for adoption in the Gulf of Mannar and the contiguous sea areas

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ABSTRACT

An integrated system of marine polyculture of shrimp with Gracilaria, *pearl oyster and sea cucumber is proposed here through this project concept for adoption to help revive the shrimp farms suffering from the problems of white spot disease and intense slush formation in the pond bottoms on account of intensive monoculture practices. The project proposes introduction of floating, mobile, motorized sea farm platforms made of four artisanal boats each, which will function as a seafarming-cum-fish aggregating-cum-fishing device. Also included in the project is the construction of artificial reef complexes made of triangular concrete modules in order to create habitats for the colonisation of commercial fish stocks. The seafarming-cum-seafishing platforms can function dependent on or independently of the artificial reef complexes. Conversion of the existing surplus boats in the Indian fishing fleets into such platforms seems to be the only means of rehabilitating the idling, unproductive boats and the fishermen. A multipurpose marine hatchery complex is included in the project to produce seeds of all the target candidate species for sea ranching in the artificial reef sites, for meeting the seed requirements of the project's onshore polyculture farm and of the seafarm, and supply for onfarm trials in the adopted farms. The project facilities and infrastructure should focus mainly on the popularisation of ecofriendly marine polyculture practices, which alone could make coastal aquculture and seafarming viable in the long run.*

Introduction

According to the Coastal Regulation Zone (CRZ) Notification of India dated the 20th February 1991, hatcheries can be established in the permitted areas within the CRZ of 500 m distance inland from the hightide. The Supreme Court of India in its judgment dated the 11th December 1996 has permitted traditional and improved traditional systems of shrimp aquaculture within the CRZ. However, there is no bar on land-based mariculture beyond the 500 m distance from the hightide.

Seafarming is virtually a new activity in India, despite the enormous potential, especially for seafarming in conjunction with seafishing by the artisanal fishermen. A number of community artificial reefs have been constructed along the southwest coast of India for the benefit of the artisanal fishermen over the last fifteen years. Floating polyculture seafarms can function either as integrated system with the artificial reefs or quite independently of them. Floating seafarms are mobile and hence can be stationed anywhere in the sea where there are optimum conditions of weather and productivity, and they would seldom come in conflict with seafishing operations. Floating, mobile seafarms, apart from being mariculture platforms, also serve as fish aggregating devices and as platforms for fishing operations from aboard, using ecofriendly, low-energy fishing gears.

Intensive mechanized fishing operations in India have substantially reduced the catch per unit effort, and in many instances, declined the stocks, over the last two decades. This situation warrants stock amelioration and enhancement through artificial reef construction coupled with searanching.

Coastal shrimp aquaculture along the east cost of India during the last ten years indicates that the whitespot disease problems affecting semi intensive systems of farming could be effectively solved by resorting to improved extensive or semi-intensive systems of polyculture with shrimps, pearl oysters, sea cucumbers and seaweeds as the integrated components of the same production system.

Therefore this proposal seeks to establish an integrated system comprising an artificial reef complex, a fleet of floating mobile sea farms, a multiple marine hatchery and an R&D polyculture mariculture farm to help restore the overexploited marine fish stocks, to facilitate adoption of seafarming-cum-seafishing practices by artisanal fishermen, to help revive the shrimp monoculture farms through the adoption of ecofriendly mariculture polyculture, to undertake stocking of backwaters with certain finfish seed, and to help promote scampi culture in natural freshwater ponds through the supply of seed produced in the multipurpose marine hatchery.

Integrated coastal mariculture in pond system for transforming shrimp monoculture into polyculture

International experience in tropical coastal shrimp aquaculture in the last one to two decades has clearly established that monoculture of shrimps in semi intensive to intensive systems cannot be sustained beyond a few crops because of rapid accumulation of organic wastes in the production ponds during the crop period itself, and the stress it imposes on the shrimp stocks and the viral disease that manifest following this condition.

It is clear that polyculture with shrimps, bivalves, sea cucumbers and seaweeds as the candidates in the right combinations and right stocking densities, seems to have the potential to provide a lasting solution to the ills of commercial shrimp monoculture systems. However, a suitable polyculture package does not seem to be readily available although this is being carried out in different ways in different countries after the collapse of shrimp farms in Taiwan, Thailand, Indonesia, Malaysia and parts of China. The polyculture ponds should, however, be properly prepared with impervious bottom lining (e.g., silpaulin sheets, costing only Rs.3 per sq.ft.) and biocrete (mixture of cement, sand and palm fibre) slabs on the inside of the dykes so that there is absolutely no formation of sludge during or at the end of the crop (Boyd and Quaitoz, 1997).

