Marine capture fisheries of India: Challenges and opportunities

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Marine fisheries production, which was only 0.5 million tonnes (mt) in 1950, increased through the time scale and peaked to 2.7 mt in 1997. Since by 1997 the production (2.2 mt) from inshore waters (< 50 m depth) reached the catchable potential (2.2 mt), scope for further increase in production from inshore waters is limited. The active fishers' population and the number and efficiency of fishing vessels have substantially increased. The improvements made so far on the craft and gear technologies with an objective to increase fish production are becoming counterproductive. Inappropriate exploitation patterns such as concentration of 80% of the total fishing effort in the inshore waters and over-dependence on trawlers are showing signs of detrimental effects on the fisheries. The catch rate of fishing vessels in several fishing centres is on the decline; the catch rate of the trawlers based at Chennai, for instance, has declined from 110.8 kg/h (1991) to 29.7 kg/h (1997). The fishing mortality coefficient (*F*) is higher than the natural mortality coefficient (*M*) for most of the exploited stocks, and the overall *M* : *F* proportion is 1 : 1.9. Fast-growing and high-fecund fishery groups such as prawns, cephalopods and many teleosts have been able to withstand exploitation thus far, but the slow-growing and/or low-fecund groups such as lobsters, sharks and catfishes are showing signs of vulnerability. As the fishers will not limit the fishing operations until zero profitability threshhold is reached, there is a need to regulate the fishing activities and manage the fisheries. There are several biological, economic, social and political factors for the non-existence of effective management policies and for the inadequate implementation of the existing policies. The concept of responsible fishing needs to be practised by introducing limited entry; temporal as well as spatial restrictions to sustain the coastal fisheries. Other options are to increase production by encouraging farsea fishing and utilizing remote sensing for locating potential fishing zones; increase coastal productivity by installing artificial fish habitats and sea-ranching; and to adopt coastal land-based mariculture and seafarming.

THE status of marine fisheries in India is in a crucial phase now. The production has progressively increased by nearly 6 times during the past 50 years. However, there are a few clear warning signals in the characteristics of fish landings, which suggest that the resources in the inshore waters are being fully exploited, and the scope for increasing the production from the present level is limited. During the earlier phases of marine capture fisheries development, the fisheries resources remained rather under-utilized, whereas in the later phases (especially in the 1990s), most of the resources have been either fully exploited or, as feared, over-exploited. Consequently, the present status of marine fisheries calls for quick implementation of appropriate management measures to sustain the production. However, the marine fisheries sector, which has thus far enjoyed free access to the resources, is not prepared to face stringent restrictive management measures. Hence, regularization of common property rights and introduction of the concept of responsible fishing pose some difficulties.

Research on marine capture fisheries conducted by the Central Marine Fisheries Research Institute (CMFRI) prior to the 1980s centered around the development of marine fisheries and improvement of production. In the succeeding years, the emphasis gradually shifted from increasing the catches to sustaining them, and from fisheries exploitation to fisheries management. The CMFRI has identified the problems of the capture fisheries sector, and evolved scientific and administrative techniques helpful in tackling these problems. The input for this paper is largely the outcome of the research conducted by the CMFRI during the past five decades.

Status of marine fisheries

Capture fisheries constitute a highly productive sector, a source of valuable food and employment, and a net contributor to the balance of payment. For India, with strong fisheries interests, the largest fish production comes from the coastal capture fisheries, which contribute, on an average, 62% of the total fish production (including freshwater fish production). The marine jurisdictional area (the Exclusive Economic Zone (EEZ)) is extensive, spanning 2.02 m km^2, which is 38% of the total (5.30 m km^2) marine, freshwater and land areas of the country. In the 3651 fishing villages situated along the 8129 km coastline, about 1 million are employed, full time, in marine capture fisheries (Table 1). The

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fishing sector, which is dominated by small-scale and semi-industrial operations, supports several ancillary industries such as boat building yards, processing plants, etc. Of the marine products export of 385,818 t valued at Rs 47 billion during 1997–98 (ref. 1), about 310,000 t (80%) was from the capture fisheries, but this formed only 11.5% of the marine capture fisheries production. In other words, the produce from the capture fisheries contributes essentially to the domestic consumption needs, and in some measure to the export trade.

Marine fish production in India is exclusively from the capture fisheries, barring the annual production of about 70,400 t of brackishwater prawns through aquaculture[2]. Marine fish production, which was only 0.5 mt in 1950, consistently increased through the time scale, reached high levels of production and peaked to 2.7 mt in 1997 (Figure 1). This phenomenal increase is largely due to (i) the introduction of mechanized fishing vessels and synthetic gear materials, and the development of infrastructure for preservation, processing and storage in the 1950s; (ii) expansion of trawl fleet and indigenous boat construction in the 1960s; (iii) introduction of purseseining, diversification of fishing, development of fishing harbours and expansion of export trade in the 1970s; (iv) motorization of traditional fishing craft, introduction of ringseines and increase in the number and efficiency of craft and gears in the 1980s; and (v) substantial growth in the number and efficiency of trawlers and motorized craft, and change in the export trade from resource-based to food-engineering-based industry in the 1990s. Thus, the marine fisheries sector, which began as a subsistence operation by employing exclusively traditional craft during the pre-independence days, has today attained the status of a capital intensive industry. The gross investment on fishing equipments at current price is estimated as Rs 42 billion, and the value of the annual production as Rs 74 billion[3].

Table 1. Profile of Indian marine fisheries[2,3,40]

Component	No.	Profile
Physical		
Length of coastline		8129 km
Exclusive economic zone		2.02 m km^2
Continental shelf		0.50 m km^2
Inshore area (< 50 m depth)		0.18 m km^2
Biological		
Potential yield in EEZ		3.9 mt
Potential yield in inshore area		2.2 mt
Marine fish production (1997)		2.7 mt
Production from inshore area		2.2 mt
Production from coastal aquaculture (1996)		0.07 mt
Human component		
Fishing villages		3651
Marine fishers population		5 m
Active fishers population		1 m
Infrastructure component		
Landings centres		2271
Major fishing harbours		6
Minor fishing harbours		27
Mechanized vessels		≈ 47000
Motorized vessels		≈ 36500
Artisanal vessels		≈ 150000
Technology component	**No.**	**Capacity (t/day)**
Freezing plants	372	6600
Canning plants	14	52
Ice plants	148	1800
Fishmeal plants	15	330
Cold storages	450	80000
Peeling sheds	900	2700
Economics component		
Gross investment on fishing component (1996)		Rs 42 billion
Value of annual production (1997)		Rs 74 billion
Marine products export (1997–98)		385818 t
Value of export		Rs 47 billion

Challenges: Overview of key issues

The growth in marine fisheries production in the past 50 years and the high levels of production till 1997 mask a series of crises this sector is facing today. Capture fisheries represent one of the best examples of the exploitation of natural resources. The most important characteristic of capture fisheries is that the resources are a common property, the access to which is free and open. The sustained increase in the demand for seafood and the commensurate rise in prices have increasingly encouraged the induction of more manpower and fishing vessels with improved catching efficiency into the traditional as well as the new fishing grounds over the years. As a result, the current harvesting capacity of the fishing fleets far exceeds the estimated biological sustainability of most commercial stocks. Consequently, the catches approach what are believed to be the upper limits of sustainable harvests for the majority of commercially important stocks of fishes, crustaceans and cephalopods.

The development of a fishery over a time scale could be categorized into the: (i) pre-development phase, (ii) growth phase, (iii) full exploitation phase, (iv) over-exploitation phase, eventually (v) collapse phase, and, maybe (vi) recovery phase[4]. Coastal fisheries in India remained in a pre-developed phase till 1962 (pre-mechanization period; annual average production during 1950–1962: < 0.8 mt) and on a prolonged growth phase till 1988 (intensive mechanization period; annual production during 1963–1988: 0.8 to 1.8 mt); and this was followed by the fully exploited phase till 1997 (exploitation of underexploited coastal areas; 1.8 to 2.7 mt/year) (Figure 1). Fishing effort increased steadily throughout the three phases of development, more so in the fully exploited phase. Marine fishing activity in India is an example of uncontrolled fisheries in the initial phase and inefficiently managed fisheries in the subsequent phases. In such a situation, the passage from the current fully exploited phase to the over-exploited phase may occur rapidly, and, if not controlled in time, may lead to collapse. Thus the key issues behind the crisis this sector is facing today are:

Increase in fishing intensity

The active fishers' population increased from 234,478 in 1961–62 to about one million in 1996–97 (ref. 2). The increase in the number of active fishers' population implies less fishing area per fisher. The number of active fishers per unit area in the inshore fishing grounds extending to a depth of 50 m (area: 0.18 m km^2) increased from 1.3/km^2 in 1961–62 to 4.4/km^2 in 1996–97 (Table 2). Despite the steep increase in marine fish production from 0.82 mt to 2.31 mt during the corresponding period from the inshore grounds, the annual production/active fisher declined from 3.5 t to 1.9 t during these decades. In an open access system, crowding of fishers leads to competition and increased physical conflicts between them, resulting in an overall depletion of resources.

Compared to the increase in the manpower, the increase in the number and efficiency of the fishing fleet has been even more substantial. Although the following developments in the fishing sector have led to an overall increase in marine fish production, these have also led to considerable pressure on the fisheries resources: (i) After the progressive introduction of mechanization into the fishing fleets since the late 1950s, the number of mechanized craft kept growing every year and at present there are about 47,000 mechanized craft operating mostly in the inshore areas[2]. (ii) Smaller mechanized craft (overall length (OAL): 8 to 10 m) are being gradually replaced by larger ones (OAL: 13 to 15 m), thereby considerably increasing the sea endurance, fish-hold capacity and fishing efficiency of the vessels. (iii) Trawlers have become the mainstay of the fishing sector (50% of the total catches are from the trawlers[3]), which effectively sweep the entire biota on the sea bottom with great efficiency. (iv) After the introduction of outboard motors since the mid-1980s, the artisanal sector has been steadily upgraded into a motorized sector, and there were 36,500 of such motorized craft in 1996–97 (ref. 2). Motorization has effectively reduced the search duration, increased the sea endurance as well as the accessibility to areas of fish concentration[5]. Nearly 45% of Kerala's marine landings is by the motorized sector[3]. (v) The mouth opening of the trawls has been increased so as to sweep and filter a large volume of water, and the codend mesh size (stretched from knot to knot) decreased (from about 35 mm in the 1960s to the present 20 mm or even 8 mm) to retain the entire gamut of biota that is trapped. (vi) Operation of minitrawls from motorized traditional craft since the late 1980s add to the effective exploitation of inshore demersal stocks. (vii) Operation of purseseines, ringseines, trammelnets and gillnets of more than a kilometer length and an array of different mesh sizes (ranging from 10 to 300 mm (ref. 6)) effectively exploit the entire water column. (viii) Employment of fish finding devices such as echosounders and sonars is of great benefit in precisely locating the fish shoals.

