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Evolution of eco-friendly coastal aquaculture/mariculture technologies

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ABSTRACT

Global aquaculture production from marine waters, which accounts for 54% of total production, increased from 6.86 million metric tonnes in 1987 to 18.51 million mt in 1996, registering an increase of 270% over the decade. India's marine/coastal aquaculture production is almost restricted to shrimps, as the production of marine finfishes, molluscs and sea weeds are negligible. An index of Biodiversity Utilization for Aquaculture (BUA) calculated for India is quite low (0.13) when compared to the highest (0.51) for Taiwan and Korea (RoK).

India's coastal aquaculture technologies for marine organisms, such as shrimps, crabs, lobsters, mussels, edible oyster, pearl oyster,

sea bass, mullet and milkfish, Gracilaria *and holothurians are yet to spread out. Serious efforts are needed to develop more applicable eco-friendly technologies and improved extension system to propagate them, and perhaps also through transfer of technologies from our Asian neighbours, who have proven expertise in specific areas. It is important, however, to overview and ensure that all the existing and newly introduced technologies are suitably modified, so that they are environment friendly and socially acceptable.*

More recent researches have shown that improved management practices can ensure pollution-free and disease-free culture systems. It is also necessary that besides technological considerations, environmental and socio-economic considerations according to laid-out plans and policies, and effected through discussion and dialogue among all the stakeholders of the aquaculture ventures, should take place, sufficiently early as a part of pre-siting / siting exercise. This should involve also the various sectoral interests in the coastal zone so that aquaculture development would blend in harmony with the other concomitant sectoral developments of the eco-system primarily and the region, as is envisaged in an integrated plan for coastal area development.

Introduction

The aquaculture/mariculture production from marine waters has increased from 6,863,270 metric tonnes (mt) (51% of the total aquaculture production) in 1987, valued at 10.95 billion US$ to 18,609,269 mt (54% of total production) in 1996, valued at 25.80 billion US$, showing an increase of 270% in quantity and 236% in value, over the decade, on the basis of production of all farmed aquatic organisms (FAO, 1998). Eco-friendly aquaculture/mariculture systems, are the present need as a stage has reached in aquaculture development where the impacts of some aquaculture systems have affected and/or will soon affect, if unchecked, the ecology/environment of the aquaculture sites. Besides, these ecological impacts would be accentuated by the socio-economic impacts of the culture activities (Lin, 1989; FAO/NACA 1995; Kutty, 1997, 1998, 1999a). It is largely true that this situation is reflective presently of mainly shrimp culture, around the tropical and semi-tropical belt of the world, but mainly of Asia and the Lain American countries.

The fear of the collapse of shrimp culture began with that of Taiwan (Lin, 1989), followed by partial collapses of farmed shrimp production in China, Indonesia, Thailand and Philippines among other countries (FAO/NACA, 1995). The collapse of shrimp culture was owing mainly to the lack of understanding of the impacts of the lucrative shrimp farming and its over-exploitation and abuse of the sensitive coastal environment/eco-system and also the socio-economics of the communities around the farms. This has given rise to the different types of reactions, at one end the puzzled farmer/entrepreneur trying to re-establish the collapsed or collapsing system, avoiding environmental degradation, which caused bursts of uncontrolled diseases in his site, and at other end, serious criticism of the environmentalists, social workers and other vested interests. The latter eventually, in the case of India, lead to the intervention of the Supreme Court India (1996). The SCI banned semi-intensive and intensive aquaculture in the 500m belt along the coasts of India. Virtually this left out only the least producing system, the traditional and extensive, of coastal aquaculture to be continued. Obviously this system is sustainable, but would it be able to produce adequate quantities of shrimp and fish, for nutritional needs of country, and also the needs of an expanding aquaculture sector, bringing considerable economic benefits to the country - to the farmers and the community - and also poverty alleviation through employment and other benefits to the people?

It is paradoxical, that despite some initial collapses, countries like Thailand and China have reacted differently to the above described situation - in that subsequent to initial environmental and socio-economic problems, they have developed new culture technologies to overcome the previous lapses. Thailand has come to an understanding of the problems and has come to set a code of conduct for shrimp culture (Tookvinas *et al.*, 1999 as advised in FAO, 1997) and their shrimp production still maintained at a high level (211,100 mt in 1997, in spite of a small decline a few years ago, FAO, 1999), as world's top producer of farmed shrimp, which ultimately paved the way for an eco-friendly shrimp culture system on a sustainable basis.

The sustainability of aquaculture has been discussed in various national and global fora, the latest being NACA/FAO aquaculture of the Third Millennium Meeting at Bangkok (NACA/FAO, 2000, resulting in the "Bangkok Declaration on Aquaculture Development"). Other references on discussions on sustainable aquaculture can be seen in Kutty (1999a, 1999b). I have pointed out here a most serious problem facing aquaculture, shrimp culture in particular, owing to its topical and chronological importance, at the outset itself, but salient aspects of eco-friendly and sustainable coastal aquaculture will be discussed further below on the basis of this and other experiences in the relatively short history of aquaculture.

In the present discussion coastal aquaculture and mariculture will be treated together for convenience, even though one can make some distinctions. Coastal aquaculture has been defined to include all land and water based culture systems in brackish and marine waters in a two kilometre belt in the continental shelf off the coastline, and also in the low lying areas beyond the tidal zone (Nunes and Parsons, 1998). In this context it is interesting to cite Barg (1992), who states: "The coastal area is an interface between land and sea, which extends inland and seaward to a variable extent. The term "coastal area" refers to a geographic space, which has not been defined as a zone. Defining boundaries of a coastal "zone" in a given area ("Zoning") will depend on political, administrative, ecological and pragmatic considerations. "Zoning", i.e., the process of defining the boundaries of a coastal area to be developed and managed, is an essential component of Integrated Coastal Area Management (ICAM)". We shall refer to this again, but as it is the definition of coastal aquaculture would include culture in marine waters as well, which would be restricted to the near shore area. There are only a few examples of real offshore aquaculture, even though one could expect that culture of Atlantic salmon, tunas and a few other new entrants could be the first candidates in this respect. It must be pointed out that in several of these cases, as for the tunas and other scombroids, and even in several groupers, the life cycle has not been closed - the culture being mainly dependent on wild seeds. For the real expansion of the culture of such species it is important as a primary requirement that further studies should be immediately made to close the complete life cycle of the species. This is one of the recommendations of the Aquaculture for the Third Millennium Meeting (NACA/FAO, 2000). More discussion on the species used in aquaculture will follow.

Mariculture, which can be referred to, as culture aquatic denizens in marine waters exclusively, would be different from brackishwater aquaculture, the latter having shares from inland and marine species. The FAO production statistics takes care of this distinction in providing split-up figures for the two components.