Among these four groups of candidates - shrimps, bivalves, sea cucumbers and sea weeds - the shrimps, sea cucumbers and sea weeds are compatible among themselves. If optimum balance could be maintained between the biomass of shrimps and seaweeds, the latter would be able to effectively utilize the organic wastes from the former for their nutrients, and hence, there would be only very minimum accumulation of organic matter at the pond bottom and margins, which will be cleaned up by the sea cucumbers. The resultant oligotrophic conditions would impoverish phytoplankton, rendering the system unsuitable for the bivalves. However, some minimum stocks of clams, mussels and/or pearl oysters may also be kept in the system if and when plankton algae develop, in spite of the seaweeds. Since the spores from the seaweeds (e.g., *Gracilaria*) form a substantial input into the ponds, these spores should be able to sustain a certain level of bivalves (e.g., the commercially lucrative pearl oyster) in the system even if there is no significant stock of phytoplankton. In this method of polyculture, cut pieces of *Gracilaria* are uniformly spread at the pond bottom. In exclusive pond culture of *Gracilaria* the pond is manured with 3kg urea per week per ha and 16 to 180kg fermented pig manure per ha 2 or 3 days after every water exchange (RAPA, 1986). Recent studies on marine polyculture include Newkirk (1997), Qian *et. al.* (1996), Rijin (1996) and Shpigel and Neori (1996).

It is necessary to promote the concept of coastal mariculture polyculture into a commercial practice throughout the tropical-subtropical world to help revive the collapsed shrimp monoculture farms and to transform coastal aquaculture into an ecofriendly proposition. Towards this objective, the available information on coastal mariculture polyculture in the tropical-subtropical region needs to be collated and a sound R&D system created for practicing polyculture on a pilot to commercial scale in order to refine it further and transfer it as a sound package to various target groups to bring about economically and environmentally sustainable coastal aquaculture.

The integrated coastal mariculture polyculture system described above is meant for the existing earthen shrimp farms where the individual ponds are larger in size ranging from about 0.5 ha to 1.0 ha, sometimes even upto 2.0 ha or more. These ponds are constructed invariably below the ground level with only the dykes raised above it. The drain canals, in level with the pond bottom, from the individual ponds join the common drain, dug much below the ground level, which ordinarily opens directly into an estuary or the sea. The requirement of a stabilization pond of a size of about 10% of the total farm area for farms exceeding 5 ha area, has created the opportunity to store farm effluents for treatment and use for secondary (integrated) aquaculture practices.

The shrimp stocking density in the monoculture system recommended by the Aquaculture Authority (1999) of India is only 40,000 to 60,000 seed per ha, but in the Taiwanese polyculture with *Gracilaria*, the shrimp stocking density is much less at 10,000 to 20,000 seed per ha. There is no aeration in either of these systems, but there is water exchange and artificial feeding. The returns in the Taiwanese polyculture with seaweed are three times that in monoculture. Therefore, it is obvious that a polyculture system with increased shrimp stocking densities at different rates (say, 100,000; 200,000; 300,000 etc. per ha), sea cucumber seed (say, 20,000; 40,000; 60,000 etc. per ha), vegetative cut pieces of *Gracilaria* (say 4000kg; 8000kg; 12,000kg etc. per ha) and (optional depending on the availability of planktonic algae) pearl oyster spat (10mm size say 100000; 200,000; 300,000 etc. per ha) and/or adult pearl oyster (40 to 60mm) (unimplanted and/or implanted) (say 50,000; 100,000; 150,000 etc. per ha) supported with proper aeration, water exchange, formulated shrimp feed and fertilizer for seaweed, could be expected to yield very rich economic dividends, much beyond that from even intensive shrimp monoculture systems. At the above rates of stocking, the per m^2 stocking works out to figures shown below in Table 1.

