1. RESERVOIR FISHERIES RESOURCES OF INDIA

Despite the overwhelming importance of reservoirs in the inland fisheries of India, a reliable estimate of the area under this resource is still elusive, causing serious constraints to the R & D activities. The available estimates made by various agencies are conflicting and wide off the mark. The National Commission on Agriculture (NCA) has estimated the total area under reservoirs at 3 million ha during the mid-sixties and projected its growth to 6 million ha by 2000 AD (Anon., 1976). Bhukaswan (1980) put the figure at 2 million ha. Srivastava *et al*. (1985) compiled a list of 975 large and medium reservoirs in the country with an estimated area of 1.7 million ha. One of its major shortcomings is the exclusion of small reservoirs, especially those in Tamil Nadu, Karnataka and Maharashtra.

1.1 TANKS AND SMALL RESERVOIRS

Enumeration of the medium and large reservoirs is relatively easy, as they are less in number and the details are readily available with the irrigation, power and public works authorities. However, compilation of data on small reservoirs is a tedious task as they are ubiquitous and too numberous to count. The problem is further confounded by ambiguities in the nomenclature adapted by some of the States. The word *tank* is often loosely defined and used in common parlance to describe some of the small irrigation reservoirs. Thus, a large number of small manmade lakes are designated as tanks, thereby precluding them from the estimates of reservoirs. There is no uniform definition for a tank. In the eastern States of Orissa and West Bengal, pond and tank are interchangable expressions, while in Andhra Pradesh, Karnataka and Tamil Nadu, tanks refer to a section of irrigation reservoirs, including small and medium sized water bodies. In fact, some of the tanks in Tamil Nadu and Karnataka are much bigger than Aliyar and Tirumoorthy reservoirs.

David *et al*. (1974) defined the peninsular tanks as *water bodies created by dams built of rubble, earth, stone and masonry work across seasonal streams, as against reservoirs, formed by dams built with precise engineering skill across perennial or long seasonal rivers or streams, using concrete masonry or stone, for power supply, large-scale irrigation or flood control purposes*, which is obviously tedious and inadequate. Irrespective of the purpose for which the lake is created and the level of engineering skill involved in dam construction, both the categories fall under the broad purview of reservoirs, *i.e.*, man-made lakes created by artificial impoundment of surface flow. From limnological and fisheries points of view, the distinction between small reservoirs and tanks seems to be irrelevant. Moreover, numerous small reservoirs fitting exactly into the description of the south Indian tanks are already enlisted as reservoirs in the rest of the country. Therefore, the large tanks have been treated at par with reservoirs for the purpose of this study.

In Andhra Pradesh, the tanks and small reservoirs are segregated either arbitrarily or based on yardsticks that have no limnological relevance. For instance, all the small reservoirs in the State, created before independence and those without a masonry structure and spillway shutters are called tanks. Tanks in Andhra Pradesh are classified as *perennial and long seasonal.* Of the 4 604 perennial tanks, 1 804 in Srikakulam, East Godavari and Krishna districts, having average size less than 10 ha, are not considered as reservoirs in this study. The remaining 2 800 tanks covering a total area of 177 749 ha have been reckoned as reservoirs.

In Tamil Nadu, the tanks are classified as *short seasonal* and *long seasonal*. The latter, also known as *major irrigation tanks*, have an average size of 34 ha and retain water for 9 to 12 months a year. Major irrigation tanks of Chengalpattu MGR and Salem districts are larger with average area 222 and 156 ha respectively. A total of 8 837 major irrigation tanks of Tamil Nadu with water surface area of 300 278 ha have been included under small reservoirs. Similarly, 4 605 perennial large water bodies in Karnataka, listed as *major irrigation tanks* are brought under the ambit of reservoirs.

1.2 CLASSIFICATION OF RESERVOIRS

Fish Seed Committee of the Government of India (1966) termed all water bodies of more than 200 ha in area as reservoirs. David *et al.* (1974) while classifying the water bodies of Karnataka State, considered impoundments above 500 ha as reservoirs and named the smaller ones as irrigation tanks. In the former USSR, reservoirs up to 10 000 ha area are assigned the status of small reservoirs, whereas in USA they may range from 0.1 ha to several ha (Bennet, 1970). In China, where reservoirs are classified on the basis of storage capacity (Lu, 1986), those holding more than 100 million m^3 of water are classified as large reservoirs, 10 to 100 million m^3 as medium and 0.1 to 10 million m^3 as small reservoirs. Assuming an average depth of 10 m, small reservoirs of China are in the size range 10 to 1 000 ha.