The present paper sequentially presents below details of marine aquaculture production - global, country-wise and species group-wise, including as referred to above, a full list of species, categorised by family/order of finfishes, crustaceans, molluscs, seaweeds, and also their respective production figures for 1994 and 1996. We shall also discuss the diversification of aquaculture - the species diversity involved, with examples from some selected countries including India. Some of the major techniques of coastal aquaculture/mariculture have been pointed out and lastly evolution of eco-friendly culture technologies for achieving sustainable production of farmed aquatic organisms discussed.

Some specific examples of attempts to towards sustainable aquaculture incorporating a holistic approach to coastal area development, especially with reference to shrimp farming will be discussed. Much of the descriptions/discussion, which follow are from a global context, except for a few instances such as bio-diversity utilisation in aquaculture, but the experiences/lessons learned from other countries, in a global context are highly pertinent to India, as well as to other developing countries, which have a high stake in aquaculture for food and nutrition, poverty alleviation and other socio-economic advantages. Much of these could accrue from aquaculture development integrated within itself, and with other sectoral activities in the coastal region (Barg, 1992; FAO - Code of conduct on responsible fisheries, 1995; FAO, 1997; NACA/FAO, 2000).

Coastal aquaculture/mariculture production

Global production

The salient aspect of recent increase in production from marine waters has been referred to initially herein. Table 1A gives the details of aquaculture production of all aquatic organisms from marine and inland waters and their proportional changes from 1987 to 1996. These indicate that the percentage increase in production from marine waters is higher (270%) than for inland waters (236%). The relative share of production from marine waters showed that it increased from 51% in 1987 to 54% in 1996.

Table 1A. Global aquaculture production (all aquatic organisms) (in mt.) in marine and inland waters

(Source : FAO, 1998a)

Year	1987 (% of total)	1996 (% of total)	% increase 1987-1996
Marine	6,863, 270	18,509,269	270
	(50.9)	(54.3)	
Inland	6,617,161	15,606,980	236
	(49.1)	(44.7)	
Total	13,480,431	34,116,249	257
		(100)	

Table IB gives the corresponding production for fish and shellfish only (excluding seaweeds and some non-edible species) over the same period. It must be noted that the proportion of marine production is lower here, the main reason being the exclusion of seaweeds. The treatment of statistical information on aquaculture production is being refined by the FAO (FAO, 1999), and different treatments of data obtained by FAO, is reflected herein. Thus Table IC is still different, presenting the same information, but categorised on the basis of environment (aquatic medium) of the species. Here production from brackish water has two components (taken from marine and inland sources), as explained in the Table itself.

Table 1B. Global aquaculture production (fish and shellfish only) (in mt.) in marine and inland waters

(Source : FAO, 1998a)

Year	1987 (% of total)	1996 (% of total)	% increase 1987-1996
Marine	4,018,872 (37.8)	10,772,979 (40.8)	268
Inland	6,616,315 (62.2)	15,606,604(59.2)	235
Total	10,635,187 (100)	26,384,583 (100)	248

Table 1C. Global aquaculture production (in mt.) in 1996 marine and inland waters

(Source : FAO, 1998a)

Environment	All aquatic organisam (% of total)	Fish and shellifish only (% of total)
Marine	17,450,358 (51.1)	9,733,992 (36.9)
Freshwater	15,082,601, (44.2)	15,082, 225 (57.2)
Brackish water	1,583,790* (4.1)	1,568, 366* (5.9)
Total	34,116, 246 (100)	26,384,583 (100)

Leading aquaculture producing regions and countries

Out of a global total production of 32.1 million mt in 1996, Asia accounted for most of it (91,1%), trailed by a wide margin by Europe (4,7%), N. America (1.8%), S. America (1.5%), Africa, Oceania and other countries (former USSR), producing 0.3% in each case (FAO, 1998).

On the basis of overall aquaculture production of fish and shellfish in 1996 (FAO, 1998) the ten leading producer countries are China (17,714,570 mt, accounting for 61% of the global total), India (1,768,422 mt, 7.1%), Japan (829,354 mt, 3%), Indonesia (672,130 mt, 2.5%), Thailand (509,656 mt, 1.9%), USA (393, 331 mt, 1.5%), Bangladesh (390,088 mt, 1.5%), Ro Korea (358,003 mt, 1.4%), Philippines (342,543 mt, 1.3%) and Norway (324,678 mt, 1.2%). An overview of total aquaculture production is needed to understand the relative shares of different categories in production. According to FAO, these comprise seven categories: freshwater fishes, diadromous fishes, marine fishes, crustaceans (all marine, except for a fraction of freshwater crustaceans as shown in the descriptive tables), molluscs (again mostly marine), aquatic plants (almost all marine/ and other aquatic organisms.

On the basis of the magnitude of production of the major categories of framed organisms the leading producer countries have been ranked (Table 2). Here it can be seen that Japan, China and Indonesia are leading producers of farmed finfishes, but it can be seen that the total production under this category is much less than those of the other categories (see also Table 3). China is the lead producer of crustaceans, molluscs and seaweeds (and also freshwater fishes). As reported in FAO statistics for 1996, India's coastal farming concerns shrimps only (this is discussed further herein) and India is listed as fourth in the list under crustaceans.

Table 2. Leading producer contries of marine fishes, crustaceans, molluscs and aquatic plants (seaweeds) in 1996.

(Source : FAO, 1998a)

Quantity in Mt.

Order of production	Country		(% of total country production)
Marine fishes			
1.	Japan	-	247,827 (18.4)
2.	China	-	240,592 (1.0)
3.	Indonesia	-	113,000 (1.4)
Crustaceans			
1.	China	-	236,309 (1.0)
2.	Thailand	-	230,832 (47.3)
3.	Indonesia	-	157,710 (20.2)
4.	India	-	87,527 (4.95)
5.	USA	-	22,430 (57)
Molluscs			
1.	China	-	6,406,595 (27.7)
2.	Japan	-	490,072 (36.3)
3.	France	-	218,178 (76.4)
4.	USA	-	98,183 (25.0)

Seaweeds

1.	China	-	5,419,950 (23.4)
2.	Philippines	-	631,387 (65)
3.	Ro Korea	-	539,995 (60)
4.	Japan	-	520,051 (39)
5.	DPR Korea	-	381,000 (78)

Table 3. Global aquaculture production of marine and brackishwater species/groups

(Source:FAO, 1998a; for details of individual species production for 1994 and 1996.)