Table 1. Coastal mariculture polyculture: Stocking density, yield and income (only one crop is recommended per year as the remaining part is meant for pond preparation and maintenance)

(1)	(2)	(3)	(4)	(5)	(6)
Crop duration in months	Candidate species	Stocking density per m^2	Stocking density per ha	At harvest @ 80% survival in a ha pond = No.xAv.Wt (g)=kg	Revenue per ha-crop = yield in kgxRs/kg
5	Shrimp	L1 = 10	100,000	80,000x20 = 1600	1600x500 = 800,000
		L2 = 20	200,000	160,000x20 = 3200	3200x500 = 1,600,000
		L3 = 30	300,000	240,000x20 = 5800	5800x500 = 2,400,000
2	Sea cucumber	L1 = 2	20,000	16,000x200 = 3200	3200x100 = 320,000
		L2 = 4	40,000	32,000x200 = 6400	6400x100 = 640,000
		L3 = 6	60,000	48,000x200 = 9600	9600x100 = 960,000
4	* Pearl oyster	L1 = 10	100,000	80,000 - -	80,000(No.)x4=320,000
	spat (optional)	L2 = 20	200,000	160,000 - -	160,000 (No.)x4=320,000
		L3 = 30	300,000	240,000 - -	240,000(No.)x4=960,000
6	Implanted adult	L1 = 5	50,000	40,000 - -	10,000x200=2,000,000
	pearl oyster	L2 = 10	100,000	80,000 - -	20,000x200=4,000,000
	(optional)	L3 = 15	150,000	120,000 - -	30,000x200=6,000,000
3 to 5	Seaweeds:	L1 = 0.4kg	4,000kg	12,000kg - -	12,000x10 = 120,000
	Gracilaria	L2 = 0.6kg	6,000kg	18,000kg - -	180,000x10 = 180,000
	or *Gelidiella*	L3 = 0.8kg	8,000kg	24,000kg - -	24,000x10 = 240,000

* 25% of column (5) is taken as Grade A pearl of 3 to 6mm dia at an average of Rs.300/- per pearl. There are good land - based pearl culture prospects throughout the Indian coast.

Note: These stocking densities are only tentative figures, which will have to be confirmed and suitably altered based mainly on organic waste generation and utilization and dissolved oxygen concentration. The shrimp feed input and intensity of aeration will depend on the shrimp biomass and the DO content. The periodicity and magnitude of water exchange will also be standardized based on the actual requirements.

Table 2. Economics of mariculture polyculture in a one ha pond

Column (1)	Column(2)			Column(3)		
	Total revenue per ha per crop (Rs.)			Operating cost per ha per crop (Rs.)		
Level of stocking	L1	L2	L3	L1	L2	L3
1. Shrimp	80,000	1,600,000	2,400,000	Seed 50,000	100,000	150,000
				Feed=128,000	256,000	380,000
2. Seacucumber	320,000	640,000	960,000	Seed 40,000	80,000	120,000
3. Pearl oyster spat	320,000	640,000	960,000	Spat 80,000	160,000	240,000
4. Implanted oysters (pearl)	2,000,000	4,000,000	6,000,000	Oyster 200,000	400,000	600,000
				Bead= 200,000	400,000	600,000
				Surgery= 50,000	100,000	150,000
5. *Gracilaria*	120,000	180,000	240,000	Vegetative cut pieces=20,000	30,000	40,000
Total	3,560,000	7,060,000	10,560,000	768,000	1,526,000	2,280,000 (Note 1)
				ELGS 700,000	700,000	700,000 (Note 2)
Total cost	1,468,000 or $3.5x10^6$	2,226,000 or $7.0x10^6$	2,980,000 or $10.5x10^6$	or $1.5x10^6$	or $2.3x10^6$	or $3.0x10^6$
Profit before tax				$2.0x10^6$	$4.7x10^6$	$7.5x10^6$
Rate of return (% profit to total cost)				133%	200%	250 %

Note 1 : Basis for calculation of operating cost per ha per crop:

		L1	L2	L3
1. Shrimp				
Cost of seed @ Rs.0.50 per piece	:	50,000	100,000	150,000
Cost of feed @ Rs.40.00 per kg.	:	128,000	256,000	384,000
2. Sea cucumber seed	:	Rs.2/- per seed		
3. Pearl oyster spat (10mm size)	:	Rs.0.25 per spat		

4. Implanted oyster:

Cost of oyster @ Rs.4/- per oyster

Cost of bead @ Rs.4/- per bead

Cost of surgery @ Rs.1/- per oyster

(one technician can operate about 100 oyster per day)

5. *Gracilaria*: Cost of seed material (cut vegetative pieces) @ Rs.5/- per kg.