Thus, while these advancements in the fishing sector have yielded considerable economic and social gains, they have not been properly planned in providing long-term solutions to the problems of sustained growth in production. Mechanization, motorization and other technological advancements have been allowed to expand

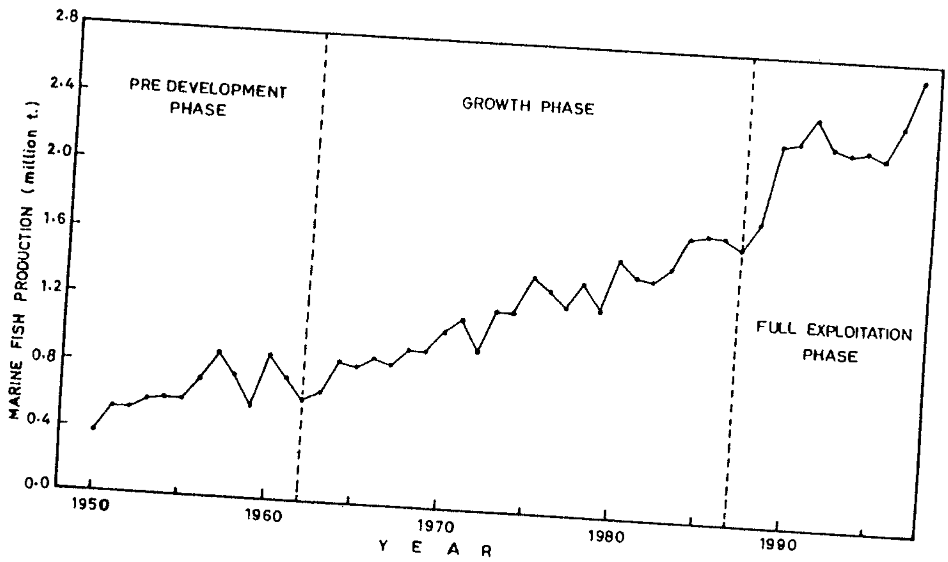

Figure 1. Marine fish production in India during different developmental phases.

without restrictions, or proper assessment of the productive potential of the fishing areas. Consequently, there are indications that these advancements may prove to be counterproductive sooner or later.

Conflicts between fishing sectors

Increasing competition between different fishing fleets as to who should have access to coastal fisheries resources and thereby, benefit directly from the use of these resources is leading to conflicts and confrontations. These disputes are of two types: (i) those involved in different fisheries in the same locality (e.g. conflict between fishers engaged in artisanal and mechanized fishing in sharing a common fishing ground), and (ii) those involving fishers from different localities (e.g. the frequent conflicts between the trawlers of south Andhra Pradesh and Chennai over sharing the productive fishing grounds off the south Andhra Pradesh coast). These disputes frequently culminate in violence between the two opposing parties.

Production *vis-à-vis* resource potential

The ability to increase fish production is limited both by the natural productivity of the environment and the potential of the fish stock, and not just the level of fishing effort employed. Estimates of the total potential yield from the EEZ and their comparison with the actual production yield are important in evolving appropriate strategies for sustaining the yields on a long term basis. There have been several attempts to assess the potential yield of the Indian seas based essentially on the following 3 data sources: (i) past catches and catch trends, (ii) exploratory surveys, and (iii) primary and secondary productivity estimates. As the origin of the data for the analysis was from diverse sources and the potential yield was estimated based on several assumptions, the annual fishable potential yield reported by different authors varied widely from 2.4 to 5.5 mt (Table 3). This uncertainty could be an impediment to a clear understanding of whether a given fishery is under-exploited, optimally exploited, or over-exploited. Therefore, the Ministry of Agriculture, Government of India, constituted a working group for the revalidation of the potential yield in the India EEZ. In 1991, the committee reported that it was not possible to obtain full and adequate data for certain regions and for certain types of fisheries to make precise estimates of the resource availability, abundance and other related information. Regarding the resources in the deeper and oceanic waters and the highly migratory fishes which move into and out of the EEZ, only indirect estimates could be made. Nevertheless, the committee analysed the available information related to productivity, catches and exploratory surveys to a great extent and estimated the annual fishable potential yield of the Indian EEZ as 3.9 mt (ref. 7).

Of the total landings of 2.7 mt during 1997, about 2.2 mt was from the inshore waters (< 50 m depth) and the rest from 50 to 100 m depth. According to the revalidated estimate, the catchable potential in the inshore areas is 2.2 mt (Table 4), which has almost been reached by the commercial fisheries. There is scope for obtaining higher yields in the grounds beyond the 50 m depth, from where the present catch is only 0.5 mt against the potential of 1.7 mt. In the 50 to 100 m deep grounds in northwest zone, there is considerable gap between the potential yield (435,000 t) and the current annual catches (76,000 t) (Figure 2). The depth beyond 100 m remains virtually unexploited at present in all the zones.

Table 2. Impact of increase in the number of active fishers on the fisheries; the estimates on the fishing area and production are estimated for the inshore area (< 50 m depth)

State	Active fishers (No./km^2)		Annual production (t/fisher)	
	1961–62	1996–97	1961–62	1996–97
West Bengal	0.3	2.2	2.1	1.9
Orissa	0.3	2.4	0.5	0.5
Andhra Pradesh	2.9	7.6	1.3	0.7
Tamil Nadu	2.4	5.2	2.0	1.8
Pondicherry	9.6	38.6	1.8	0.6
Kerala	5.9	16.5	2.5	1.7
Karnataka	1.1	9.7	5.3	1.3
Goa	2.4	4.3	2.9	2.9
Maharashtra	0.8	3.2	6.1	3.5
Gujarat	0.2	1.0	8.4	6.0
All India	1.3	4.4	3.5	1.9

Warning signals

The health of a fishery cannot be assessed on the basis of catches alone. As the fishing intensity increases, the catches increase initially but are later followed by adverse effects. Even when the catches are on the increase, a few indicators on the adverse changes could be diagnosed as warning signals. For example, as the fishing intensity increases, (i) the abundance decreases, which is reflected as decrease in the catch rates, i.e. catch per unit effort; (ii) the yield per recruit and the recruitment decreases; (iii) fishing mortality equals or exceeds natural mortality; and (iv) there would be deviations from the normal characteristics of landings (Table 5). The present fisheries situation along many parts of the Indian coast follow any one or more of the signs mentioned above.

Decline in catch rate

Information on the catch rate provides insights into the fishable stock size and the availability of fish to the fishers. In multicraft, multigear and multispecies fisheries,

Table 3. Estimates of marine fisheries resource potential (mt) in the EEZ of India; NW = northwest coast; SW = southwest coast; SE = southeast coast; NE = northeast coast

Area/depth	Coast NW	Coast SW	Coast SE	Coast NE	Lakshadweep	A & N islands	Oceanic	Total	Data source	Ref.
Up to 200 m depth	1.6		0.8					2.4	Fish landings	Jones and Banerji[41]
Up to 200 m depth and oceanic	0.9	1.4	0.7	0.7	0.1	0.2	0.5	4.5	Fish landings	George *et al.*[42]
Up to 200 m depth	1.1	0.9	0.7	0.3				3.0	Fish landings	Alagaraja[43]
Up to 500 m depth and oceanic	1.6	0.9	0.4	0.5	0.1	0.2	0.5	4.2	Productivity	Joseph[44]
Entire EEZ								5.5	Productivity	Nair and Pillai[45]
Entire EEZ								4.5	Exploratory survey	James *et al.*[46]
Entire EEZ	2.4		1.1		0.06	0.2	0.2	3.9	Exploratory survey	Sudarsan *et al.*[47]
Entire EEZ	2.4		0.6			0.7		3.7	Plankton, secondary, tertiary estimates	Mathew *et al.*[48]
Entire EEZ	1.2	1.3	0.6	0.3	0.1	0.1	0.3	3.9	Plankton, secondary, tertiary estimates, exploratory survey, fish landings	Anon.[7]
Entire EEZ	1.1	1.2	0.5	0.3	0.1	0.1	0.2	3.5	Exploratory survey and fish landings	Pillai[49]

Table 4. Estimates of fisheries resources (mt) in inshore and offshore areas of India

Source	0–50 m depth Pelagic	0–50 m depth Demersal	0–50 m depth Total	Beyond 50 m depth in EEZ Pelagic	Beyond 50 m depth in EEZ Demersal	Beyond 50 m depth in EEZ Total	Islands and oceanic
Sudarsan *et al.*[47]	1.0	1.2	2.2	0.7	0.6	1.3	0.4
Anon.[7]	1.2	1.0	2.2	0.7	0.6	1.3	0.4
Pillai[49]	1.1	0.9	2.0	0.4	0.7	1.1	0.4

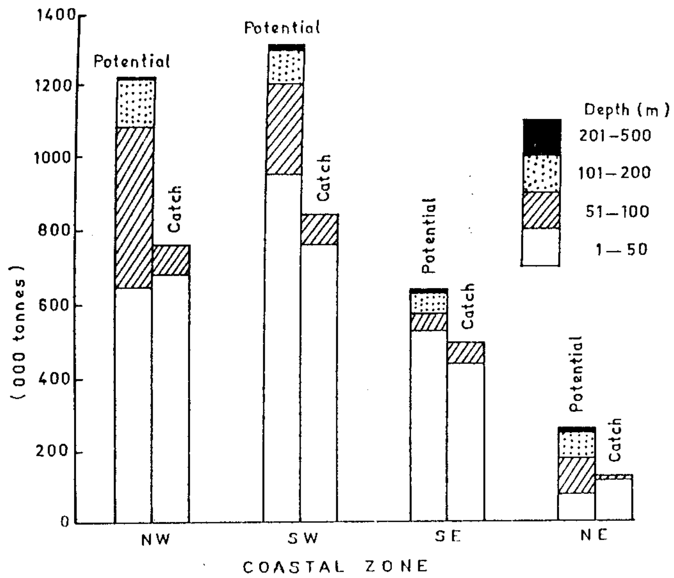

Figure 2. Comparison of catchable potential yield and catches in the four marine zones (NW: northwest; SW: southwest; SE: southeast; NE: northeast).

as in India, it is difficult to standardize the entire fishing effort expended in the country in terms of a particular craft–gear combination. However, the information collected in several major fishing harbours by the CMFRI provides valuable clues on the current fisheries situation. The annual effort of trawlers based at Chennai, for instance, increased from 175,000 fishing h in 1984 to 895,000 h in 1997; the catch/h, which was 32.0 kg/h in 1984, increased to 110.8 kg/h in 1991 but declined to 29.7 kg/h in 1997 (Figure 3). In other words, the catch/h declined considerably beyond the trawler effort of 263,000 h (Figure 4).