Main Groups/ Species		Production in 1996(mt)
Diadromous Fishes		
Sturgeons, paddle fishes	-	1077
River eels	-	216,646
Salmon, trouts, smelts	-	1,072,478
Miscellaneous diadromous fishes (eg:milkfish, seabass)	-	380,396
Sub total	-	1,670,597
Marine Fishes		
Flounders, halibuts, soles	-	198
Redfishes, basses, congers	-	221,504
Jacks, mullets, sauries	-	193,230
Tunas, bonitos, billfishes	-	2,090
Miscellaneous marine fishes	-	192,268
Sub total	-	609,290
Marine Crustaceans		
Sea spiders, crabs	-	119,137
Shrimps, prawns	-	914,706
Lobsters, spiny rock lobsters	-	62
Miscellaneous marine crustaceans (eg:*Artemia*)	-	20,269
Sub total*	-	1,054,174
*(excludes fresh water crustaceans	-	92,630)

Molluscs		
Gastropods		
Gastropods		
Abalones, winkles, conchs	-	3,349
Bivalves		
Oysters	-	3,067,316
Mussels	-	1,179,045
Scallops/pectens	-	1,275,958
Clams, cockles, arkshells	-	1,777,543
Cephalopods		
Squids, cuttlefishes, octopuses	-	1
Miscellaneous molluscs	-	1,196,023
Sub total*	-	8,499,235
*(excludes fresh water mollusca-11,821)		
Seasquirts and other tunicates	-	12,672
Miscellaneous aquatic invertebrates	-	13,550
Seaweeds/other acquatic plants		
Brown seaweeds	-	4,583,690
Red seaweeds	-	1,680,733
Green seaweeds	-	47,673
Miscellaneous aquatic plants	-	1,419,370
Sub total	-	7,731,466

Global farmed shrimp production

Global shrimp culture production for the period 1988 to 1997, taken from FAO (1999) is given in Table 4. It increased from 576,453 mt in 1988 to 941, 814 mt in 1997, but the peak of 101, 583 mt is reached in 1995, showing a plateau for the period 1995-1997. This indicates a slowing down of farmed shrimp production as also seen in shrimp culture production in India (Table 5), owing to recent catastrophes in shrimp culture as described herein elsewhere.

Table 4. Global shrimp culture production (t) for 1996

(Source: FAO, 1999)

Year	1988	1989	1990	1991	1992
Produce	576,453	620,502	671,997	832,678	889,678
Year	1993	1994	1995	1996	1997
Produce	847,697	690,385	951,593	949,301	941,814

Table 5. Shrimp culture production and area under culture in India for the years 1993-94 to 1998-99

(Source:MPEDA, Cochin)

Year	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
Area (ha)	82,540	100,700	118,983	135,582	141,591	135,007
Production (mt)	62,000	82,850	70,573	70,686	66,868	82,634
Production (Kg/ha)	751	823	593	521	470	618

Farmed shrimp production in India

In the case of India, according to MPEDA (Table 5), the farmed shrimp production was 62,000 mt in 1993-94 and 82,000 mt in 1998-99, but there was a slump in between, the production going down as low as 66,868 mt in 1997-98, when the hectarage under culture was maximum (141,591, ha). The unit area (ha) production also decreased from 823 kg/ha in 1993-94 to 618 kg/ha in 1988-99, but the lowest again was in 1997-98. We can read the exciting history of shrimp culture in India in these figures. The initial drop and slowing down was due to environmental degradation and diseases, as elsewhere in Asia, but the recent decrease in unit area production is due to the increase in the hectarage especially in extensive culture, and closing down of the semi-intensive farmers and major operators from the scene, owing possibly to the SCI intervention, as much as the lack of faith in shrimp culture when failure struck, after trying to extract the maximum from the farms, deviating from good management practices. But there is no need for despair as good management practices (GMP) can be expected to usher in sustainability to the troubled aquaculture system.

Taxonomic groups and species

Global aquaculture production of marine and brackishwater species groups falling under the major categories of diadromous fishes, marine fishes, marine crustaceans, marine molluscs and seaweeds for 1996, is given in Table 3. This gives a fair idea of the spectrum of farmed marine and brackish water animals involved in coastal aquaculture. Out of the total number of 229 cultured salt water tolerant and marine species, 91 are finfishes, 43 crustaceans, 81 molluscs and 14 seaweeds, all of them do not qualify as species under commercial culture. As Garibaldi (1996) pointed out the bulk of production is accounted for by a handful of species, but the others are not to be ignored as new technologies are being developed - the emergence of salmonids in Norwegian and Chilean aquaculture (having developed open sea cages stocking over a million salmon fry in each cage) and tuna culture in Australia are good examples of recent triumphs in mariculture.

Species adaptations to salinity

Eventhough the exclusively freshwater species are not considered here, species which can tolerate and live in the three environments, as exemplified by several diadromous species, like the salmonids, mullets and milkfish among teleosts, which are the typical euryhaline species are relevant in this context. In addition there are the stenohaline species whose salinity tolerance is limited. Among the salt tolerant species there are fresh water species which move into the brackish waters (*Macrobrachium* spp among crustaceans) and also teleosts (several tilapias). Most of these have ion-osmoregulatory capacities, but those with no capacity regulate body salt concentrations conform to the salinity of the ambient medium, and as well known are referred to as osmo-conformers (e.g., crabs, *Eriocheir* spp.).

An aspect which is important in aquaculture is the energy expenditure of the cultured species in different salt media. The regulators spent energy to keep the body fluid concentration constant (close to 10 ppt salinity in teleosts) by pumping in or out chloride ions through their gills and also by effecting permeability changes in the gill membrane through acclimation/adaptations of aquatic organisms to effect energy saving of the growing organism in the culture set-up, as this can certainly cut costs on feed, which is the costliest input in higher intensity aquaculture.

Aquaculture diversity

It can be seen that maximum exploitation of diversity of aquatic organisms, covering all seven categories has been effected by only two (China and Japan) of the eight countries. India and Bangladesh exploit only two categories - freshwater fishes and crustaceans (mostly shrimps), as per the FAO production data for 1996. There can be disparities in the FAO reporting system, as it is known that India does have aquaculture production of molluscs - especially mussels in the southwest coast but not reflected in the FAO production data. Also India is still in the process of developing and commercialising aquaculture of other marine organisms, even though technologies are available (Devaraj, 1999). It would be noted several species known to be cultured and some under experimental culture in India and other countries, which are listed in FAO (1998a), but are in the stages of being recruited into aquaculture.

An idea of biodiversity utilisation for aquaculture (BUA) can be known from the number of species used by the country for aquaculture. A crude index for BUA has been calculated to standardise comparison on a global basis (Kutty, 1999 a). The values of the BUA along with the details of the number of species and categories utilised and total production for selected countries, and the method of calculation of BUA are given in Table 6. Even though there are limitations in the use the BUA, owing to geographical and country differences, it is felt that the index enables macro comparisons at global level and also accommodates the increase in numbers of species, which will be utilised in future.

It comes out clearly that India has not utilised its biodiversity adequately as India uses only 13 species and has only a BUA of 0.13, while maximum utilised (51 species and BUA of 0.50 by Taiwan and Ro Korea) are quite high.

