Aquaculture development in India from a global perspective

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While Asia's share in 1996 global aquaculture production of fish and shelfish (26.38 million mt as estimated by FAO) was maximal (91%), those of Europe (4.7%) and North America (1.8%) were low. Intriguingly, the relative increases (%) in production over the decade in both the developed continents have decreased. Among the top ten producer countries, China accounted for 67% of total world production, followed by India (7%), Japan (3%), Indonesia (2.5%), Thailand (1.9%), USA and Bangladesh (1.5%), Korea (RoK) (1.4%), Philippines (1.3%) and Norway (1.2%). While India has increased its farmed freshwater fish production and shrimps very impressively, utilization of marine aquatic resources (except for shrimps), spread over an expansive EEZ of two million km^2, is poor. India has little production of farmed marine fishes, molluscs and seaweeds, in which even smaller Asian countries excel. An index of Biodiversty Utilization for Aquaculture (BUA), calculated for India is quite low (0.13), when compared to the highest (0.51) for Taiwan and RoK. India can gain much by diversification of aquaculture, recruiting more species from her rich aquatic fauna and flora and also by developing eco-friendly and sustainable aquaculture systems by sharing of experience and technology with our Asian neighbours through cooperative efforts.

AQUACULTURE and agriculture are not strictly parallel developments in food production, even though food gathering, hunting and fishing might have started at about the same time in human history. The complexity of aquaculture as a multi-disciplinary activity, even more complex than agriculture, is perhaps one of the reasons for the late start of modern aquaculture[1]. Asia, in particular China, has dominated aquaculture developments in the world right through history. The first known '*Treatise in Fish Culture*' was written by Fan Li in 476 BC. While this could be considered as the beginning of traditional aquaculture, China still dominates the world scene by accounting for over 65% of global aquaculture production. Though India is second only to China, it accounts for only 7% of global aquaculture production[2].

Global aquaculture production has been steadily increasing over the last decade. The global production of farmed fish and shellfish (according to FAO categorization) increased from 10.64 million metric tonnes (mt) in 1987 to 26.38 million mt in 1996, indicating an increase of 148%. The corresponding increase in value was 110%, from 16.38 billion to US $ 41.55 billion[2]. The boom in aquaculture production is reflected in the production figures for India as well which shows an increase from 0.78 million mt in 1987 to 1.77 million mt in 1996 (126%), and the corresponding value increase was from 0.83 billion to US $ 1.98 billion (139%). This estimate by FAO might appear conservative when, according to the Marine Products Export Development Authority of India (MPEDA), the export earnings from shrimp alone exceeded one billion dollars consecutively for the last four years. Asian countries claim the lion's share (91%) of global aquaculture production, adopting a spectrum of different culture systems and intensities, from the traditional to the most modern, with other continents trailing behind, some excelling however in production of certain categories of fishes (diadromous fishes), such as salmonids.

The aquaculture boom and increased socio-economic benefits, such as increase in employment and social well being, concomitant with the increase in the extent and intensity of aquaculture, are alleged to have created several problems, particularly those of a deteriorating environment owing to worsening water and soil quality, as well as owing to incursions by aquaculture into the other sectoral activities, such as agriculture, capture fisheries, forestry, public health, tourism, urbanization and housing. The impacts can be two-fold, one affecting aquaculture itself by autopollution and consequent outbreak of diseases, leading to crop failures and collapses eventually. The first such national complete collapse in shrimp culture was observed in Taiwan[3], followed by partial collapses of cultured shrimp production in China, Indonesia, Thailand, Philippines[4] as well as in India in 1995–97. This has resulted in several complex social problems and litigation at the national level in India, still awaiting legal settlements to decide on the directions Indian coastal aquaculture will take[5]. Sustainability of aquaculture itself has been questioned, and several international, regional and national level studies and discussions on this subject have taken place recently[4,6–19].

With limitations in land-based food supply and the Malthusian fear becoming real, man has turned more seriously to water-based production systems, mainly to meet the increasing demand of food/proteins-deficit to sustain the exploding global population. While it was

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easier harvesting wild fish stocks than culturing fish, it has come to a stage that the production through capture fisheries cannot now be increased further. The global annual production has reached a plateau of 85–90 million tonnes, in the last decade. 'The collapse of fisheries in many regions shows danger plainly'[20]. It was therefore and is still the right strategy to concentrate on aquaculture to increase farmed fish production, which has been achieved fairly successfully as the statistics show. Some of the salient developments in the national and global context are detailed below, and a balanced approach to sustainable aquaculture development is discussed.

Aquaculture production

In this paper the major trend in global aquaculture production has been presented. Quantities and corresponding values of aquaculture production (fish and shellfish only) in the world and in India, for the period 1987 to 1996, are graphically shown in Figures 1 and 2. While the growth in aquaculture production is similar, the rate of increase in global production in quantities is more impressive. The per cent increase in world production for 1987–1996 is 148%, while that for India is 126%.

Continentwise aquaculture production of all aquatic organisms (including seaweeds) for 1987–1996 is given in Table 1. As pointed out earlier, Asia's share is maximal (91%), Europe being a poor second (4.7%), and North America accounting for only 1.8% of world production in 1996. It is intriguing that even though the actual production figures for both N. America and Europe (developed countries) increased, the relative production values (percentages) decreased during 1987–1998, while Asia increased its share from 84% to 91%. The per cent increase is highest for S. America (409%) and least for N. America (23%), excepting for the special category (former USSR) (– 70%) shown in FAO statistics. This is possibly an indication of the recent slowing down of aquaculture activities as with other economic activities in Russia. The African continent accounts for 0.3% of global production only. The low figure may be mainly owing to inadequacy of technology and possibly also lack of tradition in aquaculture, unlike in Asia[21]. This, however, shows a great scope in production of cultured fish in Africa. Unlike in N. America and Europe, there could be no suspicion that aquaculture as a human enterprise in Africa is discouraged.