Note 2. Common cost for a one ha pond per year:

1. Electricity @ Rs.25,000 per month for 12 months for a one ha pond (E) - Rs.300,000/-
2. Labour @ Rs.100 per day for 5 labourers per day for 350 days for a one ha pond (L) - Rs.182,500/- rounded off to Rs. 200,000/- per year
3. General maintenance cost for a one ha pond per year (G) - Rs.100,000/-
4. Servicing capital cost of Rs.300,000 per ha (S)

Interest @ 20% per year = Rs.60,000
Depreciation @ 10% per year = Rs.30,000

Total Rs.90,000 or 100,000

Cost on account of 1+2+3+4 (i.e., E+L+G+S) = Rs. 700,000 per year

In this polyculture system, two alternative systems have been recommended above: (1) shrimp, sea cucumber and seaweed with or without pearl oyster, and (2) shrimp, sea cucumber and pearl oyster with or without seaweed. However, both these systems should operate simultaneously, side by side, in two adjacent ponds, each of one ha area, so that the seaweeds and/or pearl oysters could be exchanged between them based on the intensity of microalgal populations in each.

Moreover, in such a simultaneous system, after the successive harvest of the crops in the time sequence of 3 to 5 months for seaweeds, 4 months for pearl oyster, 5 months for shrimps, 6 months for pearl and 12 months for sea cucumber, after the harvest of the pearls in the 6^{th} months, the sea cucumbers could be shifted to the adjacent pond, so that 3 to 6 months of pond preparation by drying, filling and sufficient exposure to sun could be facilitated.

It is however not necessary to allow as long a period as 6 months for this purpose, but the period required for the establishment of optimum pond hygienic conditions should be allowed, and once optimum conditions are established, the operations could be restarted.

Thus, in this simultaneous alternative system, any number of pairs of ponds (one for alternative one and the other for alternative two) could be envisaged depending on the scale of investment and the availability of all the basic resources required for polyculture.

Intensive integrated coastal mariculture polyculture in nonearthen smaller tank systems

The polyculture system described in the above section above is basically an improved traditional (extensive) to semi intensive practice considered to be ideal for earthen ponds of about 0.5 to 1.0 ha size each, where the waste from the shrimp component forms the input to the seaweeds and sea cucumber, thus improving pond hygiene as well as productivity. In such large earthen ponds intensive system has been found to be difficult or impossible because of the limits to the carrying capacity of the system without proper flushing of the surplus wastes and metabolites.

Studies at the Mandapam Regional Research Centre of the Central Marine Fisheries Research Institute, India and elsewhere in many Western and southeast Asian regions in both freshwater and marine intensive aquaculture systems including raceways, constitute the basis for the intensive raceway-type polyculture in nonearthen smaller tanks, proposed here.

The system consists of a series of smaller tanks, each of 2.5m length, 1.5m width and 1.0m depth (3.75 ton capacity), made of concrete flooring with brick wall or seasoned mango wood with epoxy coating inside. The bottom of the tanks slopes from the centre at a height of about 8cm towards the length side to 0 cm, and there are four exit holes (2.5cm dia.) on each of the length side at 0-cm level. The exit holes are connected to PVC pipes, which in turn are connected to vertical pipes of 1.0m height by means of a gooseneck outside so that drainage could be regulated according to needs. The advantage with the wooden tanks is that they could be shifted from one location to any other location by means of a small crane and a trolley.

A polyculture unit of 100 such wooden tanks for crop production in

10 rows of 10 tanks each with a distance of one metre distance between tanks to provide space for drainage and logistics (manual operation of and access to tanks, movement of people etc.,) is proposed here to serve as a compact R&D unit for practicing the polyculture technology, refine it and transfer it as a sound package to different target groups.

The polyculture unit has a downstream effluent reservoir and an upstream phytoplankton production system of three ponds. The effluent reservoir is about 400 ton capacity (20mx20mx1m) to store about 375 t plus (100 tanks x 3.75t=375t) effluent almost continuously draining into it from the 100 crop production tanks through a common drain pipe, leading vertically down to the bottom of the effluent reservoir (so that the fecal wastes in the effluent do not pass on as such through the surface exit into the plankton ponds). The effluent reservoir is provided with a bottom outlet for complete draining, when required.

The effluent reservoir is connected to two tanks of 200t capacity each (two tanks with a common wall) upstream (built below the ground level in level with the effluent reservoir) for plankton production, through a surface exit from the former to facilitate surface entry of the treated effluent.