Table 6. Country-wise details of aquaculture production, numbers of major categories and species used and calculated Biodiversity Utilization for Aquaculture (BUA) in seleccted producer countries (Based on data obtained for 1996, taken from FAO (1998a) (from Kutty, 1999a)

Country	Aquaculture Production in 1996(mt)	No.of major categories utilised [b]	No.of species utilised [c]	Crude Bio-diversity Utilisation Index [d]
Korea (Rok)	896,998[a]	7	51	0.50
Taiwan	272,209	7	51	0.50
France	285,721	6	45	0.44
Thailand	509,656	6	35	0.34
Japan	1,349,405	7	33	0.32
Spain	233,833	5	32	0.31
China	23,134,52	7	29	0.28
USA	393,331	5	28	0.27
Philippines	342,678	6	27	0.26
Indonesia	780,130	5	23	0.23
Australia	26,323	5	30	0.29
Chile	323,115	4	15	0.15
India	1,768,422	3	13	0.13
Norway	324,543	3	8	0.08

a) 60% sea weed/aquatic plants

b) Maximum number of categories is 7, namely, fresh water fishes, diadiomous fishes, marine fishes, crustaceans, molluscs, other aquatic animals and aquatic plants

c) Number of species recruited for aquaculture.

d) A Crude Biodiversity Utilization Index is calculated by dividing the number of species utilized by the specific country, by twice the maximum recorded for any country, eg.for India, BUA, is estimated as 0.13, ie.13/51x2,51 being the highest number utilized (Korea, RoK/Taiwan)

Aquaculture systems

The different culture systems such as the coastal ponds, cage and pen culture and the raft/rack and pole and line culture for the different sea farming species along with species names in selected countries in Asia are shown in Table 7. Salient aspects of these culture systems with reference to eco-friendly coastal quaculture are pointed in following section.

Table 7. Major seamfarming species and their culture technologies in selected countries in Asia (Based on NACA, (1991); Taw, 1994 FAO, 1998)

Culture type	Farming technology (Country)	Species-Scientific name(local name) Countries
1. FINFISHES		
Grouper culture	Floating net cages/refts (HK) Hong Kong (HK)	*Epinephphelus akaara* (Red spotted grouper)
	Floating net cages/ponds (MAL)	*Epinephphelus akaara* (Yellow grouper)
		Epinephphelus tauvina (Greasy grouper)
		Epinephphelus chlorostigma (Brown)
	Hong Kong, Malaysia	*Epinephphelus suillus* (Spotted grouper)
		Epinephphelus malabaricus (Strip spotted grouper) Malaysia
Seabass culture	Floating net cages (HK)	*Lates calcarifer* (Giant sea perch)
		Floating net cages/ponds (MAL)
Seabream culture	Floating net cages (HK)	*Chysophrys major* (Silver seabream)
		Rhabdosargus sarba (Goldlined seabream)
	Hong Kong	
		Mylio berda (White seabream)
		Mylio latus (Yellow finned seabream)
		Mylio macrocephalus (Black seabream)
Snapper culture	Floating net cages (HK, MAL)	*Lutjanus russelli* (Russell's snapper)
		Lutjanus argentimaculatus (Mangrove red snapper)
	Hong Kong, Malaysia	*Lutjanus johni* (Golden snapper)

2. CRUSTACEANS		
Crab culture	Floating wooden bamboo (MAL, VIE)	*Scylla serrata* (Mud crab) cages with plastic/Styrofoam drum as floats/earthen ponds
Shrimp culture	Earthen ponds-India and several other countries in Asia India, Thailand	*Penaeus indicus* (Indian whita shrimp) *Penaeus* merguiensis (Banana shrimp) *Penaeus monodon* (Giant tiger shrimp) *Penaeus* semisulcatus (Green tiger shrimp)
3. MULLUSCS		
Cockle culture	Bottom culture/mud flats (MAL)	*Anadara granosa* (Blood cockle)
Mussel culture	Suspended (Raft/stack) bottom culture (MAL)	*Perna viridis* (Green musel)
Oyster culture	Bottom culture (HK), Suspended (raft and long line) Malaysia, Philippines bottom rack (MAL) Raft (SRL, IND)	*Crassostrea belcheri* (Large oyster) *Crassostrea iredalei* (Philippine cupped oyster) *Crassostrea gigas* (Pacifis cupped oyster)
	Hong Kong, China Sri Lanka, India (IND)	
	Suspended raft & stake / Vietnam, China	*Crassostrea rivularis* (Chinese large oyster)
	floating and fixed rafts (MYA)	*Ostrea folium* (Flat oyster)
	Bottom and suspended (raft & stake) Myanmar (MYA) (VIE)	*Saccoatrea cucullata* (Rock cupped)
Pearl Oyster culture	Suspended raft, net cages (VIE, IND)	*Pinctada formosa* *Pinctada foucata (Japanese pearl oyster)* *Pinctada margaritifers (Black-lip*pearl oyster)
	Vietnam	*Pinctada maxima (Silver-lip pearl* oyster)
	Vietnam	*Pteria penguin* (Wing oyster)

4. SEAWEEDS		
Red algae culture	*Eucheuma* - bottom method (nylon between stakes; semi-raft and raft method-stretched nylon mono-filament nets) (MAL) *Gracilaria*-pond culture (net fixed off bottom); open sea long line floating system (SRI, MYA); pond culture (tidal ponds) (poly culture) (VIE); fixed bottom monoline, floating raft monoline, mangrove pond (PHIL)	*Eucheuma cottoni* *Eucheuma spinosum* *Gracilaria* edulis *Gracilaria verrucosa* Gracilaria firma *Gracilaria changi* *Gracilaria heteroclada* *Gracilaria fastigata* *Gracilaria tenuistipitata*

The Regional Seafarming Development and Demonstration Project (RAS/86/024 and RAS/90/002) under FAO/NACA brought together member countries including India in Asia which had committed programmes, in seafarming developments, conducted country based specialised training and workshops on various farming systems and activities through regional co-operation and TCDC. This resulted in transfer of various coastal aquaculture and mariculture technologies to participating countries from expertise donor countries, such as sea-bass culture (Thailand), marine cage culture (Singapore, Hong Kong), seaweed culture (China and Philippines) and pearl culture (India).

As advised by an FAO/NACA mission (Butler *et al.* 1989) a series of seafarming atlases involving 12 countries in the region, namely India, China, Hong Kong, Indonesia, Korea Rep., Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand and Vietnam, were produced (Regional Seafarming Resources Atlas - Vol. I (China, India, Indonesia, Korea Rep., Philippines, Singapore and Thailand, released by RAS/86/024 in 1990, and Vol. II (Hong Kong, Malaysia, Myanmar, Sri Lanka and Vietnam), released by RAS/90002 in 1991).

Evolution of eco-friendly coastal aquaculture/mariculture systems

Environmental and socio-economic impacts of the different culture systems are discussed separately below.