Aquaculture production (fish and shellfish only) in the leading producer countries in the world is shown in Table 2. China accounted for 67% of total production and India (7%), Japan (3%), Indonesia (2.5%), Thailand (1.9%), USA (1.5%), Bangladesh (1.5%) and others in sequential order, as shown in Table 2. The highest increase in production over the decade, 1987–1996 (476%), is shown by Norway which is an exception among developed countries. More detailed analyses of production composition of selected countries are shown in Table 3. For Norway this dramatic increase is owing to the increase in production of diadromous fishes, but mainly a single species, Atlantic salmon (301, 426 mt)[2]. Chile (again owing to high production of salmonids successfully introduced recently for aquaculture) and Thailand (being the present world leader in farmed shrimp production) have also shown remarkable increases in production over the decade, 264 and 236% respectively (Table 2). From this context India's (124%) increase is moderate, but the production over the decade has almost stagnated in Japan (12%), USA (3%), Philippines (0.7%), and Korea (RoK) (– 0.3%). The reduction in growth in Korean Republic[3] and Philippines[5], might be due mainly

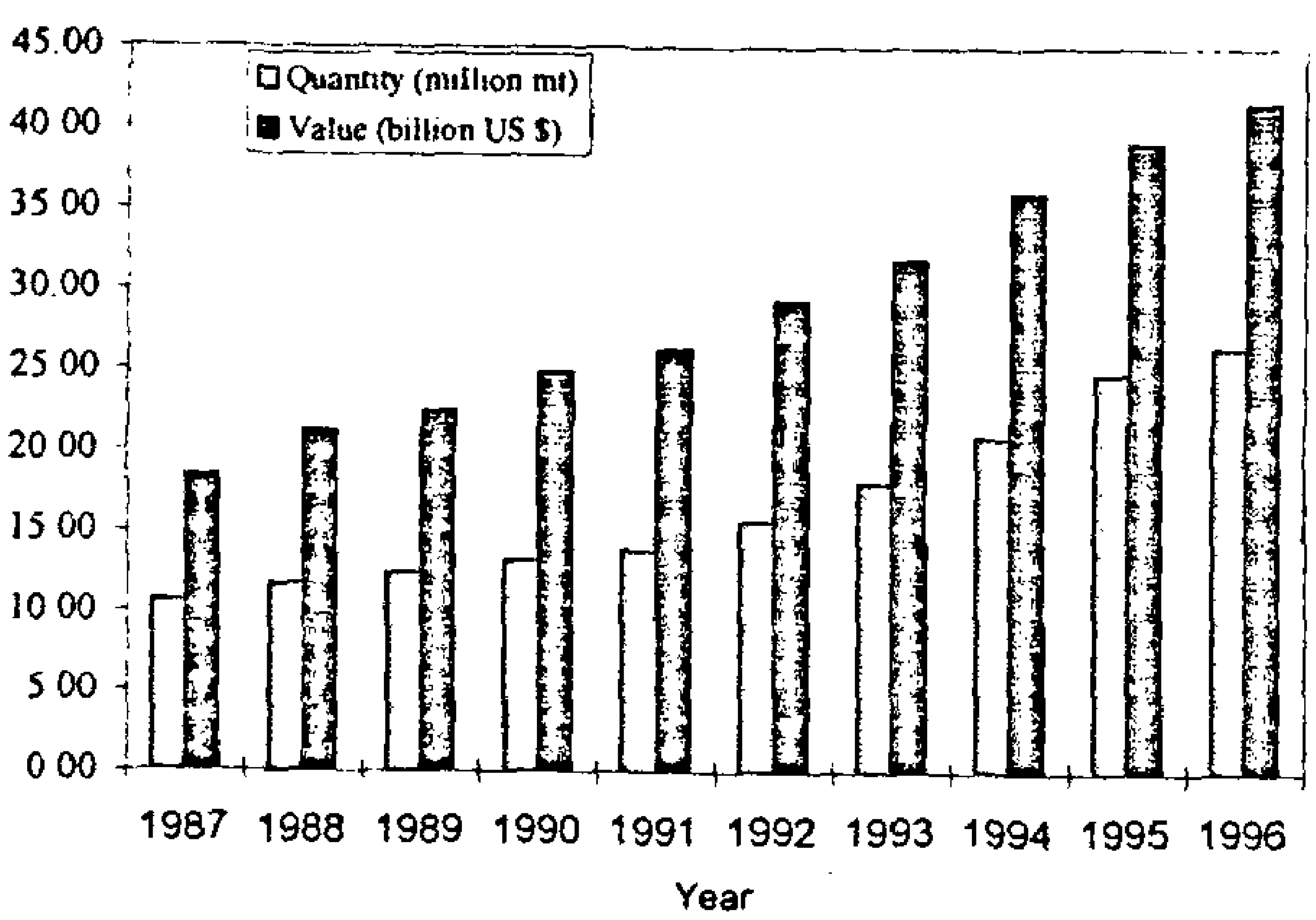

Figure 1. World aquaculture production (fish and shellfish only) quantity (in million mt) and value (in billion US $) for 1987–1996 (based on FAO[2]).