A plankton feeder tank of 200t capacity is built with a common wall to both the plankton production tanks, which could be opened into the former through a surface pipe, as and when required, alternately depending on which of the two plankton tanks has reached the required level of bloom. All the three plankton ponds are provided with bottom outlets for complete draining, when required. The operation of the system begins with the raising of the desired level of phytoplankton bloom of the right species combination in one of the two plankton tanks by proper manuring (both inorganic and organic), inoculation of the right combination of microalgae from the laboratory-maintained nucleus cultures and intense aeration.

Depending on the conditions created in the plankton tank, the bloom at its peak may attain a density of even more than 2 million cells per ml. It is, however, desirable to keep the density at much less than one million cells per ml. The plankton water is then let into the plankton feeder tank in pulses, and diluted with filtered seawater to reduce the plankton density to about 100,000 cells per ml (the feeding optimum for pearl oysters) at which it is pumped to an overhead tank of about 100 ton capacity. Since the bloom lasts for about 5 days only, the second plankton pond should be simultaneously got ready with the required level of bloom to take over from the first pond, and the cycle thus repeated without break.

In the intensive polyculture proposed in this section, the main crop production unit is meant to be stocked exclusively with implanted pearl oysters (*Pinctada fucata* of 40 to 60 mm sizes). In one square metre area (100cmx100cm) of the tank, 400 oysters of 5cm size can be accommodated by arranging them in 20 rows at the rate of 20 oysters per row. Thus in one tier, for the tank area of $3.75m^2$, 1500 oysters can be stocked. Since the tank depth is one m, leaving 10 cm at the bottom for providing space for the rest of the central slope and 10cm on the top as vacant space, the column of 80cm can be divided into 8 tiers. At the rate of 1500 oysters, the 8 tiers can hold 12,000 oysters. However, in order to provide sufficient space for the individual oysters, each tier may be stocked with only 100 oysters, and thus a total of 8000 oysters per tank. The tiers, made of plastic coated metal mesh of about 2.5 cm mesh, could be held in position with proper catches stitched on to the inside of the tank. Sagging of the tiers could be avoided by providing horizontal and vertical supports at intervals of 0.5m inside the tank.

The tanks are aerated intensely from oil-free air compressors (twin lobe blowers) of required capacity through a system of pipes, tubes and air stones with the air stone terminals hanging vertically down at a distance of 0.5m from each other within the space of each tier. Aeration should be so maintained that the dissolved oxygen is always kept above 5 mg/l. The plankton water showers down constantly through gradient flow from the overhead tank through two or three shower points per tank positioned at a height of about 0.25m above the tank surface. The tank is kept covered with coarse-knit dark netting to shut out direct sunlight falling on the oysters. Free flow of plankton water into the tank is facilitated by providing windows in the netting directly below the shower points. The outflow through the series of bottom holes drains out the excreta, which constantly descend down to the tank bottom due to the impact of intense agitation from the aeration points uniformly in all the eight tiers and the vertical shower effect. If required, fresh seawater may be forced through a hosepipe, manually or mechanically from the top of the tank in different angles to force down the excreta for proper flushing, once a day.

In this system, the volume of inflow of plankton water through the showers and the volume of outflow that drains out are kept constant at the same rate so that the water in the production tanks remains constant at a level of 90 to 95cm. The density of algal cells in the inflow and outflow is checked regularly four times a day in the morning, noon, evening and midnight to monitor feeding activity and to decide the candidates species choice and density for the downstream effluent reservoir to utilize the plankton in the drain.

The effluent reservoir is also kept aerated intensely to help aerobic breakdown of pearl oyster excreta to release the nutrients for the *Gracilaria* stock. The reservoir is divided into two equal halves with a vertical partition of plastic coated metal mesh of about 2.5cm mesh size.

The distal half (i.e., the portion distal to the drain pipe) is stocked with cut pieces of 200kg *Gracilaria* (i.e., @ 5ton/ha) while the frontal half is stocked with pearl oyster spat and adults (unimplanted) in cages (40cm x 40cm x 10cm) in densities matching with the microalgal population, for the supply of adult oysters for implantation and stocking the crop production tanks. The need for and the dosage and periodicity of manuring the effluent reservoir can be decided based on the rate of growth of *Gracilaria* and microalgal density and also the concentration of various micronutrients. The surface outflow from the reservoir is let into the plankton tanks alternately in cycles of about 5 days each depending on which of the two plankton production tanks is in the process of developing bloom.