Impacts of pen and cage culture: Pen and cage culture has developed more prominently in the temperate region lately, than in the tropical region, especially owing to the expansion of Atlantic salmon culture in Norway, and also salmonid culture in Chile. It is opined that if the intensity of cage culture is increased, the problems of coastal aquaculture in the tropics, similar to those faced by shrimp culture (Nunes and Parsons, 1998), would increase if not managed properly. Since carnivorous species are usually used they need high protein feeds, and so waste generation can be high. The amount of wasted feed (uneaten feed and unabsorbed nutrients) is higher in cage culture than in shrimp culture. In the temperate region it is estimated that waste generation is in the range of 10-15kg P and 75-95 kg N per year per tonne of fish produced (Enell and Lof, 1983, in Nunes and Parsons, 1998).

It is also feared that feeds given in powder form by cage operators in the tropics would lead to serious feed losses and water quality deterioration around the cages. Nunes and Parsons (1998) list the following effects of waste accumulation in the vicinity of cages, namely, reduction in redox potential, increase in C and N in the sediments, generation of hydrogen sulphide and methane, increase in oxygen consumption by the sediment, biological changes in macrobentic communities around the cages, starting with growth of sulphur bacteria, followed by reduction in the biomass of macrofauna such as crustaceans and molluscs, and eventually dominance of low oxygen tolerant species (eg. capellid polychaetes). These impacts, though limited to 30-100m around the cage site, can at times be significant.

The release of nutrients, N and P can be considerably reduced by improving the quality of the feeds in Atlantic salmon cages, as evidenced by feeding low FCR feeds: which has a very positive effect on the environment and the carrying capacity of the water body (Kutty, 1995).

Polyculture of finfish and holothurians in net pens: An interesting experiment in polyculture of Pacific salmon and holothurians has been reported by Ahlgren (1998). Pacific Salmon - pink *(Oncorhynchus gorbuscha)* and chum (*O.keta*) - one million fry each kept in 18-m diameter circular floating net pens ("Norwegian style") off Alaskan coast, developed problems of net-web fouling and so one hundred red sea cucumbers *(Parastichopus californicus)* were placed individually along the webbing of three selected pens. After six weeks the area of clean webs in the experimental and control pens were measured by counting the number of quarter m^2 quadrants with clean or fouled mesh. In four replicates, Ahlgren(1998) observed that the percentage of cleared surface area was 54-68% in the test pens, while in control pens it was 0%, effectively providing that red sea-cucumbers could be cultured successfully in combination with salmon fry. The sea cucumbers assimilated amino acids and other organic matter 2-3 times more efficiently than in their natural environment. This is an example of a positive impact through use of polyculture in net cages.

Impacts of shrimp culture

Potential impacts: Tookvinas *et al.* (2000) from their experience in Thailand list the following as potential impacts of shrimp farms:

- conversion of mangroves and other coastal wetlands to ponds;
- nutrient enrichment and eutrophication of coastal wetland by pond effluents;
- discharge of potentially toxic and bio-accumulative chemicals into natural ecosystems;
- sedimentation in coastal waters because of erosion from ponds and other earthen structure;
- salinisation of freshwater sources by pond effluents and seepage;
- reduction in bio-diversity of coastal eco-system caused by water pollution, sedimentation and toxicity of effluents;
- introduction of non-native species or new shrimp diseases into coastal waters;

- competition with activities for natural resources, and land use disputes.

Problem of aquaculture waste accumulation/disposal from shrimp ponds: The aquaculture waste from shrimp farms is mainly composed of uneaten feed (15-20% of feed given) and faecal wastes (20-25% of feed given), the animal retaining the balance for its growth, maintenance and metabolised waste (excretion). Primavera (1998) observes in the case of shrimp 15% of the feed given is not consumed, 20% egested, 48% spent in maintenance, excretion and ecdysis, and 17% is harvested.

As in the case of other aquaculture systems the faecal and excretory waste and uneaten feed are the source of nutrients, N, P & C, released into the pond water. N and P waste vary considerably with several factors such as the feed quality, feeding patterns and also the environmental variables. The quality of nutrients released changes with the intensity of culture. Gavine and Phillips (1994) estimated that an intensive shrimp farm generates 43% more N and 98% more P waste than a semi-intensive farm. The excess nutrients released, in cases where flushing is inadequate, accumulate in the pond bottom and cause water quality degradation, auto-pollution, and cause algal blooms, and mortality of stocked shrimps. The poor water quality also makes them vulnerable to diseases. So in the process of intensification of the culture activity, excess stocking and feeding, namely, result in algal crashes, and diseases. The wastes/nutrients released from the ponds cause problem, unless the release water is treated and regulated. It is claimed that effluent disposal into oligotrophic waters have caused in some cases, more production of fish and shellfish in the coastal waters, as reported in Thailand, but by and large the effluents disposed cause more damage, as proven in many cases. The serious consequences of bad pond management leading to collapse of farmed ponds and the ecosystem has already been referred to.

Impacts of bivalve culture

Even though the bivalves do not need any artifical feed, as they feed mainly filtered natural food, they can cause similar problems as in other coastal aquaculture systems (cage and pen) by deposition of organic wastes and faecal matter, causing the same chain of events in water quality deterioration and unwelcome biological changes around the oyster/mussel racks/rafts. As effective filter feeders an individual mussel is reported to filter 2.5 litres of water per day and a rope of mussels over 90,000 litres/day. Filter feeding bivalves retain a very high percentage (35-40%) of seston ingested (Barg, 1992) and it is estimated that a typical oyster rack holding 420,000 oysters would produce 16mt of faecal matter in one season (9 months) (see Nunes and Parsons, 1998). Thus the positive side of using bivalves as biofilters in treatment ponds is to a large extent offset by the negative influence of loading wastes in the environment.

Towards eco-friendly and sustainable coastal aquaculture/mariculture technologies.

Reduction of wastes from aquaculture systems

Reduction of waste from aquaculture installations is the most serious problem to be tackled for evolving eco-friendly aquaculture systems. The following methods (based on Phillips, 1995; Nunes & Parsons, 1998, New, 1999) would help resolve some of the issues involved in coastal aquaculture/ mariculture:

- Using sedimentation and oxidation tanks for treatment of aquaculture effluents.
- Use of biofilters - polyculture of filter feeding fish, oysters, mussels and nutrient absorbing seaweeds.
- Use of mangroves as natural biofilters, adjacent to land-based farms - serving as buffer zones, removing nutrients and organic matter from the effluents.
- Improved management strategies.
- Cage site rotation, allows sediment recovery through natural dispersal and disintegration of wastes.

- Introduction of floating pellets released from cage bottom, which rise/float slowly to surface.
- Using a funnel shaped catchment device and submersible pumps and mixers to collect and disperse organic wastes.
- Use of closed recirculation systems eliminating or reducing discharge of pond effluents to adjacent waters.
- Use of a flow-through system, high flow, circular self-cleaning culture ponds and full treatment ponds for inflow and outflow (effluent) waters to and from rearing ponds

Approaches to sustainable coastal aquaculture

There are several approaches to sustainable aquaculture. The details of some of these are discussed below.