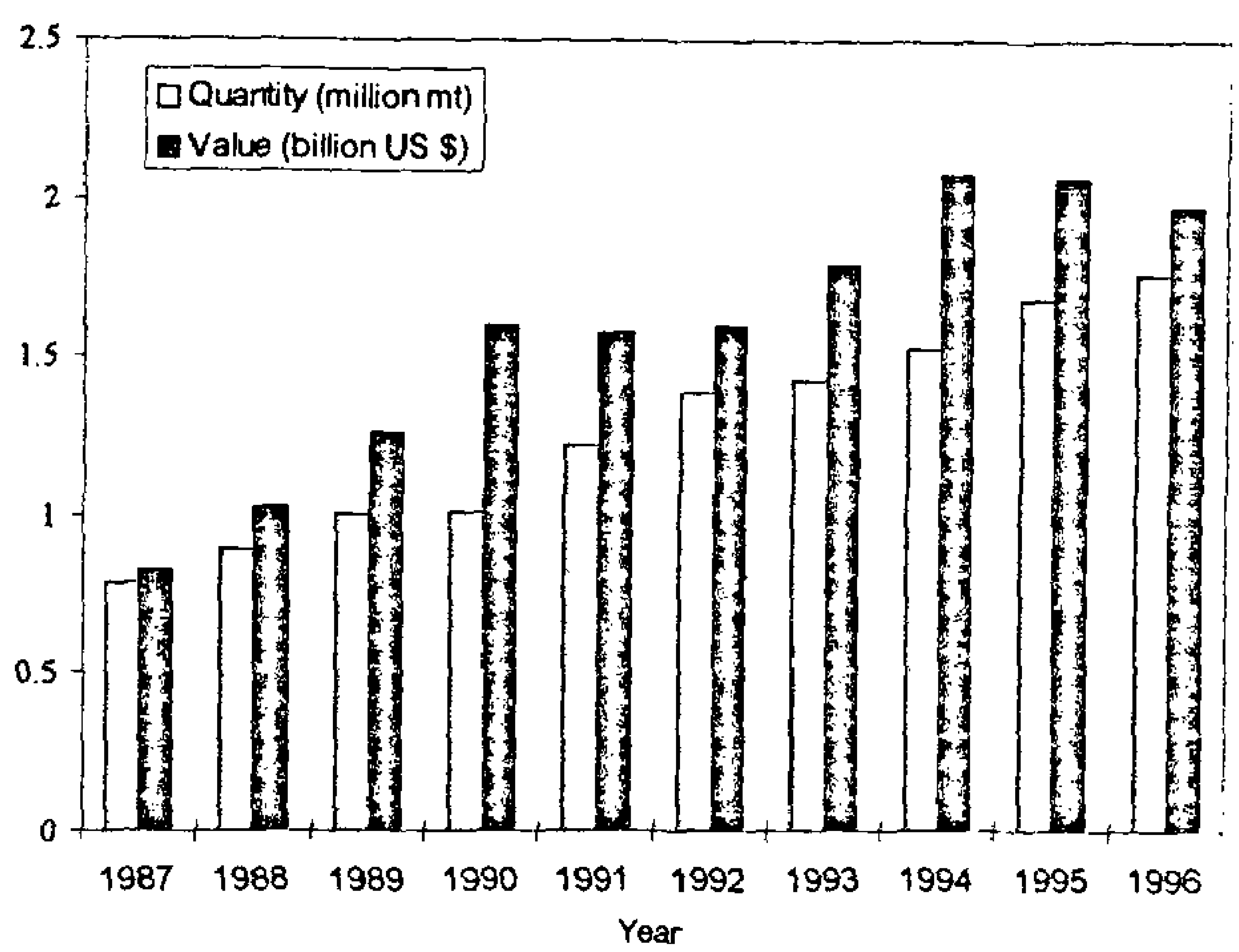

Figure 2. Aquaculture production (fish and shellfish only) quantity (in million mt) and value (in billion US $) in India for 1987–1996 (based on FAO[2]).

to collapse of shrimp culture. However, in the case of USA and Japan, it might be suspected that the countries do not deliberately increase their production, since they could benefit from aquaculture (often alleged as a pollution-causing activity) elsewhere, mostly through imports from the developing countries. It is also interesting to see that USA, an economic super power, and Bangladesh, an LDC, are ranked six and seven among the top ten aquaculture producer countries. This indicates that aquaculture is accessible and facile and therefore suitable culture systems can be chosen and practised according to national objectives and plans, irrespective of their economic strength.

Specieswise production of farmed teleosts and crustaceans in India, based on FAO statistics for 1996, and percentage increase in production of the different species are given in Table 4. Freshwater fish farming, mainly through composite culture of Indian major carps and Chinese carps, account for most of the production. Production increases in other freshwater species are not high, and some such as, the snakeheads (*Channa* spp) and tilapia (though considered a weed fish, are available in most freshwater ponds and tanks, providing low cost protein source for the rural poor), are not listed. The absence of snakeheads and lower production of other air-breathing fishes, which fetch good price in the market, are possibly reflective of the change in boidiversity, owing to the excess use of pesticides and chemicals in the paddy fields. India can increase its rural fish production considerably by harmonizing fish culture and rice production, adjusting farm management through integrated pest management by cutting down on the use of chemicals and relying more on biological control of pests. However, integrated fish farming, either with agricultural crops, or with animals/birds, which would be of great value in rural development, has not spread as much as desired in India, despite substantial and successful research inputs. The aquaculture successes and the unrivalled position reached by China is considerably due to widespread practice of integrated farming. The integrated marine farming, which is yet to reach large-scale operation, has begun with serious research efforts in China, Korea, Thailand and Philippines. India could gain much by initiating studies in the integrated farming of fish, crustaceans, molluscs and seaweeds, as a more sustainable system than monoculture of shrimps, presently in vogue in India and elsewhere (see also below).

Table 1. Continentwise aquaculture (mt) of all aquatic organisms (including seaweeds) in 1987 and 1996

Continent	1987	1996	% increase (1987–1998)
Asia	11,360,448 (84.3)	31,076,231 (91.1)	(173.5)
Africa	58,404 (0.4)	120,722 (0.3)	(106.7)
Europe	1,088,207 (8.1)	1,589,396 (4.7)	(46.1)
N. America	490,720 (3.6)	603,242 (1.8)	(22.9)
S. America	103,911 (0.8)	528,599 (1.5)	(408.7)
Oceania	29,917 (0.2)	99,256 (0.3)	(231.8)
Other (former USSR)	348,824 (2.6)	103,803 (0.3)	(– 70.2)
World total	13,480,431	32,116,249	(153.1)

Figures in brackets denote percentage (Based on FAO) (ref. 2).