High fishing mortality

Fishing activities influence the stocks mainly by affecting fish mortality. There appears to be a consistent relationship between the magnitude of natural mortality rate (M) and sustainable levels of fish mortality rate (F). If the magnitude of F is equal to or higher than the M, it is a sign of overfishing[8]. Estimates of the mortality coefficients are available for a number of fishes and crustaceans distributed along the Indian coast (Table 6). The value of F is higher than the M value in most of the species and the overall $M:F$ proportion of the species given in Table 6 is 1 : 1.9. Clearly, the fishing mortality is the dominant cause of mortality in the Indian marine fisheries.

Table 5. Symptoms and indicators of overfishing on the resources; F refers to fishing mortality; M to natural mortality; L to mean length and lm to length at first maturity

Symptoms	Indicators
Decrease in abundance	Decrease in catch rate Change in species composition
Decrease in recruitment	Decrease in number of spawners
High fishing mortality	$F = M$ or $F > M$
Deviations from normal patterns	Changes in size/composition of catch $L = lm$ or $L < lm$ Changes in fecundity

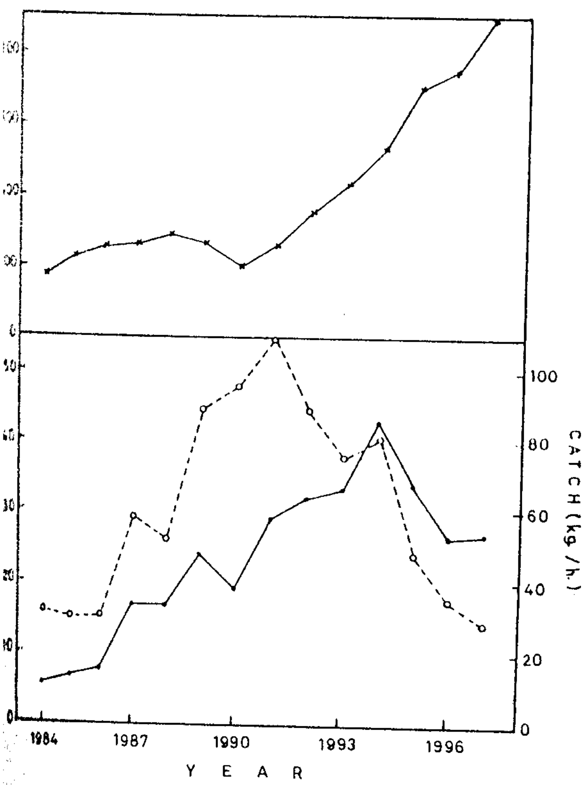

Figure 3. Annual fishing effort (*upper panel*) and catch (•—•) and catch/h (o--o) (*lower panel*) of trawlers based at Chennai Fisheries Harbour.

Decrease in yield per recruit and recruitment

If the fishing effort is very high in a fishery, the growth of individual fish cannot keep pace with the deaths caused by fishing. This situation, called growth overfishing, occurs when the effort is so high that the yield decreases with increasing effort[9]. The Beverton and Holt yield per recruit model[10] considers that the yield is relative to recruitment. The yield per recruit (Y/R) curve often has a maximum, the maximum sustainable yield/recruit (MSY/R), which is dependent on the fishing effort and F (ref. 11). The Y/R for several fish stocks along the Indian coast has either reached the MSY/R or is on the decline due to high F. The F and Y/R of the threadfin bream *Nemipterus japonicus* along the south Andhra Pradesh–north Tamil Nadu coast was 0.46 and 6 g, respectively during 1980–1983 (Figure 5). The stocks were under-exploited then and there was scope for increasing the fishing effort so as to attain the MSY/R of 10 g. The situation changed in the past 15 years. The F increased by several times and reached 3.60 during 1993–1997 and after reaching the MSY/R, the Y/R is presently on the decline (9.5 g). As the F too has increased in a similar magnitude for several fish stocks, it is reasonable to conclude that the fish stocks along the Indian coast are currently being overfished and with further increase in fishing effort, the yield may drastically decline.

Recruitment is the main source of fish biomass which replaces losses from the stock due to F and M. When recruitment declines due to reduction in the parental stock size below the optimum, the potential for depletion becomes high. This situation is known as recruitment

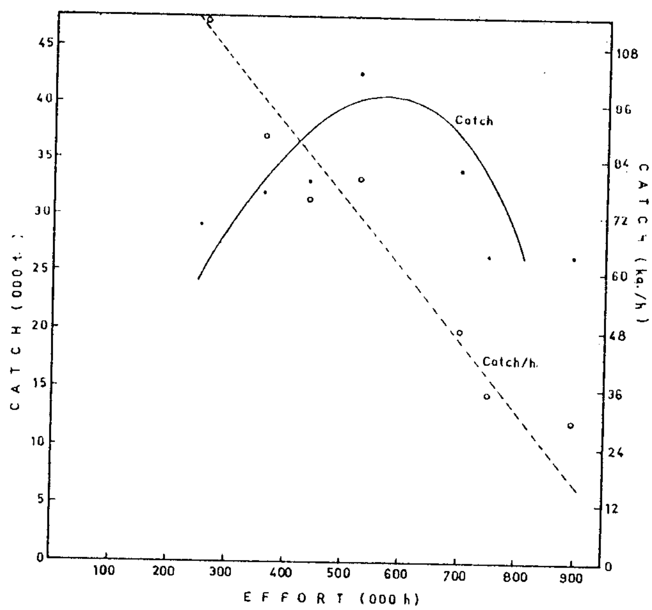

Figure 4. Effects of increase in trawl effort on catch and catch (kg/h) off Chennai.

overfishing [11]. Recruitment–stock relation in respect of the Indian mackerel *Rastrelliger kanagurta* suggests rapid decrease in recruitment if the fishing effort is not controlled to sustain the parent stock at the optimum level of about 3.25×10^{10} fish along the southwest coast of India[12].

Deviations in landing patterns

Alternative indicators of overfishing include the deviations from the normal landing patterns, such as: (i) changes in the size composition of fishes in the catch and (ii) mean length at capture approaching the length at first maturity. For instance, the length range of the threadfin bream *N. japonicus* exploited by the trawlers along the south Andhra Pradesh–north Tamil Nadu coast gradually reduced from 50–309 mm in 1984 to 90-273 mm in 1997 (Figure 6); the annual mean length of this fish in the landings also decreased from 148 mm (1993) to 132 mm (1997). The fish attains first maturity at

Table 6. Mortality coefficients of major species in Indian waters (modified from Devaraj and Vivekanandan[16]); Z = total mortality; M = natural mortality; F = fishing mortality

Species		Z	M	F	Area
Fishes					
Scoliodon laticaudus	(♂)	5.11	1.76	3.35	Veraval
	(♀)	4.03	1.53	2.50	Veraval
Rhizoprionodon acutus	(♂)	4.75	1.12	3.63	Veraval
	(♀)	2.71	1.01	1.70	Veraval
Carcharhinus sorrah	(♂)	3.00	0.63	2.37	Tuticorin
	(♀)	4.90	0.54	4.36	Tuticorin
Sardinella longiceps		2.15	0.75	1.40	Cochin
Rastrelliger kanagurta		3.68	1.24	2.44	Southwest coast
		2.5–6.2	1.50	1.0–5.20	Mangalore
Caranx carangus		6.54	1.18	5.36	Tuticorin
C. leptolepis		6.10	2.19	3.91	Tuticorin
Decapterus russelli		6.65	1.90	4.75	Kakinada
Atropus atropus		6.45	1.76	4.69	Veraval
Harpodon nehereus		2.68	1.46	1.22	Nawabunder
Coilia dussumieri		2.70	1.30	1.40	Northwest coast
Katsuwonus pelamis		2.56	0.75	1.81	Minicoy
Thunnus albacares		3.49	0.49	3.00	Minicoy
Trichiurus lepturus		3.16	0.46	2.70	Kakinada
		1.96	1.05	0.91	Mumbai
Tachysurus dussumieri		1.10	0.20	0.90	Visakhapatnam
T. tenuispinis		1.00	0.51	0.49	Visakhapatnam
		2.00	0.30	1.70	North Kerala
Leiognathus bindus		5.20	0.8–1.5	3.7–4.4	Kakinada
L. jonesi		4.10	2.10	2.00	Palk Bay
Secutor insidiator		6.10	1.8–2.6	3.5–4.3	Kakinada
Johnius carutta		5.10	1.00	4.10	Kakinada
Nemipterus japonicus		2.64	1.10	1.53	Kakinada
		2.99	2.53	0.46	Chennai
		1.37	1.00	0.37	Cochin
		1.67	1.32	0.35	Northwest coast
Crustaceans					
Penaeus monodon	(♂)	5.13	2.02	3.11	Kakinada
	(♀)	10.58	2.89	7.69	Kakinada
Metapenaeus monoceros		4.36	2.42	1.94	Kakinada
		3.66	2.22	1.44	Kakinada
M. dobsoni	(♂)	12.51	2.54	9.97	Kakinada
	(♀)	12.72	3.44	9.28	Kakinada
Exhippolysmata ensirostris		9.90	3.10	6.80	Veraval
Panulirus polyphagus		1.76	0.33	1.43	Mumbai

145 mm length[13] and disturbingly, 37 to 63% of the individuals exploited were juveniles. It is estimated that, on an average, about 31 million juveniles of *N. japonicus* are landed every year by the trawlers operating from Chennai alone.

The indicators and symptoms given above are not exhaustive. Every fishery is unique in some respects and the relevant indicators and considerations vary accordingly. Nevertheless, these symptoms underscore a warning on the adverse changes in the abundance of the marine fisheries resources despite the increases in the catches.

Inappropriate exploitation patterns

Inappropriate patterns of exploitation have led to adverse effects and suboptimal benefits from the resources. Concentration of fishing effort in shallow, coastal shelves (< 50 m depth) has been one of the major problems of Indian fisheries. Marine fisheries operations have remained essentially an inshore activity till about the mid-1980s. Though fishing subsequently extended to the offshore areas, only about 20% of the total landings is from the offshore areas. It is estimated that 80% of the total fishing effort is employed in the inshore area (< 50 m depth) to realize 2.2 mt (80% of total production) during 1997. This causes enormous fishing pressure on the coastal fish stocks.