Traditional/extensive culture: The easiest and simplest is the time honoured system of traditional extensive aquaculture, where intensity of applied technology is low, characterised by very low production, stocking and, correctly, without any fertilisation or supplementary feeding. But often increased stocking and fertilisation have crept into the extensive system (improved extensive) practised now in India, though feed may not be applied for increasing the intensity of culture. To begin with this culture was based on natural or auto-stocking, without recourse to stocking of any seed, and hence here a naturally developed polyculture system prevailed. As recognised by the SCI in its ruling this kind of original extensive polyculture would do no harm to the environment and would not also cause any socio-economic problems and hence sustainable. But as pointed out earlier, adopting this method of aquaculture covering all the coastline of India, will seal the fate of aquaculture, *doomed to a very low production for perpetuity*, as pointed out already. Therefore unless for very sensitive environmental and socio-economic constraints, it would be nonadvisable to leave large tracts of potential aquaculture area to simulate the natural ecosystem, and hence low output, especially at this time, when the demand for animal protein (fish protein), to combat malnutrition and need for food/nutritional security is very high.

New approaches: The way out of this muddle is to develop sustainable aquaculture through new approaches and we should also initiate action on realistic policies, plans and regulations, which would protect the interests of all stakeholders in aquaculture. Two new approaches to sustainable aquaculture have been identified: one is the recirculation of water, almost coming to a 'closed system' and the other is the 'open system' of intensive aquaculture as demonstrated in the case of shrimp culture, called the 'third generation culture technology' by New (1999), as exemplified by dry tropical full sea water shrimp farm, set up in the Red Sea Coast of Saudi Arabia (New, 1999).

'Third generation' flow through system: 'Zero pollution' has been reported in this case, as the effluent discharged in the flow through system has almost the same high quality as that of the pumped up water inflow. As can be seen from the details (Fig. 1) the investment and skills needed for construction and maintenance of this third generation farm is high, but the high cost of shrimp *(Penaeus monodon,* supplemented very little by *P. indicus)* makes the farm highly profitable - the sale of one year's harvest alone has covered most of the inception costs of the farm. The nuances of the technology involved is indicated as much as possible in Fig. 1. Basically the success on the enterprise described according to New (1999) is built around a few elements, namely:

1. Siting in a dry tropical area (in this case 'sapkha' of alluvial mud flats).
2. Water management hydraulics, bio-tech adaptations - buffer ponds and treatment ponds occupy a total of over 50% of water surface in the system.
3. Pumping large amounts of high quality natural seawater, to a large upstream reservoir - buffer pond, to let it flow by gravity to rearing ponds, large treatment (depuration) ponds, through mangroves to sea.
4. Development of controlled algal bloom through fertilisation to develop green water in the buffer pond for avoiding algal blooms later in the rearing ponds.

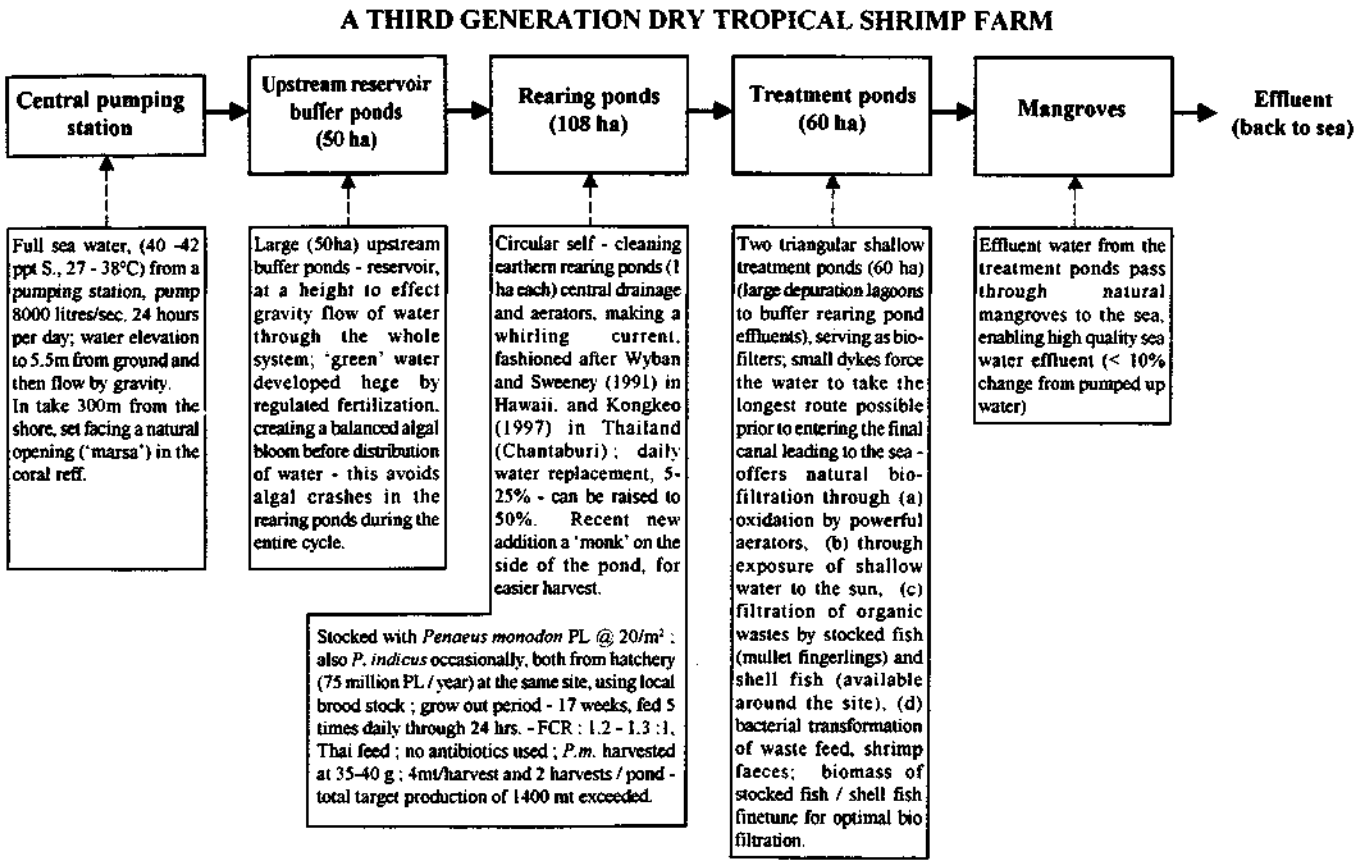

Fig.1. Schematic diagram showing successivel levels of water use/treatment in a 'zero pollution' system - Red Sea Shrimp Farms managed by "Group Consultatif Internationa" in a dry tropical (desert) site ('sapkha') - alluvial mud flats in Red Sea coast of Saudi Arabia (based on New, 1999) (thick arrows indicate flow of water and broken arrows indicate structural/functional details)

5. Having circular central drainage, self-cleaning (aerators making a whirling current) after Hawaiian (Wyban and Sweeney, 1989) and Thailand (Kongkeo, 1997) experiences.
6. Non-use of antibiotics in the culture ponds.
7. Complete dependence on indigenous seeds - development of breeding local species - *P. monodon, P. japonicus and P. semisulcatus.*
8. Having large shallow treatment ponds (27% of total surface area) where depuration takes place through extensive culture of filter-feeding fish (mullets) and shellfish, bacterial disintegration of faecal/excretion wastes, and sunlight enhancing the photosynthesis and oxidative function of the effluent from the shrimp ponds.
9. Further cleaning through natural biofilter - mangrove.
10. Release to sea, high quality effluent sea water, with only about 10% deviation of quality from that of pumped-up inflow water.