Shrimp production

In view of the importance of shrimp culture in India and elsewhere in the world, the case of shrimp production

Table 2. Aquaculture (fish and shellfish only) production (mt) including producer countries in the world, in 1987 and 1996

Country	1987	1996	% increase
China	4,865,503 (45.7)	17,714,570 (67.1)	(264)
India	788,310 (7.4)	1,768,422 (6.7)	(124)
Japan	739,121 (6.9)	829,354 (3.1)	(12)
Indonesia	376,727 (3.5)	672,130 (2.5)	(78)
Thailand	151,658 (1.4)	509,656 (1.9)	(236)
USA	383,259 (3.6)	393,331 (1.5)	(2.6)
Bangladesh	150,215 (1.4)	390,088 (1.5)	(160)
Korea (RoK)	477,455 (4.5)	358,003 (1.4)	(–0.3)
Philippines	340,131 (3.2)	342,678 (1.3)	(0.7)
Norway	56,344 (5.3)	324,543 (1.2)	(476)
France	231,778 (2.2)	285,659 (1.1)	(23)
Taiwan	299,897 (2.8)	262,276 (1.0)	(–13)
Spain	270,724 (2.5)	233,833 (0.9)	(–14)
Chile	4,758 (0.4)	217,903 (0.8)	(448)
Other countries	1,499,307 (14.1)	2,082,137 (7.9)	(39)
Total	10,635,187	26,384,583	

This table differs from Table 1 in that the production figures here concern only edible fish and shell fish, as per FAO terminology, and does not include other products such as seaweeds.
Figures in brackets denote percentages (Source: FAO[2]).

is detailed separately. World farmed shrimp production increased from 177,000 mt in 1984 to 921,000 mt in 1994 (refs 22–24) accounting for an increasing share of farmed shrimp in total shrimp production (Table 5). The share of shrimp from capture fisheries decreased from 91% in 1984 to 71% by 1991, and stagnated around that level till 1994. The plateau in farmed shrimp production, around 29%, does not mean that it has remained static during the period, but is reflective of the fact that while some countries had faced collapses (e.g. China, Taiwan), some (e.g. India, Bangladesh) have made considerable increases during the period 1984–1994 (Table 6). It is likely that the farmed shrimp production will increase further with the containment of shrimp diseases and evolution of more eco-friendly and sustainable shrimp culture.

Farmed shrimp production in India has increased from 10,000 mt in 1984 to 92,000 mt in 1994, showing an 820% increase, according to FAO (Table 6). The steady increase in area under culture, from 68,227 ha in 1991–92 to 135,582 ha in 1996–1997, as estimated by the Marine Product Development Authority (MPEDA), is shown in Figure 3. On the other hand, farmed shrimp production increased from 40,000 mt in 1991–1992 to 82,850 mt in 1995–96, but subsequently decreased to 70,573 tonnes in 1995–1996 and 70,686 mt in 1996–97. The shrimp production declined in India, despite the increase in hectarage as well as the intensity of aquaculture and per hectare production[25], can be owing to the combined effects of incidence and spread of shrimp diseases, crop holidays, and also climatic vagaries resulting in cyclones and floods.

Diversity in aquaculture production

Production of different categories of aquaculture organisms, such as freshwater fishes, diadromous fishes, marine fishes, crustaceans, molluscs, aquatic plants and other aquatic organisms[2], for selected countries is shown in Table 3. India and Bangladesh culture only two major categories, freshwater fishes and crustaceans (mainly shrimp), which is indicative of a lower stage of aquaculture diversification. FAO records[2] indicate that India does not produce through culture any marine fishes, molluscs or seaweeds. However, reports of the Central Marine Fisheries Research Institute indicate that India produced 60 mt of oysters and 15 mt of mussels in 1996 (ref. 26).

It is possible that there are lacunae in reporting statistics of production. In any case the production figures, for example for molluscs and aquatic plants for China, are in the range of 5–6 million mt and for Japan about 0.5 million mt (Table 3), and India has to go a long way in exploitation of these resources to increase their production. This is a major lacuna in Indian aquaculture, i.e. the inadequate or even nonexploitation of the coastal aquatic resources over long coastline of 8000 km and an EEZ of two million square kilometers[27].

To compare from another angle, the poverty of Indian coastal aquaculture (apart from the sumptuous shrimp culture) becomes clearer when production estimated per kilometer of coastline[28] is compared to other Asian countries in this context. India was found behind these countries, with nil or negligible production in all mariculture categories other than shrimps. In cultured marine fish production, the lead country was Taiwan, and Malaysia was tenth, respectively producing 27.5 and 0.7 mt per kilometer of seacoast. In production of cultured marine molluscs, the lead country was Korea (RoK) (127 mt/km), followed by China (85), Taiwan (36), Thailand (35), Japan (31), Korea (DPR) (22), Malaysia (10), Singapore (4), and Philippines and Hongkong (one mt each). As for cultured marine aquatic plants (sea-

Table 3. Aquaculture production (in mt) in selected countries in 1996

Category	India	Bangladesh	China	Japan	Indonesia	Thailand	USA	France
FW fishes	1680895 (95.05)	340828 (87.4)	10651754 (46.0)	15170 (1.1)	343000 (44.0)	188380 (37.0)	230853 (58.7)	10143 (3.5)
Diadromous fishes			147316 (0.6)	65142 (54.8)	160120 (20.5)	3750 (0.7)	38294 (9.7)	54405 (19.0)
Marine fishes			240592 (1.0)	247827 (18.4)	11300 (1.4)	800 (0.2)	3561 (0.9)	2728 (1.0)
Crustaceans	87527 (4.95)	49260 (12.6)	236309 (1.0)	1859 (0.1)	157710 (20.2)	230832 (47.3)	22430 (5.7)	205 (0.1)
Molluscs			6406595 (27.7)	490072 (36.3)		85710 (16.8)	98193 (25.0)	218178 (76.4)
Aquatic plants			5419950 (23.4)	520051 (38.5)	108000 (13.8)			62 (0.1)
Other aquatic organisms			32004 (0.1)	9289 (0.7)		184 (0.1)		
Value/kg (in US $)	1.1	–	0.91	3.71	2.60	3.60	1.87	2.03