The biomass of implanted oysters in the production tanks is 240kg including the shell weight (8000 oysters x 30g average weight of oyster) and only 40 kg excluding shell weight (8000 oysters x 5g) for the total tank volume of 3.75m^3, which is much less than the already reported range of fish biomass per unit area in raceway ponds (Lawson, 1995; see

PP 180-181; 60 to 120kg/m^3 for salmonids; in some cases 234kg/m^3 for salmonids; 32 to 64kg/m^3 for catfish; 40kg/m^3 for channel catfish). The technology of onshore pearl culture (monoculture) has been tried at CMFRI. There are however, a number of excellent publications on offshore marine pearl culture and spat production techniques by the CMFRI (Dharmaraj *et. al.*, 1991; James *et. al.*, 1992).

Integrated system of an artificial reef, searanching (stock enhancement), seafarming and seafishing complex

The seafarming platform proposed here is made of four used (secondhand) artisanal fishing boats of about 30' or 40' or 50' length each, rigged together into a single structure. The boats are joined into pairs, with each pair separated from each other by a distance of about 15m (for a platform of 15m length) but connected by means of alternating horizontal wooden planks and painted steel rods across a quadrapod built into the proximal boats of the two pairs. The rods are used for hanging vertical nylon ropes seeded with implanted pearl oysters or mussels or *Gracilaria*, one alternating with the other. The seeded ropes are first covered with a knitted cotton banian cloth (which will decay and disappear in about 10 days) to hold the seed in position, and then with a very loose nylon netting bag of 15 to 25 mm mesh, and the ropes hung down into the water column from the metal rods. The wooden planks facilitate easy movement of men and material across the platform for operational purposes. Vertical ropes carrying series of mud pots or plastic pots could be hung down from the rods for the purpose of collection of peuruli (youngones) of rock lobsters for mariculture purposes in the onshore polyculture system. The two distal boats in the two pairs of boats can be properly roofed with side ventilation, doors and windows for accommodating men and storing material. A pulley is also provided in the quadrapod for operating the seeded ropes. Two outboard motors each of about 20hp are fitted, one on either side, to move the platform mechanically rather gently from place to place.

The platform can be positioned right above or on the immediate sides of the artificial reef. The number of sea farm platforms per peer group can be decided based on the area occupied by the reef and the number of stakeholders in the system. Since the farm platform itself is an artificial reef or a fish aggregating device (FAD), the occupants of the platform can operate various fishing devices such as hooks & lines, jigs and traps for fishing from this platform, besides attending to the maintenance and management of the crops held in the ropes.

The advantage with this type of sea farm platform is that it need not necessarily be operated in integration with the artificial reef as a community property, but also be operated independently of and away from artificial reefs by individual owners, and above all, it can be moved to any desired locations depending on where optimum conditions of weather and productivity occur. Thus, the potential for legal conflicts likely to arise in fixed sea farm platforms does not exist with this mobile sea farm. The fishermen onboard the platform, by regularly exploiting the fish aggregations, can generate good daily income for their sustenance as well as for the maintenance of the farm. Therefore, this dual system has immense potential for creating wealth among fishermen, if it is popularised through intensive demonstration, training, government subsidy and awareness creation, and open a new revolutionary chapter in marine fisheries throughout the tropical and subtropical world. Since the sea farm will have to remain in the sea for the entire crop duration, it should deploy a carrier boat to take the catches ashore and to bring in supplies daily.

In a sea farm platform installed, say at a location where the depth is 20m, the vertical ropes carrying various crops can hang down to a depth of upto 18m from the surface. A platform made of four boats, each of 50 ft length (15m) can have a quadrapod of 10m length (with 2.5m free board on either end). Which can be fitted with 10 wooden planks, each of 0.5m width, at 0.5m intervals and 10 plastic coated metal rods of 4 cm diameter in between the wooden planks, to carry the seeded ropes of 18m vertical length each. Since the effective distance between the 2 pairs of boats is 15m (at 1:1 ratio with the overall length of the platform), each rod can be stocked with 10 seeded ropes at intervals of 1.5m, and thus the carrying capacity of the platform can be fixed at 100 crop ropes, giving a total running length of 1800m at the rate of 18m per crop rope.