Reservoirs are classified generally as small (<1 000 ha), medium (1 000 to 5 000 ha) and large (> 5 000 ha), especially in the records of the Government of India (Sarma, 1990, Srivastava *et al*., 1985), which has been followed in this study. All man-made impoundments created by obstructing the surface flow, by erecting a dam of any description, on a river, stream or any water course, have been reckoned as reservoirs. However, water bodies less than 10 ha in area, being too small to be considered as lakes, are excluded.

After removing the anomalies in nomenclature, especially with regard to the small reservoirs, by bringing the large (above 10 ha) irrigation tanks under the fold of reservoirs, India has 19 134 small reservoirs with a total water surface area of 1 485 557 ha (Table 1.1). Similarly, 180 medium and 56 large reservoirs of the country have an area of 527 541 and 1 140 268 ha respectively. Thus, the country has 19 370 reservoirs covering 3 153 366 ha (Table 1.2).

The State of Tamil Nadu accounts for maximum number (8 895) and area (315 941 ha) of small reservoirs, followed by Karnataka (4 651 units and 228 657 ha) and Andhra Pradesh (2 898 units and 201 927 ha). Medium reservoirs constitute less than 1% of the total number of units and 17% of the total area. Madhya Pradesh with 169 502 ha tops the table in respect of medium reservoirs. Andhra Pradesh, Rajasthan, and Gujarat have more medium reservoirs than Madhya Pradesh, though the water area in these States is much less. Karnataka has a preponderance in number (12) of large reservoirs. Nevetheless, the 7 reservoirs in Andhra Pradesh in this category are much larger and have a water area of 190 151 ha (Table 1.2).

The predominance of reservoirs in the peninsular States, *viz.*, Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Orissa and Maharashtra is elucidated by Figs 1.1 to 1.4. These six States account for more than 56% of the total reservoir area in the country. Of the 19 134 small reservoirs, 17 989 (94%) are located there, contributing 63% of the total water area. Similarly, 34% of the medium reservoirs is distributed in these States.