Figures in brackets denote percentages. (Source: FAO) (ref. 2).

weeds), the lead country was again Korea (RoK) (185 mt/km of coastline), followed by China (159), Korea (DPR) (48), Japan (41), Philippines (13), Taiwan (6), Indonesia (2) and Vietnam (1). The listing above clearly shows that even small (Taiwan, Hongkong, Singapore) and less developed (Vietnam) countries in Asia are far more active in marine aquaculture than India.

It certainly appears that India has been complacent in developing its vast marine resources for aquaculture, despite research efforts and well-known publications of the GoI/ICAR institutions and universities over the past half a century in the culture of marine molluscs, sea weeds and fishes. It is obvious that very strong efforts have to be made to boost our marine aquaculture on the basis of a few lessons from our own experience and the successful efforts of our Asian neighbours. An all-out effort in extension and open policies of exchange of known successful technologies from other Asian countries when effected, might give the required boost in production of these marine commodities.

Table 4. Species-wise aquaculture production (mt) in India in 1996

Species	Production (mt) in 1996	% increase 1987–1996
Teleosts		
Catla catla	417,650 (23.6)	(131)
Cirrhinus mrigala	409,980 (23.2)	(233)
Labeo rohita	422,260 (23.9)	(131)
Cyprinus carpio	13,705 (0.8)	(69)
Ctenopharyngodon idellus	15,305 (0.9)	(15.9)
Hypophthalmicthys molitrix	3,755 (0.2)	(150)
Anabas testudineus	55,000 (3.1)	(51)
Clarias spp	57,638 (3.3)	(56)
Other (*Osteichthyes*)	285,602 (16.2)	(34)
Crustaceans		
Penaeus monodon	87,187 (4.9)	(481)
P. indicus	162 (0.01)	–
Macrobrachium rosenbergii	178 (0.01)	(– 61)
Total	1,768,422	(125)

Figures in brackets denote percentage composition (col. 2). Percentage increase (col. 3) in production during 1987–1996, except for *C. carpio*, *C. idella*, and *H. molitrix* (1993–1996) and *M. rosenbergii* (1992–1996) (Source: FAO) (ref. 2).

Biodiversity utilization in aquaculture

While a comparison of the number of categories of fauna and flora utilized for aquaculture might give a rough index of biodiversity utilization, more precise information can be obtained from a countrywise comparison of the number of species used for aquaculture (Table 7). A Crude Biodiversity Utilization Index (BUF) is calculated by dividing the number of species utilized by the specific country, by twice the maximum recorded for any country, e.g. for India, BUA is estimated as 0.13, i.e. $13/51 \times 2$, 51 being the highest number utilized [Korea (RoK)/Taiwan]. Actual BUA can only be known if the potentially utilizable species for aquaculture can be enumerated, which is not such an easy task since the measure of desirable characteristics can change with time and preferences. Therefore, for the present, an approximation to it is the use of maximum number of species utilized in an aquaculturally-active country, as we have in Korea (RoK) and Taiwan. These countries have almost the same maximal achievement in the respect of 51 species, spanning through the spectrum of aquatic fauna and flora, in the seven major categories, as per FAO listing[2]. The crude BUA can be calculated accordingly:

$$\text{BUA (India)} = \frac{\text{Number of species utilized for aquaculture in India}}{2 \times \text{maximal number of species for any country (51, for Korea (RoK) and Taiwan)}}$$

$$= \frac{13}{2 \times 51} = 0.13.$$

Crude BUA values calculated for selected countries are shown in Table 7. It comes out that India's score is low, indicating once again the unexplored opportunities in aquaculture diversification and production.

Table 5. World shrimp production (1984–1994) through capture fisheries and aquaculture[22–24]

Year	Wild catch ('000 mt)	Aquaculture ('000 mt)	Aquaculture % total	Total ('000 mt)
1984	1,748	177	9.2	1,925
1985	1,938	213	9.9	2,151
1986	1,962	305	13.5	2,267
1987	1,900	490	20.5	2,390
1988	1,985	566	22.2	2,552
1989	1,949	613	23.9	2,562
1990	1,967	662	25.2	2,630
1991	2,013	823	29.0	2,836
1992	2,062	881	29.9	2,943
1993	2,071	835	28.7	2,906
1994	2,160	921	29.9	3,080

Development of sustainable aquaculture

Aquaculture can be defined as tending the confined waters for growing aquatic organisms and harvesting the production for human benefits. One of the main objectives of the aquaculture technologies was to increase productivity of the cultured waters, i.e. increasing the intensity of production. In a closed system, for all purposes, such as a fish-pond, the increase in intensity of culture causes changes in the ambient water and soil, leading to deterioration of the environment. With suitable inputs, which would raise the costs, the water and soil conditions can be recovered, though not easily to the original purity, but to tolerable levels. If the aquaculture units are small or dispersed, the problem of greater environmental deterioration may not be much, and can be managed. However, if the density of the units were too high for the environment, i.e. the water shed or the ecosystem, i.e. beyond its *carrying capacity*, then serious problems could arise.