Over-dependence on trawlers

Following the demand for prawns in the export market, there is an over-dependence on the trawler, which is the most effective gear for their exploitation. It is estimated that 50% of the total landings (1.2 mt) in India was from the trawlers in 1996 (ref. 3). Besides increase in the number and efficiency of the trawlers, there are also instances of conversion of other craft into trawlers. For instance, 35 purseseiners were converted into trawlers in Mangalore. The nonselective trawls indiscriminately exploit almost every fishery group: clupeids to flatfishes, crustaceans to cephalopods, and jellyfishes to sea urchins. An operation of 7 h trawling/day lands 72 species of elasmobranchs (5 species), teleosts (53), crustaceans (12) and cephalopods (2) besides several species of gastropods, bivalves and echinoderms, and an operation lasting to about 60 h by multiday trawlers land 134 species (elasmobranchs, 12; teleosts, 101; crustaceans, 15; and cephalopods, 6) in Mangalore[14]. As the trawlers use very small mesh size in the codend of the net, they are responsible for the exploitation of large quantities of juveniles of all the

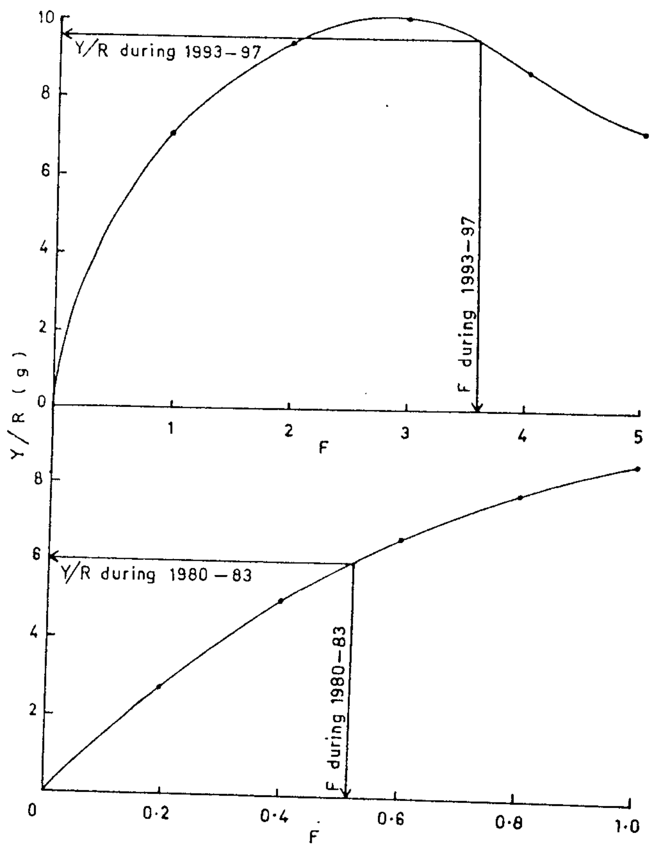

Figure 5. Yield per recruit (*Y/R*) of *N. japonicus* during two time periods (1980–83 and 1993–97) along south Andhra Pradesh-north Tamil Nadu coast; *F* refers to fishing mortality.

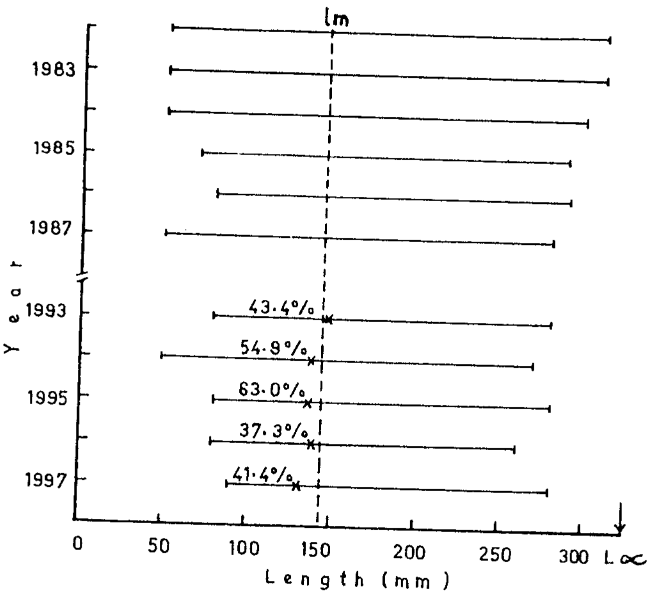

Figure 6. Length range of threadfin bream, *Nemipterus japonicus* exploited by trawlers off Chennai; *lm* = length at first maturity; *L*∞ = maximum length of the species; × refers to mean annual length of the fish in the catch; the values given in percentage refer to the individuals exploited before attaining *lm* (juveniles).

economically important large-sized fishes which are either used as fish meal for poultry or discarded in the sea. Exploitation of juveniles by bull trawlers off Mangalore is estimated as 13% of the catches (see Table 7). With increasing number of large trawlers with sea endurance of 5 days and longer, the magnitude in the value of post-harvest losses is assuming alarming proportions. In addition to the juveniles of economically important fishes, medium quality fishes such as the threadfin breams, lizardfishes and goatfishes are discarded due to lack of adequate storage space in the fish-hold of these vessels. It is estimated that about 10% of the trawl catch worth 5 million rupees was discarded by the Chennai-based trawlers in 1995 (ref. 15). Assuming that 10% of the trawl catch was discarded all along the Indian coast, the quantity and value of the discard are likely to be 120,000 t and Rs 600 million, respectively every year. Selection of proper mesh size and increase in the fish-hold capacity of the multiday trawlers would minimize or eliminate the problem of discards, but little has been done technically to prevent it so far.

Target fishing

The biggest effect of fishing is expected on the fish stocks which are most attractive to the fishers. Being sea food of high export value, the crustaceans – penaeid prawns, spiny lobsters and crabs – the cephalopods – squids and cuttlefishes, and the finfishes – sharks, pomfrets and seerfishes – are the prime target groups of the fishers. The fishery groups are targeted by suitably modifying the gears and by restricting the fishing activities to the areas of abundance of these groups. For instance, the fish trawls have been modified as shrimp trawls by attaching sinkers to the net and by reducing the codend mesh size. The sinkers facilitate the net in properly setting and sweeping the sea bottom so that the prawns ascend from the sea bed and are caught in the net. The small meshes (< 20 mm) in the codend retain even very tiny prawn. The operation of trawlers are concentrated in the areas of prawn abundance and the economic returns of the trawlers are determined by the ratio of shrimp to the total catch. The closer the fishing ground to the shore, more are the prawns caught and the ratio could be 1 : 10 and less, which is considered to be reasonably good. Further the ground from the shore, fewer the prawns caught and the ratio falls to 1 : 20 or 1 : 30. Hence, the fishers do not incline to fish in deeper waters (beyond 50 m depth). While bottom-set gillnets (mesh size: 30 to 70 mm) and traps (funnel width: 150 mm) are employed for exploiting the lobsters and crabs, specialized monofilament gill nets with specific mesh size (ranging from 25 to 100 mm and longlines (hook size: 1 to 14) are employed fc the sharks, pomfrets and seerfishes. In addition to th above-mentioned groups, low-value fishes such sardines, whitebaits and Indian mackerel are also targete by the artisanal fishers, by employing gillnets (me size: 20 to 50 mm) and bagnets (mesh size: 60 mi (ref. 6).

Each fish stock responds to fishing, particularly full exploitation, depending upon its biological characteristics. The biological characteristics, especially the growth rate and reproductive potential of the species determine the capacity of the stocks to withstand target fishing. These two characteristics are obviously the major determinants of the potential yield, and thereby, the catches. Growth determines how quickly the first maturity and maximum size of the species are attained, and the fecundity, which represents the reproductive capacity, determines the recruitment to the fishery. The annual growth coefficient (K in the von Bertalanffy growth equation) varies from 0.1 to 1.8 and the annual fecundity from 2 to > 1 million for the major exploited species of finfishes, crustaceans and cephalopods[16]. Based on these two important characteristics, the major fishery groups could be categorized as follows: (i) fast-growing, high fecund teleosts ($K = 0.5$ to 1.0; fecundity = 80,000 to 1 m eggs), and penaeid prawns ($K = 1.5$; fecundity = 0.4 to 0.9 m eggs); (ii) fast-growing, moderate fecund cephalopods ($K = 0.8$ to 1.0; fecundity = 7,000 to 14,000 m eggs); (iii) slow-growing, high-fecund spiny lobsters and crabs ($K = 0.1$ to 0.2; fecundity = 0.2 to 0.4 m eggs); and (iv) slow-growing, low-fecund sharks ($K = 0.2$ to 0.3; fecundity = 2 to 40 litters) (Figure 7). The difference in response of the above-mentioned 4 categories to target fishing is reflected in the trends in the landings during the growth and full exploitation phases of fisheries development. The annual landing of the fast-growing, and high- and moderate-fecun groups increased during 1980–1997. The landings of the

Table 7. Exploitation of juveniles by bull trawlers off Mangalore during September–November, 1992 (modified from Rohit *et al.*[50])

Species	Total catch (t)	Juvenile catch (t)
Chorinemus spp.	61.2	61.2
Sardinella longiceps	11.6	11.6
Tachysurus thalassinus	4.7	4.7
T. tenuispinis	4.7	4.7
Scomberomorus commerson	3.7	3.7
Decapterus spp.	43.1	8.6
Caranx kalla	25.8	5.2
Leiognathus spp.	15.2	3.0
Megalaspis cordyla	6.0	0.6
Johnius spp.	4.5	0.5
Cynoglossus spp.	1.7	0.2
Pampus argenteus	2.5	0.3
Thryssa spp.	5.1	0.5
Others	800.7	24.0
Total	990.5	128.8

teleosts, for instance, increased from 0.9 mt (1980) to 2.0 mt (1997), the penaeid prawns from 112,037 t to 190,000 t and the cephalopods from 11,335 to 118,000 t (Figure 8).

The prawns are exploited at various stages of their life cycle. The breeders of *Penaeus monodon* and *P. indicus* are exploited for the hatcheries by the trawlers; the post-larvae as wild seeds for aquaculture by artisanal cast nets and scoop nets; the juveniles and migratory subadults are exploited by stake nets and mini trawls; and the adults by bottom trawls and trammel nets (Table 8). Fishing at one stage reduces recruitment to the next fishery and ultimately may affect spawning potential to the extent that recruitment to the post-larval, juvenile and adult stock could be negatively affected[17].