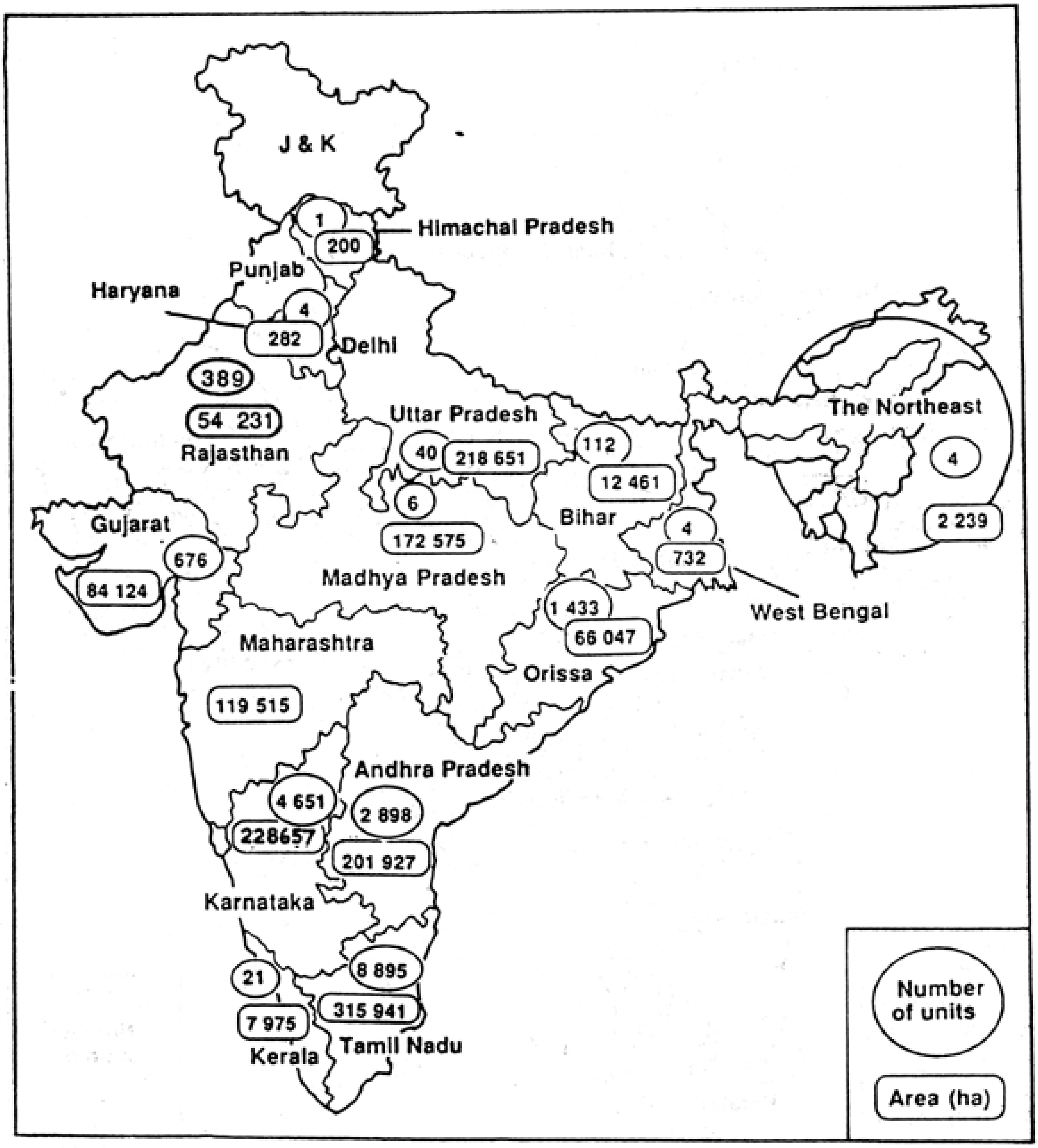


Figure 1.1 Distribution of small reservoirs in India

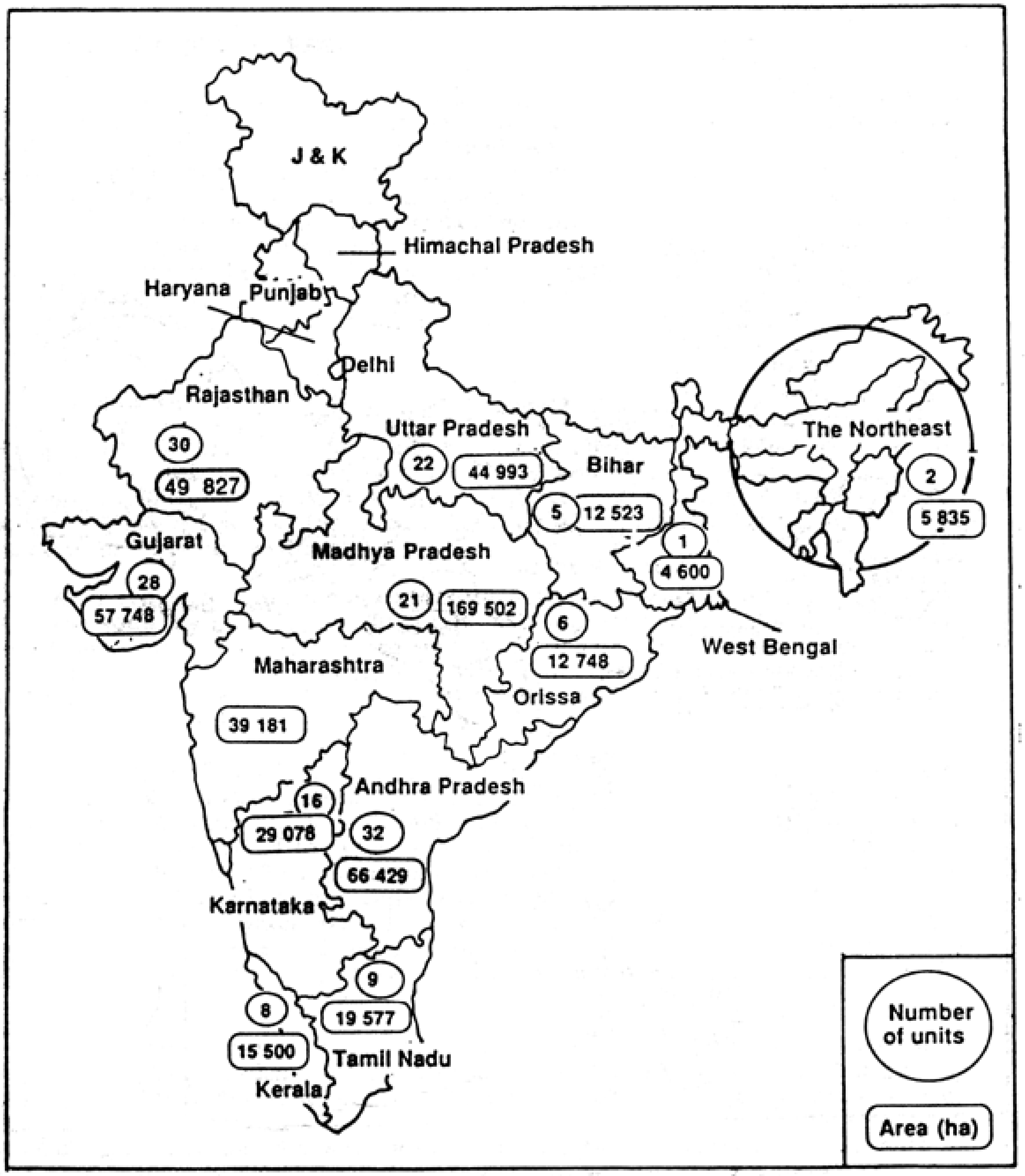


Figure 1.2 Distribution of medium reservoirs in India

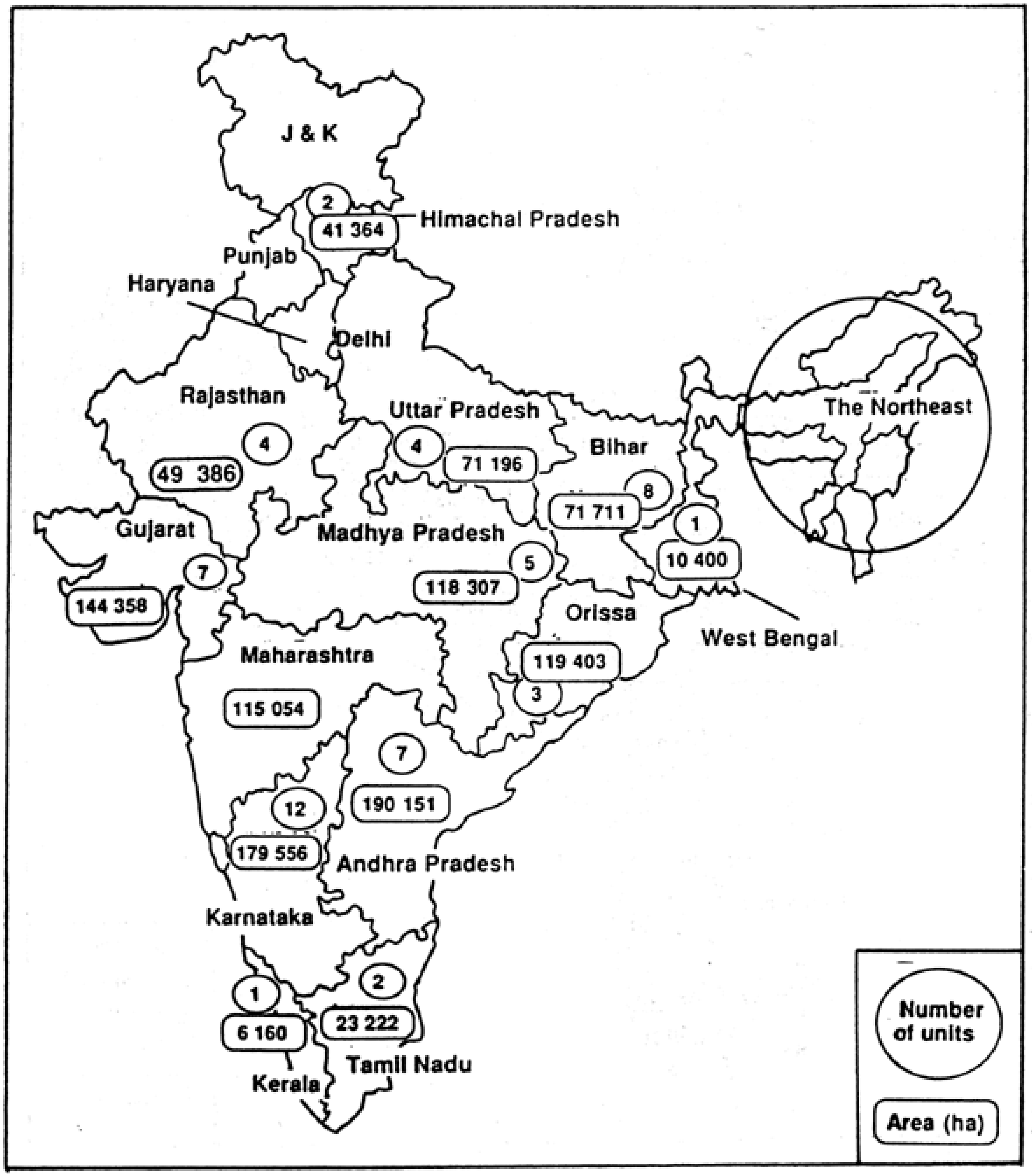


Figure 1.3 Large reservoir in India

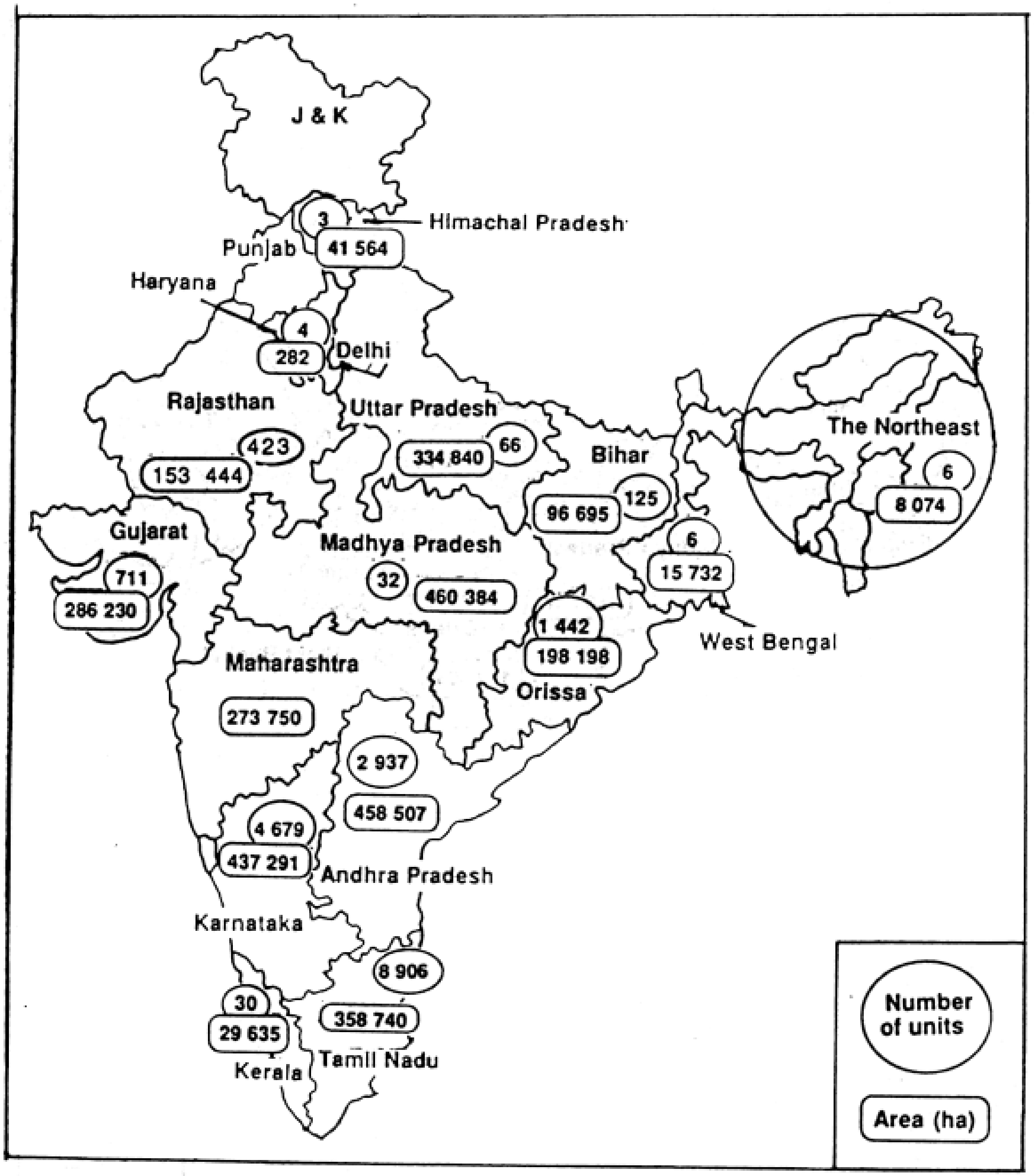


Figure 1.4 Distribution of reservoirs (all categories) in India

Table 1.1. Distribution of small reservoirs and irrigation tanks in India

States	Small reservoirs		Irrigation tanks		Total	
	Number	Area(ha)	Number	Area(ha)	Number	Area(ha)
Tamil Nadu	58	15 663	8 837	300 278	8 895	315 941
Karnataka	46	15 253	4 605	213 404	4 651	228 657
Andhra Pradesh	98	24 178	2 800	177 749	2 898	201 927

Gujarat	115	40 099	561	44 025	676	84 124
Uttar Pradesh	40	20 845	-	197 806	40	218 651
Madhya Pradesh	6	172 575	-	-	6	172 575