When there is a high price for the aquaculture product, such as the shrimp, unless proper plans, policies and enforcement through legislation are in place, haphazard development of aquaculture ventures could take place. This would be unsustainable, creating impacts not only to aquaculture itself but also to other competing/co-operating sectors. This would cause problems concerning deterioration of environment, and inroads to other sectors through demands for water, salination, restriction of movements of people, navigation and fish capture, urbanization, tourism, etc. Above all, this would affect the sustainability of the system itself through autopollution, which results in diseases and mortality of the cultured organisms to the extent of making the system itself uneconomical due to poor returns or its complete collapse, as already pointed out. In many of these cases uncontrolled increase in the number of shrimp culture units/ponds per unit area/coastline has gone much beyond the *carrying capacity* of the ecosystem (environment) and has led to the collapse of the systems. While in the case of individual units/ponds or farms much can be recovered by improved management of the systems, in collective development of the ecosystem the developments should be restricted to an overall plan on density of units/farms (water area) and their distribution, based on EIA studies. Further, adequate consideration should be given to legal and social aspects, according to the policies laid out, and enforce these policies through legislation, as indicated before, so that under no circumstance the *carrying capacity* of the environment is exceeded[29,30] and socio-economic norms violated.

Thus, it is not just the development of technology alone, however perfect and high yielding, which is needed, but also a *holistic* approach to development of aquaculture, taking into consideration all the factors involved (technical, environmental and socio-economic). The various factors involved in such an approach, at the stage of site selection of the aquaculture ventures are shown in Figure 4. It is with this background that we have to review the current developments in shrimp culture in the country at the highest level.

Though aquaculture is considered by some as a pollution-causing agricultural system, leading to environmental deterioration to the point of auto-collapse (of the system itself) and to the detriment of the ecosystem around and other human sectoral activities, there is perhaps no evidence to fully substantiate this (see country studies and summary report of the regional study on environmental assessment and management of aquaculture development, FAO/NACA) (ref. 5). Despite some

Table 6. Regionwise and countrywise cultured shrimp production in 1984 and 1994 (refs 22–24)

Region/ country	Quantity (1,000 mt) 1984	1994	Increase (%) 1984–1994	% total 1984	1994
Grand total	177.0	920.6	420	100.0	100.00
Asia	139.2	766.7	451	78.60	83.30
Asean	82.5	569.7	591	46.60	61.90
Thailand	13.0	267.8	1959	7.30	29.10
Indonesia	32.1	167.4	422	18.10	18.20
Philippines	29.3	92.6	216	16.60	10.10
S. Asia	18.2	121.8	568	10.30	13.20
Bangadesh	8.2	28.8	250	4.60	3.10
India	10.0	92.0	820	5.60	10.00
Srilanka	0.0	1.0	9900	0.00	0.10
China	19.3	63.9	231	10.90	6.90
Taiwan	12.1	8.9	–26	6.80	1.00
Latin America	37.5	144.3	285	21.20	15.70
Ecuador	33.6	98.7	194	19.00	10.70
Honduras	0.6	8.1	1372	0.30	0.90
Other	0.3	9.6	3222	0.20	1.00