Depending on the availability of seed material, pearl oysters, mussels and *Gracilaria* can be stocked in individual ropes exclusively and hung in sets of 3 ropes, the first for pearl oysters, the next for seaweeds and the third for mussels, with the sets alternating in the same sequence to the full distance of the rods. The carrying capacity of an 18m rope (of 20 to 25mm diameter) is: (i) about 1080 implanted pearl oysters (1800cm rope length divided by 5cm vertical extent of each oyster row x 3 oysters per row) weighing about 30kg (at the rate of about 30g per oyster at implantation), (or) (ii) about 2340 adult mussels (18m rope length x 130 adult mussels per m of rope), weighing about 175kg (at the rate of about 75g per mussel of about 70mm length) after about 6 months of seeding with young mussels of 15 to 20mm length at the rate of about 0.6kg seed material per m rope length, (or) (iii) about 80kg *Gracilaria* (at the rate of about 0.32kg per m length).

Thus, the seafarm will have a total biomass load of 10,065kg consisting of:

(i) about 1080x33ropes
35,643 implanted oysters weighing 50kgx33 rope= 1650kg (plus)
(the oysters are assumed to have grown from a weight
of 30kg to 50kg per rope in 6 months)

(ii) 2340x33 ropes
77,220 mussels weighing 175kgx33ropes =5,775kg, (plus)

(iii) 80kg *Gracilaria* x 33ropes = 2,640kg

Since the platform has been got rigged with proper balance and ratio between its length and width (including the farming space between the 2 pairs of boats), it should be able to carry a weight of about 10 tons of biomass in the seawater medium at ease without undue stress. The ropes carrying pearl oysters should be covered with a black top, while the other ropes should be left free.

Sunlight required for the seaweed would be available at optimum levels as the platform floats in the euphotic zone. Only the ropes seeded with pearl oysters and mussels are required to be initially covered with knitted cotton banyan cloth and then covered with loose nylon netting bag of about 2.5cm mesh. After a few days these bivalves form fresh bysses threads, holding on to the ropes tightly, while the loose outer bag provides sufficient growing space as well as protection (the cotton cloth gets decayed after about 10 days). The seaweed ropes, after seeding the bits between the twists of the ropes, are covered with the loose nylon netting bag of the same 2.5cm mesh size so that the outgrowing branches (thalli) are able to freely protrude outside through the mesh for proper exposure to sunlight and nourishment from seawater. Two crops could be harvested at intervals of 3 months, the basal portions remaining between the twists of the ropes after the first harvest, forming the seed material for the second crop.

The economics of an artificial reef complex formed of 10 reef groups, each of 50,000m³ size (One group occupying 4.43ha, and hence, one complex of 10 groups, with a distance of about one km between two groups, occupying 44.3ha), and a fleet of 100 mobile sea farm platforms floating above this complex at the rate of 10 per one group reef (the space occupied by each sea farm platform is 15mx15m=225m^2 and hence for each group reef, the area occupied by a fleet of 10 platforms is = 10x225=2250m^2 which is about 1:2 ratio with the area of 4.43ha occupied by one group reef), will workout quite attractive.

Benefits to the country (India) and others willing to adopt this project

1. Mariculture polyculture in coastal farms of large earthen ponds

Economic revival of shrimp farms of over 120,000 ha area will take place by the adoption of polyculture of high value crops of shrimps, pearl, sea cucumber and *Gracilaria*. Polyculture eliminates shrimp white spot disease by reducing the organic load of excreta and feed remnants to most minimum and very safe levels. Coastal polyculture is ecofriendly and ensures very high ecosystem quality. The revival of the currently cultivated farms alone through polyculture would yield over 240,000 ton shrimp at the rate of 2 ton per ha per single crop, and substantial quantities of marine cultured pearl, sea cucumber and *Gracilaria*. Consequently, the export of shrimp and beche-de-mer would increase and the Indian demand for pearl and *Gracilaria* would be met to a great extent. India is annually importing pearl worth over Rs.400 million and there is acute shortage of *Gracilaria* for the existing agar plants.

2. Mariculture polyculture in coastal farms of small nonearthen tanks

Technology is innovative, production intensive and revolutionary, while at the same time, it is absolutely ecofriendly. It is comparatively much less capital intensive, but produces high value commercial crops like pearl and shrimp mainly, and other important crops like sea cucumber and seaweed (*Gracilaria* and/or *Euchema*. The exotic *Euchema*, being cultured at Mandapam Camp and Bhavanagar by the Central Salt and Marine Chemicals Research Institute, grows extremely fast under Indian conditions).