Recirculation/closed systems of land based farms: Thailand pioneered the use of closed systems for shrimp culture when harassed by shrimp diseases entering through inflow water from the estuary/sea. The principle is to store water in large reservoir ponds and strip it of all pathogens and use the clean water to feed the culture ponds. The effluent water is not released out to the natural environment, but is collected in treatment ponds, where filter-feeding fish and shellfish, as well as seaweeds are cultured so that the effluent water is cleaned of debris and effluent nutrients, ready for reuse. This is the ideal system, but in all cases this is not possible as there is need for a large portion of the area kept aside for recycling the water and there is always the need for some water to let and some new water taken. The Thai farmers and administrators are aware of this and have hence formulated a code of conduct for shrimp farming, which has already been referred to. The experience of the 'third generation shrimp farm', which use a flow through system (New, 1999), described above in water treatment will be of interest to the recirculation system exponents as well.

An example of a closely related system referred to as Intensive-Extensive System (Avanimech, 1998) will again be of much value in adapting new systems. Use of "Intensive-Extensive System (IES)" in trials in Negev desert (Israel), which have now become commercial, involves a group of smaller (500 ha) intensive ponds located beside one or more large earthern ponds (5000 ha), that are used for extensive fish culture and water treatment through culture of algae and bacteria.

An intensive pond can hold a fish biomass of 10 to 100 kg (say 1ha pond) per m^2, i.e. 100 to 1000 mt/ha, needing a high quantity of feed, at 2% biomass, it would be $2kg/m^2$ or 20 mt/ha. This pond is connected to the larger extensive pond.

Both high and low (or zero) discharge intensive ponds are used. The high discharge ponds have a daily water exchange rate of 500%; thus each 1000 ha pond, need a treatment pond of 5000 ha. The ratio of 1:5 was found to be too low, for the nutrients released. The production of inorganic N in intensive ponds was 0.7 kg N/mt fish and so with 100 mt fish in pond it would be 70 kg_i N ha/day, which was found to be too much for the treatment ponds to handle. So one has to increase the proportional size of the treatment pond, which would add considerably to the expenses, which was already high. Also it was found that the treatment pond is not an infinite sink; bottom sediment has to be cleared every 2-3 years.

In low density pond daily water exchange rate is 3-20%, where the feed loss was not much, as the uneaten feed is reused by fish, amounting to feeding twice, once as fresh ingestion by fish, second by bacterial ingestion, resulting in low FCR. This is a very significant observation. The production costs are still high and so very high cost fish can only be grown economically in the set up under the conditions. This study gives much insight into the closed system aquaculture, which will be of value to those who are working in this subject area. It is interesting to note that both in the presently described recirculation system and in the flow through system there are several similarities especially in the treatment of water and the large water surface area of the treatment ponds. In both indeed high technology and high investment is needed, suggesting that the environmental and social costs of intensive pond culture is quite high, and perhaps by intuition the developing countries are inclined or forced to choose less intensive systems. But it is heartening that both systems could be sustainable, the main difference will be the economics of production; the investor has to pay more for high intensity production for meeting the costs of producing high quality effluents either for reuse or for letting into the natural ecosystem (environmental and social costs).

Integration of coastal aquaculture with halophyte crops: Brown and Glenn (1999) have been studying edible halophyte (such as *Salicornia bigelowi*) recycling shrimp effluents. The integrated system they have suggested is detailed in Fig.2. Halophytes such as *S. bigelowi* have multiple uses. While some are edible for man, they can be used as forage sheep (and goats) and some also yield oil seeds, from which high quality edible oil can be obtained. Brown and Glenn(1999) propose growing halophytes using shrimp pond effluents for irrigation - abandoned or unused shrimp farms can also be used for growing halophytes. The outflow from the halophyte plots will be hypersaline and so organisms such as *Artemia* could be cultured in this media and the final effluents taken to salt pans for extracting salt. The suggested integration may specially be applicable along southern Tamilnadu coastal areas in places like Mandapam and Tuticorin, where abandoned/unused shrimp ponds, salt pans and *Artemia salina* growing naturally are available. So the proposed system may be worthy of emulation to add to the productivity of such arid/semi-arid coastal areas and improve the socio-economics of the rural communities involved through integrated coastal aquaculture systems.

Conclusions

As evident from the present analysis, compared to other Asian countries Indian aquaculture is among the least diversified. Indian coastline and EEZ are much longer/higher than those of any other country in Asia. We have to develop these vast areas to produce more through coastal aquaculture and mariculture. Attempts to diversify Indian coastal aquaculture, by recruiting more coastal and marine species to commercial aquaculture. We certainly do not lack the technology development skills, but we should also transfer technology and skills in new ventures if we lack them and adapt them to our conditions. Perhaps we should study the market situations well in our efforts to commercialise new technologies, or we should take steps to create new market avenues for the new aquaculture products. A review of production per unit length (km) of coast line and/or unit area (Km^2) of EEZ, showed that except for shrimps we are in lowest rung, even small Asian countries doing much better in the production of marine commodities such as molluscs, seaweeds and finfishes (Kutty, 1995a).