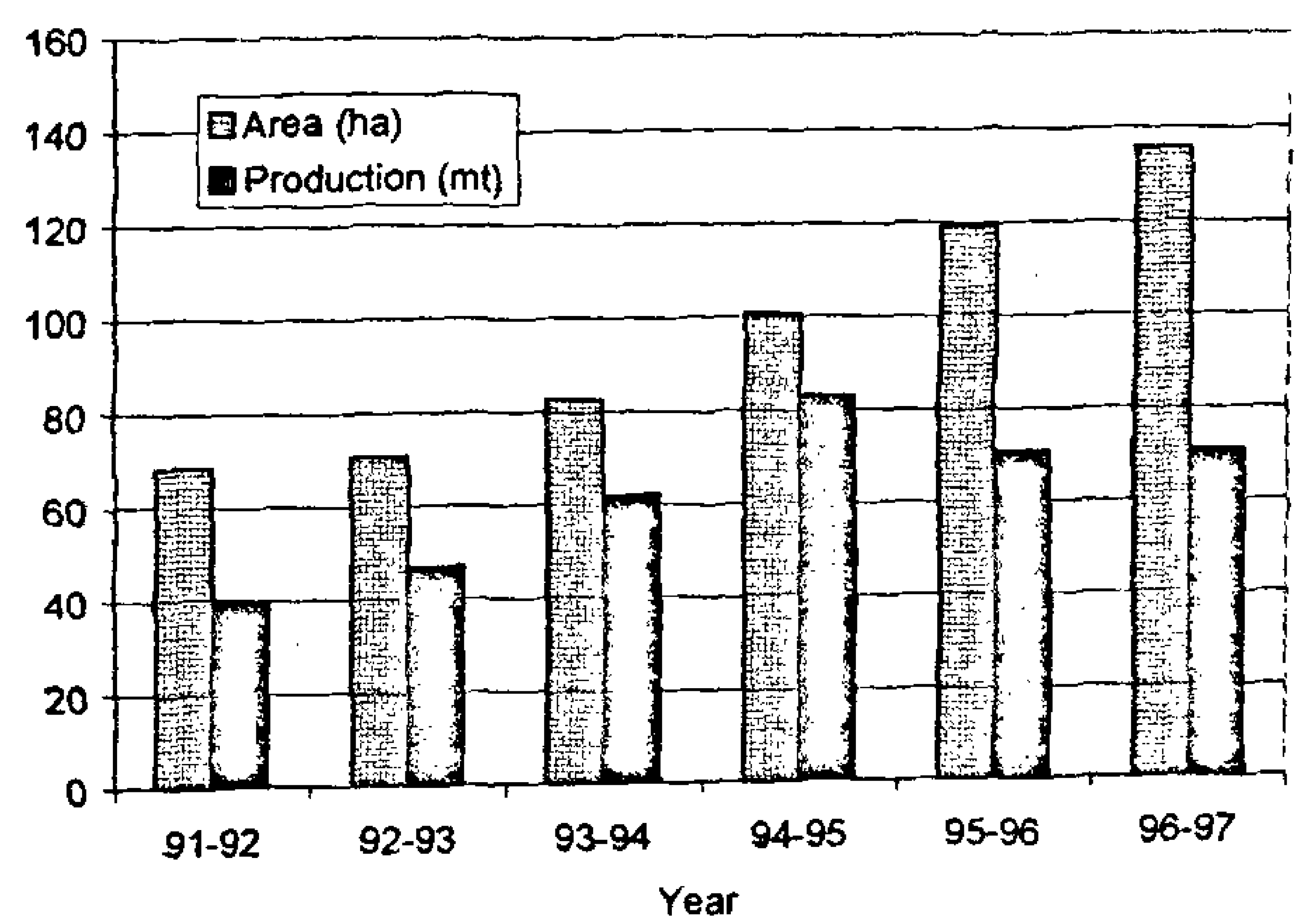

Figure 3. Year wise shrimp production ('000 mt) and area ('000 ha) under culture in India (Source: MPEDA).

sporadic cases of impacts of aquaculture on nonaquaculture activities were evident, these allegations could not be substantiated. On the other hand, there was some evidence to point out that other sectors such as agriculture, housing and tourism, have had negative impacts on aquaculture[5]. The major impact of aquaculture is on aquaculture itself, causing even complete collapse of the systems, as already pointed out. However, it has been pointed out that aquaculture, as practised, does have some negative impacts on other sectors[5]. It would appear that much more information has to be gathered to practice eco-friendly aquaculture.

Later studies[18,19] have shown that none of the impacts caused by shrimp culture in India (Nellore) are serious and that remedies can be found for some of the impacts reported, through discussion and compromise. As pointed out elsewhere[1], some of these failures in aquaculture might be more because of the complexity of aquaculture which, as a young multi-disciplinary science, has not been fully understood. As in the case of agriculture, aquaculture will also take some time to evolve suitable sustainable systems, and there is great need for the study of interacting factors, particularly with reference to environmental and socio-economic issues. This exercise should begin with the commencement of planning, i.e. the selection of site, appropriate for the selected species, covering all aspects of interacting factors and the specific aquaculture systems, as detailed in Figure 4. In short, we should look at aquaculture development from a *holistic* perspective resulting in truly sustainable aquaculture systems[1,31]. Without understanding these complexities and efforts to solve these issues, which are certainly within the capacity of modern science and technology, the cause of aquaculture, so painstakingly developed through public and private efforts is in jeopardy. In this context national and international guidelines for development for aquaculture are of considerable importance[14,15].

Agriculture development perhaps passed through similar vicissitudes, over a longer period in history. With lesser population pressure on nature earlier, much of the mono-crop developments in agriculture have taken roots and now have become necessities for human survival. Let us hope that with some more understanding and with applications of improved environmentally friendly technologies, aquaculture production systems would become more acceptable.

Problems with coastal aquaculture development have already been outlined, but some solutions for rehabilitation of the controversial shrimp farms, and reasonable exploitation of the coasts for aquaculture, in harmony with other sector developments, as a part of integrated coastal zone development through integrated coastal area management plans[8] is called for. Environmental and social problems may exist for inland fish farming also[32–34], which have to be viewed as well with the same attitude of ecological balance and compromise. Suitable environmental management of ponds/farms can lead to alleviation of environmental degradation and disease problems in coastal aquaculture[8,29].

Improvements can be effected through farm level management by incorporation of reservoirs and sedimen-

Table 7. Comparison of biodiversity utilization for aquaculture in selected producer countries (based on data obtained for 1996, taken from FAO ref. 2)

Country	Aquaculture production in 1996 (mt)	No. of major categories utilized[b]	No. of species utilized[c]	Crude biodiversity utilization 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	23,134,520	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, freshwater fishes, diadromous fishes, marine fishes, crustaceans, molluscs, other aquatic animals and aquatic plants.
[c] Number of species recruited for aquaculture; this is likely to be biased by the reporting methodology, but still allows reasonable comparison.
[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, e.g. for India, BUA, is estimated as 0.13, i.e. 13/51 × 2, 51 being the highest number utilized (Korea, RoK/Taiwan) (See text).

tation ponds, and also by appropriate treatment of pond soil and effluents; the latter can be reclaimed through biological means, by culture of molluscs (e.g. oysters in Hawaii[35], and mussels in Thailand[36]) and seaweeds (*Gracilaria*[37,38]), and also using mangroves as a biological filter[29,39]. At the ecosystem level, coastal management should incorporate shrimp culture with other sectoral activities in the coastal zone, avoiding negative impacts by design and compromise, subject indeed to plans and policies laid out. Integrated coastal aquaculture systems, incorporating polyculture of finfish, shellfish and aquatic plants, can possibly result in more harmonized ecological systems which can well be a part of the overall scheme of coastal development as pointed out. Considerable research would be needed in this context, as has been recommended by FAO/NACA (ref. 40). This is an active research area in China, Philippines, Thailand and some other countries.

In a recent study by NACA (ref. 41) it was noted specifically that much of the setbacks suffered by agro-based industries, especially the relatively young but rapidly expanding shrimp culture industry, can be attributed to weak professional management and scientific base for sustained productivity. India could certainly gain by improving both these aspects for developing truly sustainable aquaculture systems.

Lessons for India

In summing up, India could benefit considerably from global experience in aquaculture development. India has achieved considerable production increases in aquaculture, especially in the production of freshwater fishes and shrimps. While progress in research and development of new technologies have already been made, for example in mollusc culture and seaweed culture, these have not yet taken off as serious commercial ventures, and the production gaps between India and China/other Asian countries are very wide (million/s of tonnes). We could utilize much more effectively the diversity of our marine living resources for aquaculture, in the long coastline and expansive EEZ, and perhaps produce a few million tonnes of sea weeds, molluscs, and marine fishes annually through marine farming, if we go by the example of China and even other smaller Asian countries.