It requires only medium size capital, but round the clock care of the system is absolutely essential. The income and profits per unit cost are incredibly very high, and the technology has all the worth and merits for patenting.

3. Floating mobile sea farms

This is yet another technology which is perhaps more innovative, production intensive and revolutionary (than the one described under (2) above) while at the same time it is absolutely ecofriendly as well as sociofriendly in that it carries no potential for conflict with fishing or for legal problems of ownership characteristic of fixed sites, by virtue of the free mobility of this type of sea farm (like a mobile fishing vessel).

The crop chosen (like in their land-based counterparts described under (1) and (2) above) are filter feeders (pearl oyster and mussel) or autotrophic (seaweeds) and hence require no cost input on account of feed. The important added advantage is that these sea farm platforms are fish aggregating devices by themselves, and hence, can serve as fishing platforms as well, for facilitating which, the platform has been so innovatively and conveniently rigged. They can operate dependent on or independently of artificial reefs. The technology of floating mobile sea farm is worthy of patenting.

4. Artificial reef complex

There are innumerable instances of damages inflicted on the marine benthic ecosystem by intense trawling and stock depletion by overexploitation. Artificial reefs erected on terrains away from natural reefs act as strong deterrents to trawling and provide secure habitations to a chain of biota culminating at apex carnivores. The biomass accumulation is so rapid that the increase in catchers becomes quite significant. The use of low cost passive artisanal gears, benefits the small fishermen to a great extent. The establishment of a large reef complex and artisanal fishing activity in the reef site, through this project would pave the way for speedier expansion of this programme through government investments and fisher folks participation throughout the Indian seas as in Korean waters.

The current gap of 1.2 million ton between India's current annual marine fish catches (2.8 million ton in 1999) and potential (4.0 million ton) could be bridged mainly through stock aggregation (coupled with stock enhancement, where necessary and possible). Besides aggregating stocks, artificial reefs facilitate stock enhancement also by affording protection to prerecruits from predators and breeding sites for many stocks like the reef cods, rock lobsters, squids, cuttlefishes and many others. The current gap of 1.2 million ton is worth about Rs.60,000 million at Rs. 501kg. Restoration of marine ecosystems through the creation of artificial habitations brings back to full vigour the benthic biota lost due to destructive fishing practices, and serve as *in situ* biodiversity gardens.

5. Searanching (stock enhancement)

Searanching in the past has been a low key, very irregular activity in India, carried out on experimental scales by the CMFRI for the stocks of *Penaeus semisulcatus* in Palk Bay, pearl oyster in the Gulf of Mannar and clams in the Vembanad lake. Stocking seed of commercial species produced in hatcheries, in the sea has paid rich dividends in many parts of the world, mainly in the developed countries.

Although searanching is costly, requiring huge multipurpose hatchery complexes to produce massive number of seed of commercial species, the economic gains to the fisherfolk and the country, largely due to the savings on the cost of feed, electricity, labour, security etc., spent on farming are enormous. Significant increases in the catches, in some instances doubling of shrimp catches, from enchanced stocks have been reported from many countries. For instance, the doubling of shrimp catches from the Indian waters would more than double the present export earnings. Adult pearl oysters from augmented stocks of pearl oysters in their natural beds or in the artificial reef sites, can be exploited on a sustained basis for pearl culture in shore farms, floating sea farms and in artificial reef sites themselves.

6. Multipurpose marine hatchery

India has gained considerable expertise in marine hatcheries with respect to shrimps, with over 170 commercial hatcheries producing annually over 10 billion seed. Indian laboratories have perfected the technology of commercial seed production of marine bivalves, sea cucumbers and sea bass that are yet to be adopted by the industry. Serious research effort is on for the perfection of hatcheries for other marine resources like groupers, snappers, breams, rock lobsters and abalones.

Scampi hatchery technology is fairly well developed in India, but hatchery production of seed is still grossly inadequate, meeting less than one percent of current demand. Diversification of the species base of Indian aquaculture with the addition of high value stocks and searanching the vast Indian seas, require a large number of multipurpose marine hatcheries. The hatchery complex proposed in this project is expected to pave the way for the establishment of the required number of hatcheries and the development of technologies for those species for which technology is either imperfect or absent.

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