While considerable information on coastal/marine resources is available on a country wise and regional basis, in India and other Asian countries for evolving an effective coastal zone management planning (Barg, 1992) involving coastal aquaculture, there is further need for assessing the land, water, economic and human resources available for development (Kapetsky, 1987; Kapetsky *et al.* 1987). With the availability of specialised computer software it would be advisable to use the GIS (Geographical Information System) for coastal resource planning, with special reference to aquaculture (Kapetsky, 1987; Kapetsky et al. 1987). Appropriate zones in the coastal region could be identified for development of coastal aquaculture systems as done recently in Sri Lanka (FAO, 1997b, 1998b). With the background of the recent catastrophes in coastal aquaculture (collapses of shrimp culture) in Asia it is important that environmental and all other sectoral considerations including socio-economic issues, are paramount in bringing about an integrated coastal management plan, where sustainable aquaculture has its due share (Barg, 1992; Kutty, 1998; ACIR-MOFI, 1999). For inventory and monitoring

AN INTEGRATED COASTAL AQUACULTURE SYSTEM

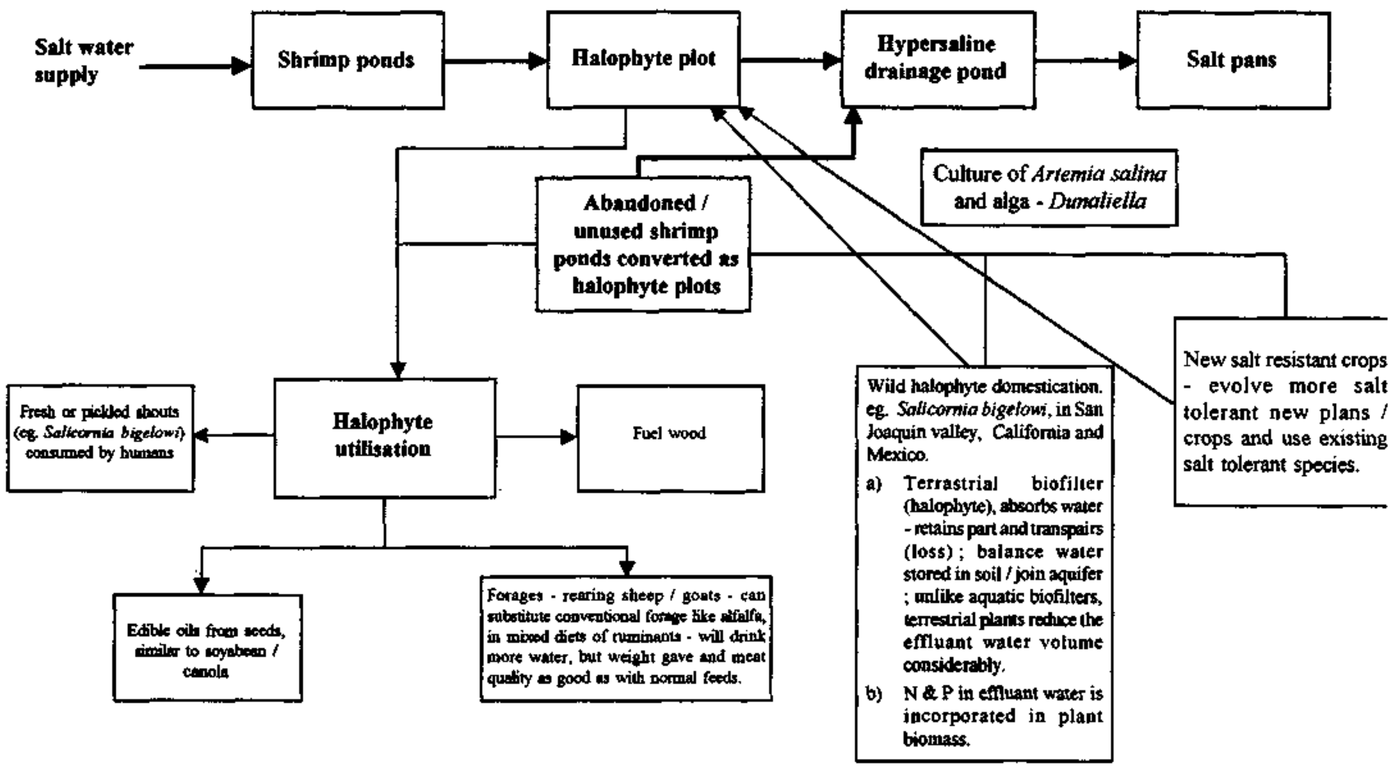

Fig. 2. Schematic Diagram showing proposed use of halophytes in integrated coastal aquaculture (shrimp - halophyte/ salt resistant crops/*Artemia* / *Dunaliella* / salt production integration (Based on Brown & Glenn (1999)) (Thick arrows indicated flow of water and thin arrows explain linkages)

of shrimp farms SAR satellite data and detailed image analysis as done recently in Sri Lanka (Travaglia *et al*, 1999) would also be especially helpful, in solving issues already existing and evolving more eco-friendly coastal aquaculture / mariculture systems.

India's coastal aquaculture technologies are yet to spread out, as already indicated and apparently Indian scientists are in different stages in developing technologies for various marine organisms, such as shrimps, crabs and lobsters among crustaceans, mussels, edible oyster and pearl oyster, among molluscs, sea bass, mullet and milkfish among finfishes, *Gracilaria* among sea weeds and also holothurians (Devaraj, 1999). While some of the technologies are known for decades or longer (shrimps, oysters, *Gracilaria*), some are in the threshold of entering the arena (groupers, holothurians).

Serious efforts are needed to boost our coastal aquaculture production, developing more applicable eco-friendly technologies and improved extension system to propagate them, and perhaps also through transfer of technologies from our Asian neighbours, who have proven expertise in specific areas, and as already indicated, it is important, however, to overview and ensure that all the existing and newly introduced technologies are suitably modified, if not already in an acceptable form, so that they are environment friendly and socially acceptable. For it has been recognized now that it is not the lack of technologies, which causes problems, but it is the impacts, environmental and socio-economic, of applied technologies, often in the absence of plans and policies, which undermines the process of aquaculture development at all levels. Coastal shrimp culture in India and elsewhere has indeed brought the problems into focus, but it is noteworthy that in no country other than India the preventive steps taken at national level are so drastic.

It is becoming obvious that culture systems, which are environmentally and socio-economically unsound, are not sustainable. More recent researches have shown that improved management practices can ensure pollution-free and also disease-free culture systems. It is also necessary that besides technological considerations, environmental and socio-economic considerations according to laid-out plans and policies, and effected through discussion and dialogue among all the stakeholders of the aquaculture ventures, should take place, sufficiently early as a part of pre-siting / siting exercise. This should involve also the various sectoral interests in the coastal zone so that aquaculture development would blend in harmony with the other concomitant sectoral developments in the coastal zone, as is envisaged in an integrated plan for coastal area development (ICAM). While integration at the biological/technological level such as by adoption of polyculture through new experimentation and trials would usher in more sustainability, inter-sectoral integration needs paramount consideration as well with involvement of the local populace. Experience and expertise in the countries in the region can be pooled together in this context through specialized development agencies such as FAO and NACA to adapt and evolve more eco-friendly and sustainable mariculture/coastal aquaculture systems.

In developing eco-friendly coastal aquaculture systems built into an integrated coastal management plan for India CMFRI should take the leadership in integrating coastal aquaculture and mariculture with activities within the fisheries sector itself and also with the other sectors such as forestry, tourism and other interests (FAO, 1995; 1997a). There are some very novel and refreshing developments as detailed above, but still the tasks are many in finding ways for developing these and sharing of experiences of other Asian countries with similar concerns, as pointed out already, will be very helpful.

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