Along with the development of technologies, there must be greater efforts to spread the message at the grass roots level, through a newly-oriented extension set-up. India could also benefit much by collaborating with other countries in Asia, which have developed and perfected some of these coastal culture systems, again enabling technology transfer at the grass roots level.

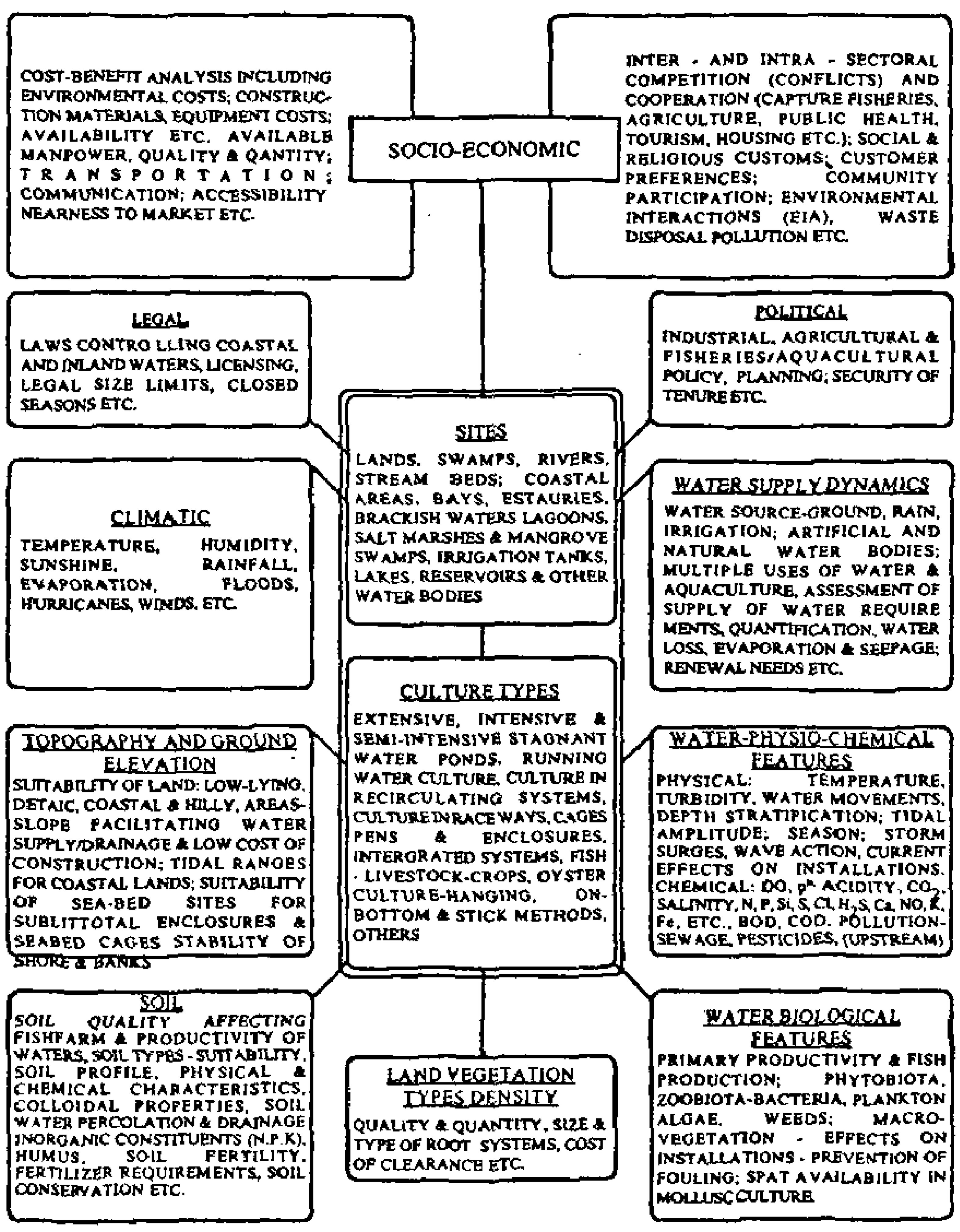

Figure 4. An overview of factors affecting aquaculture (After Kutty[31]).

The experience of shrimp farmers in boosting shrimp production, through technology transfer from countries such as Thailand and Philippines is a good example, as to how we could benefit similarly, in boosting production from our mariculture systems. This is necessary, as we know that the indigenously developed technologies for mariculture systems, e.g. sea bass, mullet, milkfish, groupers, etc. among finfish, and *Gracilaria*, among seaweeds,.are still to spread to the farmers. We certainly have some good technologies in oyster, mussel, and the beginning of holothurian farming, but here again produced quantities are negligible.

In sustainable shrimp culture as well India can benefit greatly from the experience of Thailand, China, Taiwan, Indonesia and Philippines. The Thailand experience in shrimp culture, in 'closed' recirculation systems in combination with culture of seaweeds, mussels and finfishes will be of much interest. Besides, integrated mariculture (polyculture) is a new developing area where Indian research efforts should also cooperate with the regional and global programmes, such as those organized by FAO/NACA. There is need in this context to evolve suitable plans and policies, especially in view of the similarity of environmental and socio-economical issues. This applies to integration of freshwater fish farming with rural development as well, which though highly promising, and despite some good research efforts and trials, has not spread widely in India.

Sustainable aquaculture is currently the need in India as elsewhere. Eco-friendly aquaculture in harmony with environmental and socio-economic needs of the society has to be evolved. While we have considerable manpower in fisheries, much of it is technology-oriented. We have to consider the multi-disciplinary aspects of aquaculture and recognize that the environmental and socio-economic impacts of aquaculture are grave concerns. New thrusts in research and manpower development should be there to ensure that eco-friendly and sustainable aquaculture is developed and that the benefits to the society are optimized through cooperative efforts.

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