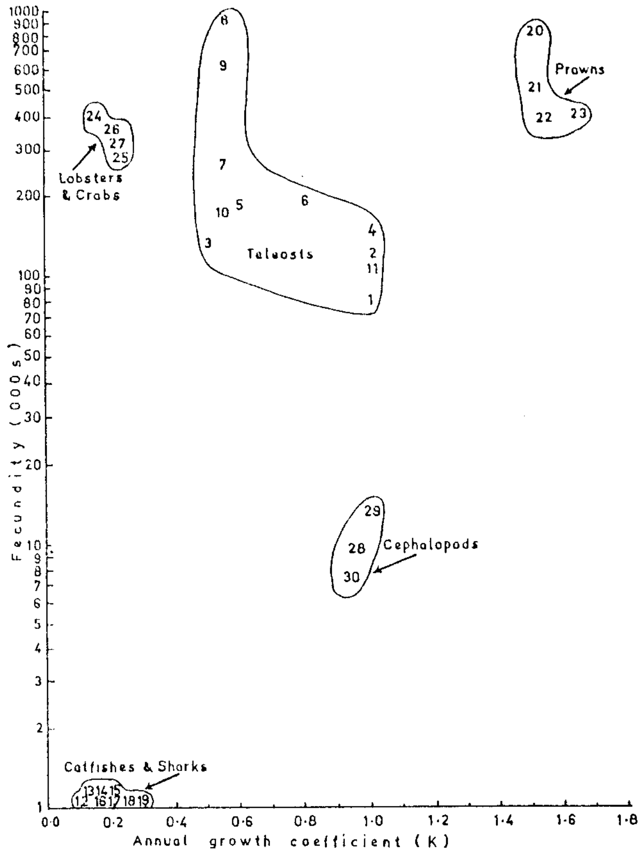

Figure 7. Annual growth coefficient and fecundity of target species along the Indian coast as compiled by Devaraj and Vivekanandan[15]. 1, *Sardinella longiceps*; 2, *Rastrelliger kanagurta*; 3, *Trichiurus lepturus*; 4, *Nemipterus japonicus*; 5, *Saurida tumbil*; 6, *Scomberomorus guttatus*; 7, *Sphyraena obtusata*; 8, *Euthynnus affinis*; 9, *Auxis thazard*; 10, *A. rochei*; 11, *Johnius glaucus*; 12, *Tachysurus dussumieri*; 13, *T. thalassinus*; 14, *T. platysomus*; 15, *T. sona*; 16, *Scoliodon laticaudus*; 17, *Carcharhinus sorrah*; 18, *C. limbatus*; 19, *Rhizoprionodon acutus*; 20, *Penaeus monodon*; 21, *P. indicus*; 22, *Metapenaeus monoceros*; 23, *M. affinis*; 24, *Panulirus polyphagus*; 25, *P. versicolor*; 26, *Scylla serrata*; 27, *Portunus pelagicus*; 28, *Loligo duvaucelli*; 29, *Sepia pharaonis*; 30, *Sepiella inermis*.

The complexity of the life cycle and the discontinuous growth pattern due to moulting could be considered as the biological negative factors of the prawn populations. However, the consistent increase in the prawn catches suggests that the prawns are able to make effective use of their advantageous biological characteristics of fast growth rate associated with short longevity (about 2 years) and high fecundity for stabilizing the populations. The seasonal reproductive patterns are usually bimodal with a major generation of southwest monsoon spawners which are born during the previous southwest monsoon[18]. There is also a generation of summer spawners, which are born during the previous summer, i.e. the generation time is usually 1 year. When a prawn stock is heavily-exploited, as in the Gulf of Carpentaria (Australia), where 85% of the population is caught in 2 months following recruitment[19], the rapid depletion of the stock leads to a maximum reproductive output of the prawns and the generation time is reduced to 6 months[20]. Perhaps similar reproductive strategy is adopted by the Indian prawns as and when the situation demands so as to enhance the reproductive output.

Compared to the penaeid prawns and teleosts, the cephalopods lay relatively few number of eggs. The eggs are yolky, the development is direct and without larval stages or metamorphosis, the young hatch out as miniatures of adult[21]. It is suggested that the cephalopods also resort to alternative life strategies in environments prone to heavy fishing stress, which may be similar to the penaeid prawns[22]. These are probably advantageous for the early development of cephalopods. The cephalopods, which are one of the major target groups of the trawls, exhibited the maximum increase in the landings among the target groups during the full exploitation phase, i.e. from 54,487 t (1989) to 118,000 t (1997) (Figure 8). The increase in the landings in India commensurates with that of the catches in the various fishing grounds of the world oceans that have been subjected to intensive fishing. The world cephalopod catches increased from 0.4 mt in 1950 to 3.0 mt (ref. 23). The relatively low fecundity of many cephalopods, however, has to be viewed cautiously; too severe depletion of the current yearclass may result in abrupt decline in the stock size in the following year[22].

Unlike the cephalopods, the spiny lobsters are highly fecund (Figure 7) but exhibit stagnation in the catches during 1989–1997 (2,500 t; Figure 8). The lobsters have complicated larval life. The phyllosoma larvae of *Panulirus homarus* moult 9 times and pass through 6 critical stages. During this development, the larvae grow from initial length of 1.5 mm to 4.9 mm length (ref. 24). After completing the phyllosoma and puerulus stages, the growth of the juveniles and the adults is very slow ($K = 0.15$). The lobster grows to 18 g in one year and 1 kg in 5 years[25]. Due to these negative factors, the high fecund spiny lobsters are not good candidates for target fishing.

The annual landings of the slow-growing and low fecund group, viz. the sharks has been stagnant (40,000 t), especially after 1992 (Figure 8). Most of the sharks are viviparous or ovoviviparous[26]. Viviparity restricts fecundity but the sharks have prolonged gestation period and produce well-formed young ones. The gestation period of the spadenose shark, *Scoliodon laticaudus*, for instance, is 7 months and the female releases a maximum of 14 well-developed young ones, 14 cm in length. The prolonged gestation and the advantage of releasing well-developed young ones are proving to be counter-productive as large number of pregnant females are captured by the trawls, gillnets and dolnets. The trawls, gillnets and dolnets captured 1.9 million, 1.2 m and 0.1 m pregnant females (total: 3.2 m) and destroyed 11.0 m, 7.5 m and 0.6 m (total: 19.1 m) foetus of *S. laticaudus*

Table 8. Gears employed to exploit different life stages of penaeid prawns

Life stage	Sector	Gear	Length (m)	Breadth/width (m)	Mesh size (mm)
Post-larva and juvenile	Artisanal	Castnet	No specific size		12
Post-larva and juvenile	Artisanal	Stakenet	15–20		10–20 (codend)
Post-larva and juvenile	Artisanal	Dragnet	30–40	2–3	10–20
Juvenile	Artisanal	Dragnet	240	4–5	50–60
Juvenile	Artisanal	Pouch trap	25	25	
Juvenile and adult	Artisanal and motorized	Trammelnet	80–100	3	2–13
Juvenile and adult	Artisanal and motorized	Gillnet	40–50	5	30
Adult	Artisanal	Gillnet and motorized	50–60	4	150
Adult	Mechanized	Trawl	30–40	5	15–20 (codend)

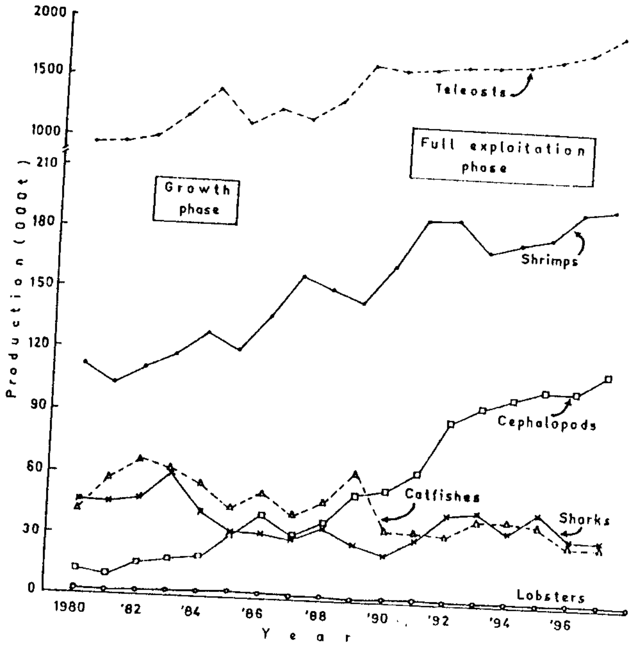

Figure 8. Production trends of the prime target groups during 1980–1997; the growth and full exploitation phases refer to the marine fisheries developmental phases of India (refer Figure 1).

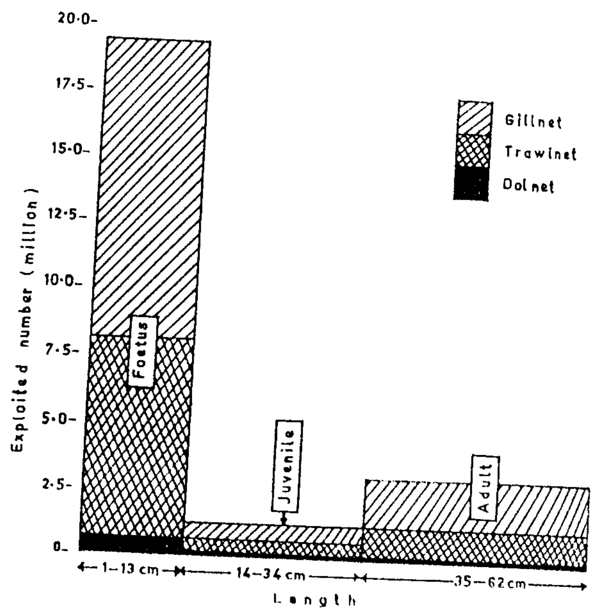

Figure 9. Annual exploitation of foetus, juveniles and adult (pregnant) females of the shark *S. laticaudus* along Saurashtra coast.

ectively along the Saurashtra coast during 1991 16) (Figure 9). Among the teleosts too, the catches a few exceptionally slow-growing and low-fecund ps are either stagnant or are on the decline. The shes, for instance, exhibit slow growth ($K = 0.3$) low fecundity (25 to 260 eggs) (Figure 7). To pensate low fecundity, the male catfishes incubate eggs in the mouth but this advantageous habit is ified by the exploitation of incubating males in large bers. The purse-seines operating off Mangalore, ch target the small pelagics such as sardines, white- s and Indian mackerel, landed 538 t of incubating es in one month and the number of developing eggs royed in the operation was 23 m (38 t) (ref. 28). ugh not highly valued (landing centre price: Rs 30 0/kg) (ref. 16), and not the prime target group, it ears that the catfishes could not withstand the increase he fishing intensity and the catches declined from 55 t (1989) to 30,200 t (1997) (Figure 8). Clearly, slow-growing and low-fecund fishery groups are the t vulnerable groups to target fishing.

oitat degradation

ongoing nonfishing human activities in the coastal, estrial and marine zones impose considerable stress he coastal environment and the coastal fish stocks ole 9). However, the wider impact of human disturbances on the fish stocks, either on short term or long term basis could not be immediately quantified. For instance, it would be difficult to demonstrate that discharge of 100 t of industrial effluents into the coastal waters would lead to a loss of x tonnes of fish. But it is certain that decline in fish biomass due to high fishing effort would be aggravated by the degradation of the coastal habitats[29].

Resource degradation

In recent years, prawn farms all along the Indian coast are severely affected by pathogenic viruses and whitespot disease is rampant in most of the farms. With immediate solution to the whitespot problem not forthcoming, there is growing concern on the threat of viral infection spreading to the wild prawn population through the wastewater discharged from the farms. Preliminary investigations indicate that the wild stocks of the tiger prawn *Penaeus monodon* and the white prawn *P. indicus* are affected by the whitespot disease. The occurrence of infected breeders of *P. monodon* in the wild is very high (> 50%) during the post northeast monsoon months of January and February along the southeast coast[16]. Though there is no direct estimate on the extent of the damage caused by the whitespot, it appears that the virus may pose a risk to the capture fisheries, especially to the penaeid prawns and other crustaceans.

Table 9. Non-fishing human activities in the coastal area of India and their possible effects on the fisheries (modified after Devaraj and Vivekanandan[51]); present seriousness level of impact represented as: 1, least serious; 2, moderately serious; 3, highly serious; 4, most serious, (modified after Rajagopalan[52])

Activity	Possible effects	Seriousness level of effect
Dense human population; increasing urbanization	Habitat degradation such as high levels of faecal coliform in water and soil	4
Discharge of large quantities of untreated domestic waste water	High BOD levels leading to eutrophication; incidence of red tide causing fish mortality	4
Terrestrial runoff of silt due to land reclamation and deforestation	Change in marine environment affects juvenile population	2
Runoff of agro-chemicals and industrial discharge	Hazardous chemicals and solid wastes are lethal beyond certain level	4
Heavy phosphorus loading in estuaries	Lethal beyond certain level	3
Removal of mangroves for wood; mining of coral reefs for lime	Destruction of nursery grounds	2
Fishing by using cyanide and other lethal chemicals	Detrimental to a whole range of organisms in the area	1
Unplanned tourism development	Beach erosion and habitat disturbance	1
Impact of ports	Soil erosion and habitat destruction; ingress of seawater	2
Oil pollution by ships and fishing vessels	Shadowing effect and reduction in dissolved oxygen leading to mass mortality	2

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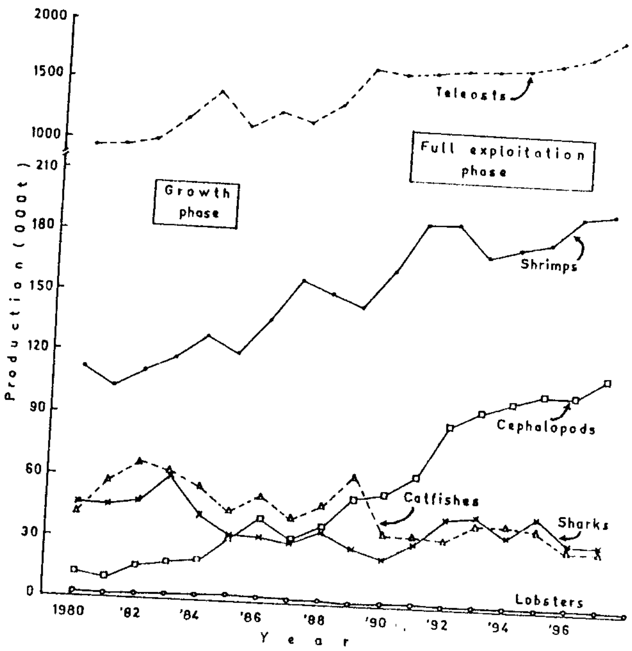

Figure 8. Production trends of the prime target groups during 1980–1997; the growth and full exploitation phases refer to the marine fisheries developmental phases of India (refer Figure 1).

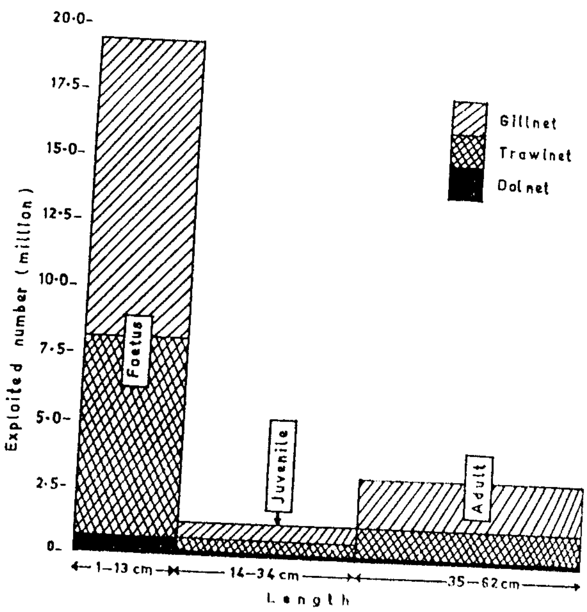

Figure 9. Annual exploitation of foetus, juveniles and adult (pregnant) females of the shark *S. laticaudus* along Saurashtra coast.

Fisheries management vs fisheries exploitation

The issues in the marine fisheries sector are unique compared to any other commercial sector industry. The limited but renewable nature of the resources and the ownership conflicts have no parallel in other sectors. Irrespective of the type of exploiters: artisanal fishers or large fleet owners, their operation will not be limited until the zero profitability threshold is reached. Hence, there is a need for a manager to intervene and regulate their activities.

The objectives of fisheries management are to provide wholesome food, gainful employment and economic benefits. In managing the fisheries, these benefits should be maximized in the short term, and the long term benefits of sustained catches, stable employment, stable economic gains should be ensured, as well as ensuring preservation of the resources for future options[4].

Although for managing the Indian marine fisheries several options are available[30,31], several biological, economic, social and political factors are responsible for the nonexistence of effective management policy, and for the inadequate implementation of the existing policies. Given the status of the multispecies, multicraft and multigear combinations, and too many stakeholders, the management plan has to work under four broad categories: (i) biological management, (ii) increasing production, (iii) increasing productivity of the coastal waters, and (iv) encouragement of alternative sources of production (Figure 10).

Biological management

Responsible fishing

The obvious need for sustaining the marine fisheries production is to regularize the fishing effort, particularly in the inshore, traditional fishing grounds. At present, there is no effective licensing system to limit the entry of new or existing fishing vessels into the coastal fisheries of India. There is no licensing of the artisanal craft and there are instances of mechanized vessels operating without licence. Consequently, the concept of responsible fishing is totally lacking. The only responsibility of the mechanized vessels is to obtain licences from the state government authorities and observe the time to time restrictions, if and when imposed. There is no accountability of the effort expended and the catch realized. As there is no proper marketing system, the revenue realized is totally unaccounted. It is absolutely essential that logbook is maintained for the fishers as part of the licensing condition and that it is made mandatory for the fishers to submit details regarding their fishing effort, catch, area of operation and sale proceedings. Predictably, the fishers will resist such a move and might not provide reliable information. Monitoring and verifying the declared information though not impossible, will be expensive. A mechanism which would facilitate collection of tax from the fishers could be devised for meeting the management cost. Licensing and responsible fishing could be extended to cover the entire fishing industry including the artisanal sector to help monitor fishing effort and optimization of inputs[30]. Implementation of these measures demands strong political will.

Temporal fishing restrictions

Given the fisheries situation that exists in India, temporal restriction, i.e. seasonal closure of fishing appears to be an option, which could be effectively implemented. At present, the maritime state governments in the west coast independently decide on the seasonal closure of operation of mechanized vessels on a year-to-year basis prior to or during the southwest monsoon and ban operation of mechanized vessels for 30 to 145 days in a year (Table 10). Along the east coast, there is no effective seasonal closure, but the mechanized vessels along the south Tamil Nadu coast fish only on 3 days in a week and the artisanal craft on the remaining 4 days. The seasonal closure of mechanized fishing during the monsoon is implemented on the basis that most fish groups undergo peak spawning during the monsoon, and hence, the spawning populations can be spared from exploitation. On the other hand, the tropical fish species exhibit prolonged spawning which is not restricted to monsoon season alone. As a result, spawning occurs throughout the year for one species or another. For

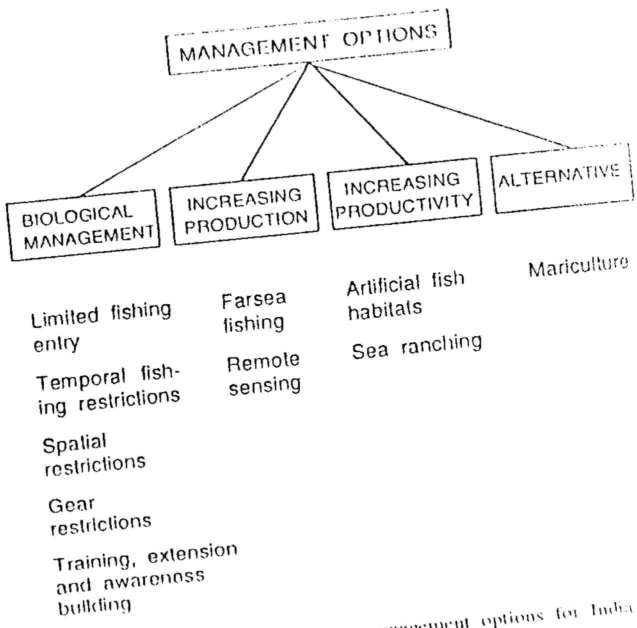

Figure 10. Marine fisheries management options for India

example, the spawning intensity of the ribbonfish *Trichiurus lepturus* extends for 8 months (January to August) in a year, and the carangids, *Caranx carangus* and *C. leptolepis* for 5 months (July to November) along the southeast coast (Figure 11). Nevertheless, seasonal closure reduces the annual fishing effort and helps the escape of the spawning population at least during the period of closure. However, the positive effects of the seasonal closure on the replenishment of fish stocks are yet to be proved. It is important that the magnitude of short-term economic losses and the long-term benefits due to seasonal closure are quantified.

Spatial restrictions

To prevent the conflicts between the fishers of the artisanal and mechanized vessels in sharing the inshore waters, the maritime state governments have banned the mechanized vessels from operating in the inshore areas (for a distance of 5 to 10 km from the shore) (Table 11). However, the regulations relating to the demarcation of fishing areas have inherent weaknesses. First, there is no surveillance to monitor the areas of different types of craft and hence, encroachment by the mechanized vessels in the areas demarcated for the artisanal craft continues for more than a decade after the promulgation of the acts. Second, demarcation of the fishing areas is meant for the protection of the interest of the artisanal fishers. If the acts are strictly implemented, the fishers of the mechanized craft would be at a disadvantage as they would be denied the opportunity to exploit the [illegible] therefore, be necessary to modify the present regulations based on the feedbacks from various sectors so that all the stakeholders are benefited.

Gear restrictions

Measures influencing the species and size composition of the catches include technological restrictions, e.g. gear restrictions such as mesh regulation, hook size

Table 10. Seasonal closure of operation of mechanized vessels during 1997

State	Period of closure	Days of closure (No.)
Gujarat	Mid May–mid September	145
Maharashtra	July and 1st fortnight of August	45
Karnataka	June, July, August	90
Kerala	Mid August–mid September	30
South Tamil Nadu	4 days/week	
North Tamil Nadu	Nil	0
Andhra Pradesh	May and 1st fortnight of June*	45*

*Only for long cruise trawlers.

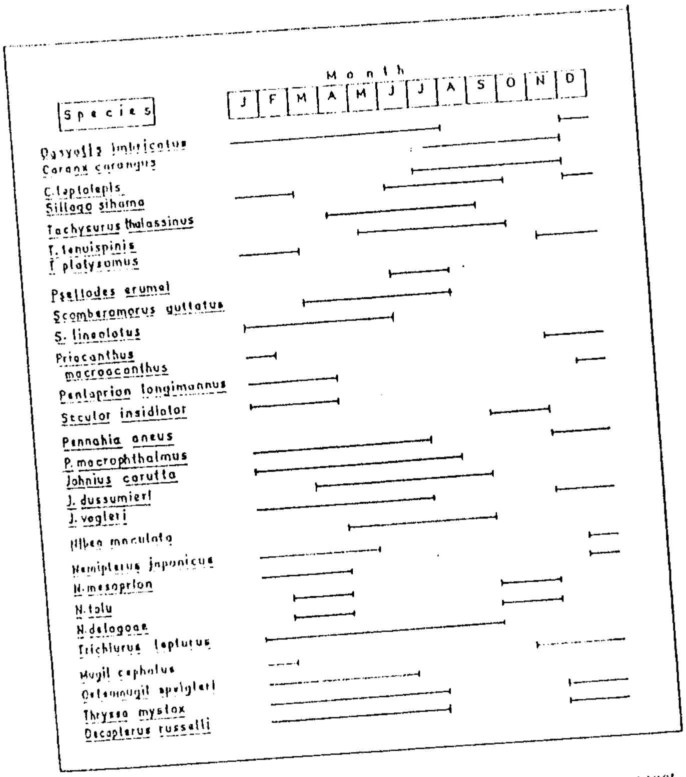

Figure 11. Spawning season of fishes along the southeast coast (modified from Devaraj and Vivekanandan[16]).

Table 11. Demarcation of fishing area for craft of different capacities; OAL: overall length

State	Area and type of operation
Gujarat	No restriction
Maharashtra	Artisanal: 10–20 m depth Mechanized: beyond 20 m depth
Goa	Artisanal: up to 5 km Mechanized: beyond 5 km
Karanataka	Artisanal: up to 6 km Mechanized: < 15 m OAL: 6–20 km > 15 m OAL: beyond 20 km
Kerala	Artisanal: up to 10 km Mechanized: < 25 GRT: 10–22 km > 25 GRT: beyond 23 km
Tamil Nadu	Artisanal: up to 5 km Mechanized: beyond 5 km
Andhra Pradesh	Artisanal: up to 10 km Mechanized: < 20 m OAL: 10–23 km > 20 m OAL: beyond 23 km
Orissa	Artisanal: up to 5 km Mechanized: < 15 m OAL: 5–10 km > 15 m OAL: beyond 10 km
West Bengal	No restriction

control. The mesh size in the mouth (30 mm) and codend (< 20 mm) parts of the trawl nets prevalent in the country is uniformly very small. The fishery scientists have recommended minimum mesh size of 50 and 25 mm for the mouth and codend of the trawls, respectively[3]. The purpose of controlling the mesh size is to permit the escape of juveniles hoping that their growth would largely compensate for the loss and increase the exploitable biomass, which might be available to the fishery later. It is also believed that if fishing of immature fish is intense, the abundance of the species may be so reduced before it approaches maturity that there would be insufficient adult fish surviving[32]. But practising mesh size regulation is questionable; considering not only the possibility of effectively enforcing it but also its relevance in a multispecies fishery where the body shapes of different species are diverse. The body shape of different species is one of the important factors, which determines the mesh size selection. The body shape, measured as depth ratio (standard length/maximum depth of body) of a few commonly-exploited species ranges from 1.6 (black pomfret *Parastromateus niger*) to 20.4 (ribbonfish *Trichiurus lepturus*) (Table 12). Also, large mesh size (> 20 mm) facilitates escape of prawns, which is not acceptable to the fishers. There is, therefore, no single mesh size which is optimum for all the species. Pauly[33] has computed the optimum mesh size suitable for all the fishery groups (including the prawns) by assuming several factors and by using *Y/R* analysis. The efficacy of this optimum mesh size is yet to be tested.

Management of human component

Fisheries management involves more of management of people than of management of fish. Of all the people involved in fisheries, the fishers are in direct contact with the resources, and hence, they play a major role in influencing fisheries management policies. The fishers are the first to face the consequences of any management measure. Any restriction in fishing activity, short term or long term, will leave several of them jobless. This is aggravated by the fact that they are too specialized to fit in anywhere else at a comparable income level. Neither an artisanal fisher nor a fisher involved in mechanized fishing wants to be managed. Although fishers are aware of the problems of overfishing, exploitation of juveniles and the declining stocks; their tendency is to maximize their gains. However, when fish stocks declined in the Japanese waters, the fishers themselves implemented management measures[34]. In India too, the present situation cannot continue for ever. The fishers will be forced to adopt management measures on their own initiative when the value of catch rate declines below the operational cost. Sustaining a fishery requires the participation of all the stakeholders and participatory management lends itself to mutual surveillance among the fishers. It is otherwise hardly possible to monitor and regulate the operations effectively by the government machinery alone as the infrastructure needed will be too elaborate and the cost involved will be prohibitive.

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Species	Body depth ratio
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Management for increasing production

Management opportunities are not limited to fishing restrictions alone. There are opportunities which should be given due consideration for improving marine fish production. Encouraging farsea fishing and utilizing remote sensing for locating potential fishing zones (PFZs) would be rewarding.

Farsea fishing

Considering the annual potential of 1.7 mt (Anon[7]; Table 4) and the present production of 0.5 mt from depths beyond 50 m in the EEZ, it appears that there is scope for increasing the annual production by 1.2 mt from the farsea. Despite the tremendous growth in India's marine fisheries from artisanal and subsistence status to an industrial status, and the declaration of the EEZ in 1977, there has never been a commercial farsea fishing worth mentioning. The Government of India chartered foreign vessels in the early 1980s and entered into joint venture arrangements with large industrial houses in the early 1990s for exploiting the farsea. As both these schemes were stiffly resisted by the local fishers, the schemes were terminated a few years after commencement[16]. As a result, there has been persistent poaching in the Indian EEZ by foreign vessels.

The fishing sector in India has not ventured into farsea fishing so far. The fishable potential in an unit area is considerably low in depths beyond 50 m (0.9 t/km^2) compared to that in the inshore waters (12.2 t/km^2). The vastness and the low resource abundance/km^2 in the farsea necessitate expenditure of considerable fishing effort in fish scouting. Also, farsea fishing requires larger vessels (OAL: > 17 m) with sophisticated fishing technologies involving high establishment and maintenance costs. Hence, it would not be possible to divert the current excess fishing vessels (OAL: < 17 m) towards farsea fishing. For the benefit of the Indian fishers, it is high time that the abundance of fishery resources in the farsea is estimated for arriving at technoeconomic feasibility of farsea fishing. The Fishery Survey of India is at present engaged in exhaustive survey to locate the abundance of resources in the farsea. Mapping of these areas and utilization of remote sensing data are urgently required for exploiting the farsea resources.

It is estimated that 0.5 mt or about 40% of the unexploited stocks in the farsea are the tunas, which undertake transoceanic migration. For exploiting and managing these straddling stocks, the concept of regional cooperation, i.e. cooperation among neighbouring countries, is gaining importance. For instance, the countries bordering the Bay of Bengal such as India, Bangladesh, Thailand and Sri Lanka could share the information available on the biological characteristics and distribution of the straddling stocks and the technical know how of exploiting them by mutual agreement and cooperation. Realizing the nature of distribution of the resources in the national and international waters, the high cost of exploiting them and the technology capability that is required, regional cooperation appears to be the most viable option for achieving the optimum potential benefits of the farseas.

Remote sensing

Satellite observations on the sea have progressed immensely consequent upon India launching her own remote sensing satellites. The greatest single advantage of satellite remote sensing over conventional observations is its coverage of wide areas in very quick time. The quality, type and sheer quantity of data have increased manyfold to the point where, for certain types of data sources, it has become possible to speak of remote measurement rather than remote sensing. However, remote sensing is in its infancy as far as fisheries assessment is concerned. Satellite imageries provide continuous data on sea surface temperature and chlorophyll, covering most of the EEZ. These data have several applications including mapping the Potential Fishing Zones (PFZs) and fisheries forecast on a short- and long-term basis. These forecasts, on an experimental basis, revealed that the catch rate of pelagic fishes in the PFZs is higher by about 60% compared to that in the nonPFZs[35]. However, the PFZ for demersal fishes cannot be forecasted based on the remote sensing data available at present. Although too few data are available now to confirm conclusions on the PFZs, the results do indicate the possible future applications for the direction of fishing effort and for the resource management. Once this is achieved and the forecasts are proved reliable, it will be of great assistance to the fishers.

Increasing coastal productivity

It has been widely recognized in several countries that installation of artificial fish habitats (AFHs) and sea-ranching are helpful in increasing the productivity of the coastal waters.

Artificial fish habitats

An AFH is an object or a construction, which provides an ecosystem and a habitat for the fishes. Any drifting or sunken object such as logs, branches of trees, palm leaves, ship wrecks serve as AFHs. In recent years, the emphasis is shifting from launching simple, temporary fish aggregating devices to installing semi-permanent fish habitats and many kinds of modern and expensive devices made up of concrete, ferrocement and high density polyethylene at 20 to 30 m depth along the southeast and southwest coasts.

When an AFH is first launched, microorganisms grow on it. A large number of invertebrates and fishes assemble to feed on the microorganisms and larger fishes later aggregate to feed on the smaller ones. The advantages of AFH are: (i) It attracts, provides shelter, concentrates fishes and thus enhances coastal fish production. (ii) It enables the artisanal fishers to fish near the shore without spending much time and energy to locate fish. (iii) Though the catch rate is only marginally higher in the AFH areas, it is possible to realize 1.5 times higher value from the catches in the AFH areas, as the catches from the AFHs consists of quality fishes such as the carangids, perches as well as cephalopods in large quantities[36]. (iv) It improves the income of the artisanal fishers as they could increase the catch by fishing in the AFH areas in addition to exploiting the regular fishing grounds.

Disputes often arise within and between fishing villages on the rights of fishing in the AFHs. However, there are good examples of cooperative AFHs functioning successfully in Kerala[36]. Knowledge on the aggregating behaviour of fishes and installation of technologically advanced structures have made the AFHs highly successful in Japan[37]. In the Philippines, each purseseine operator launches his own AFH structure in the farsea and exploits tunas which aggregate around his structure[38]. In India, the CMFRI has recommended the creation of control. The mesh size in the mouth (30 mm) and codend (< 20 mm) parts of the trawl nets prevalent in the country is uniformly very small. The fishery scientists have recommended minimum mesh size of 50 and 25 mm for the mouth and codend of the trawls, respectively[3]. The purpose of controlling the mesh size is to permit the escape of juveniles hoping that their growth would largely compensate for the loss and increase the exploitable biomass, which might be available to the fishery later. It is also believed that if fishing of immature fish is intense, the abundance of the species may be so reduced before it approaches maturity that there would be insufficient adult fish surviving[32]. But practising mesh size regulation is questionable; considering not only the possibility of effectively enforcing it but also its relevance in a multispecies fishery where the body shapes of different species are diverse. The body shape of different species is one of the important factors, which determines the mesh size selection. The body shape, measured as depth ratio (standard length/maximum depth of body) of a few commonly-exploited species ranges from 1.6 (black pomfret *Parastromateus niger*) to 20.4 (ribbonfish *Trichiurus lepturus*) (Table 12). Also, large mesh size (> 20 mm) facilitates escape of prawns, which is not acceptable to the fishers. There is, therefore, no single mesh size which is optimum for all the species. Pauly[33] has computed the optimum mesh size suitable for all the fishery groups (including the prawns) by assuming several factors and by using *Y/R* analysis. The efficacy of this optimum mesh size is yet to be tested.

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The fishing sector in India has not ventured into farsea fishing so far. The fishable potential in an unit area is considerably low in depths beyond 50 m (0.9 t/km^2) compared to that in the inshore waters (12.2 t/km^2). The vastness and the low resource abuna total of 77 AFHs each of 1 ha area in select areas along the coastline costing 77 million rupees during the IX five year plan (1997–2002) (ref. 2).

Searanching

Searanching is one of the very few alternatives to increase coastal productivity and to conserve the resources. In searanching, selected species are bred, hatched and reared in hatcheries up to juvenile/fingerling stages and released, normally in bays, lagoons and protected ecosystems. The fingerlings could be captured later when they grow to a larger size. The CMFRI searanched penaeid shrimps, pearl oysters and clams on a modest scale in the past[2]. Hatchery produced postlarvae of the green tiger prawn, *P. semisulcatus*, which were released in a lagoon off Mandapam at the rate of 0.7 million/year for 7 years, moved into the sea in 24 h and the juveniles (length: 60 to 110 mm) were recruited in about 50 days. Bivalves such as the pearl oyster and clams appear to be ideally suited for searanching because of their sedentary habit. Searanching of hatchery produced 1 million spat and 7 billion larvae of the pearl oyster. *Pinctada fucata* was observed to increase the density of the oyster population in about a year. Similarly, searanching of 64,000 seeds of the clam *Paphia malabarica* off Tuticorin produced 62 kg/25 m^2 in 5 months. These experiments prove that ranching helps in replenishing the populations.

Searanching is practised very successfully in Japan, where about 45 species are being searanched to supplement the natural stocks[34]. This activity is subsidised by the government and implemented by searanching associations in collaboration with fisheries cooperative associations. For producing and releasing enormous quantities of seeds for stock improvement through searanching, adequate hatchery and rearing infrastructure facilities are needed. For India, the possibilities of searanching should be thoroughly examined by taking into consideration the system of implementation, especially identifying the searanching agencies and the rights of capture. Despite these intriguing factors and the high initial cost, it is worthwhile to invest in searanching.

Alternative options: Mariculture

Coastal land-based mariculture and seafarming are considered as viable options to meet the shortfall of seafood production. Besides that, mariculture would diversify the extra manpower in the capture fisheries sector and also be able to socioeconomically transform rural areas through gainful employment of coastal labour. There are several economically viable small-scale technology packages readily available in India. Some of the proven technologies are: (i) pearl culture (onshore and sea); (ii) mussel culture (onshore and sea); (iii) prawn culture; (iv) prawn broodstock bank; (v) prawn backyard hatchery; (vi) cottage prawn feed industry; (vii) crab fattening; (viii) lobster fattening; and (ix) seaweed culture. Due to the nonavailability of proper hatchery and rearing techniques, aquaculture of many species has not been commercialized (Table 13). At present, only shrimp

Table 13. Marine organisms of aquaculture importance

Species	Hatchery technique	Rearing technique
Fin fishes		
Mugil cephalus	X	X
Liza parsia	X	X
L. macrolepis	X	X
Valamugil seheli	X	X
Chanos chanos	X	X
Etroplus suratensis	X	X
Lates calcarifer	X	X
Epinephelus tauvina	X	X
E. dussumieri	X	X
Lethrinus spp.	X	X
Lutjanus spp.	X	X
Sillago sihama	X	X
Anguilla bicolor	X	X
Siganus spp.	X	X
Ornamental fishes	X	X
Crustaceans		
Penaeus monodon	XXX	XXX
P. indicus	XXX	XXX
P. semisulcatus	XXX	XXX
Scylla serrata	X	XXX
Portunus pelagicus	XX	XX
Panulirus homarus	X	X
P. ornatus	X	X
P. polyphagus	X	X
Thenus orientalis	X	X
Molluscs		
Perna viridis	XXX	XXX
P. indica	XXX	XXX
Pinctada fucata	XXX	XXX
Crassostrea madrasensis	XXX	XXX
Anadara granosa	XXX	XXX
Meretrix meretrix	XXX	XXX
M. casta	XXX	XXX
Katelysia opima	XXX	XXX
Paphia malabarica	XXX	XXX
Trochus radiatus	X	X
Xancus pyrum	X	X
Sepia pharaonis	X	X
Loligo duvaucelli	X	X
Sea cucumber		
Holothuria scabra	X	X
Sea weeds		
Gracilaria edulis	XX	XX
Gelidiella acerosa	XX	XX
Porphyra spp.	XX	XX
Sargassum spp.	XX	XX
Ulva spp.	XX	XX
Euchaemia sp.	XX	XX

X = techniques under development; XX = techniques developed; XXX = techniques developed and commercialized.

farming has taken roots in the country. During 1996–97, India produced about 70,400 t of prawns through aquaculture[2] and became the fourth largest producer in the world. It is estimated that prawn farming could yield 20 times more prawn compared to similar investment in prawn fishing[39].

Most of the existing aquafarms, big or small, are owned by agricultural farmers and entrepreneurs and not by fishers. The reasons for the fishers not coming forward to take up small-scale aquaculture are many. The coastal rural fishers face shortage of capital and practically have no access to formal credit. To make aquaculture a successful coastal activity, the financial sector should provide assistance to the fishers and support small-scale aquaculture. Other suggestions are: (i) to strengthen the legal base to support rural aquaculture; (ii) to form fishermen aquaculture cooperatives which will manage the activities in the coastal villages; (iii) to arrange leasing of open sea areas to fishermen co-operatives; (iv) to train and develop skilled personnel to run hatcheries and farms; and (v) to arrange supply. Many coastal fishers are still unaware of the benefits of aquaculture but view aquaculture as an activity, which is detrimental to the coastal fish stocks. The developmental organizations should establish small-scale model farms and hatcheries in coastal areas to demonstrate and convince the fishers of the benefits and prospects of mariculture. This would greatly help in diverting the surplus manpower, that is actively engaged in fishing.

The capture fisheries sector is at its crossroads today. It is needed, at this stage, to evolve and implement scientifically planned management options for each coastal area taking into consideration the characteristics of that area. For this, districtwise coastal zone maps should be prepared from the view point of fisheries management. The CMFRI has initiated this process with a census on the number of craft and gears, fish landings and fishing effort, other fisheries infrastructure facilities, and the number of aquaculture farms and hatcheries in each coastal district, besides statistics of agricultural and industrial activities and demography. This attempt is expected to help in planning viable management options for each coastal district with multidisciplinary input from the fishery scientists, managers, economists, social scientists and the fishers.

At present, inland, brackishwater and coastal fisheries development is essentially under the purview of the state governments, and farsea fisheries development under the Govt of India. In addition, the following ministries/organizations are involved in fisheries research and development: Ministry of Agriculture (Fishery Survey of India, Integrated Fisheries Project, Central Institute of Fisheries and Nautical Engineering), Ministry of Commerce (Marine Products Export Development Authority), Indian Council of Agricultural Research (Central Marine Fisheries Research Institute, Central Inland Capture Fisheries Research Institute, Central Institute of Fisheries Technology, Central Institute of Brackishwater Aquaculture, Central Institute of Freshwater Aquaculture, National Bureau of Fish Genetics Resource, National Research Centre on Coldwater Fisheries, the deemed University Central Institute of Fisheries Education), Council of Scientific and Industrial Research (National Institute of Oceanography), Department of Ocean Development (National Institute of Ocean Technology), Department of Biotechnology, several fisheries colleges and Universities. To coordinate the activities of these organizations and for effectively implementing the research and development programmes, it is imperative to form a separate fisheries ministry in the Govt of India. A holistic approach with strong political will is urgently needed for the development of the fisheries sector, in general, and for sustaining the marine fisheries resources, in particular.

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