Maharashtra	-	-	-	-	-	119 515
Bihar	112	12461	-	-	112	12 461
Orissa	1 433	66 047	-	-	1 433	66 047
Kerala	21	7 975	-	-	21	7 975
Rajasthan	389	54 231	-	-	389	54 231
Himachal Pradesh	1	200	-	-	1	200
West Bengal	4	732	-	-	4	732
Haryana	4	282	-	-	4	282
North East	4	1 639	-	600	4	2 239
Total	2 331	551 695	16 803	933 862	19 134	1 485 557

Table 1.2. Distribution of small, medium and large reservoirs in India

States	Small		Medium		Large		Total	
	Number	Area(ha)	Number	Area(ha)	Number	Area(ha)	Number	Area(ha)
Tamil Nadu	8895*	315 941*	9	19 577	2	23 222	8906	358 740
Karnataka	4 651*	228 657*	16	29 078	12	179 556	4 679	437 291
Madhya Pradesh	6	172 575	21	169 502	5	118 307	32	460 384
Andhra Pradesh	2 898*	201 927*	32	66 429	7	190 151	2 937	458 507
Maharashtra	-	119 515	-	39 181	-	115 054	-	273 750
Gujarat	676*	84 124*	28	57 748	7	144 358	711	286 230
Bihar	112	12 461	5	12 523	8	71 711	125	96 695
Orissa	1 433	66 047	6	12 748	3	119 403	1 442	198 198
Kerala	21	7 975	8	15 500	1	6 160	30	29 635
Uttar Pradesh	40**	218 651	22	44 993	4	71 196	66	334 840
Rajasthan	389	54 231	30	49 827	4	49 386	423	153 444
Himachal Pradesh	1	200	-	-	2	41 364	3	41 564
Northeast	4**	2 239	2	5 835	-	-	6	8 074
Haryana	4	282	-	-	-	-	4	282
West Bengal	4	732	1	4 600	1	10 400	6	15 732
Total	19 134	1 485 557	180	527 541	56	1 140 268	19 370	3 153 366

* Including large irrigation tanks

** Not exhaustive

1.3 DETERMINANTS OF RESERVOIR PRODUCTIVITY

The production propensity of a reservoir is determined by a set of key environmental parameters, especially the water and soil quality which, in turn, are functions of the geo-climatic conditions under which it exists. Thus, the geography, climate, topography and a number of physiographic parameters play a vital role in bestowing the reservoirs their intrinsic productive potential. India, being a country of continental proportions, its reservoirs are spread over various types of terrains, and soil types exposed to diverse climatic conditions and they receive drainage from a variety of catchment areas.

1.3.1 The geoclimatic features

The land area of India covers 3 287 728 km^2, half of which lying above the Tropic of Cancer and the rest in the tropics. The southern limit is as close to equator as 8° 4' N. The climate varies from the warm tropical in the south to the temperate in the north. The landscapes include some great mountains, extensive alluvial plains, riverine wetlands, plateau lands, deserts, coastal plains and deltas. The main soil types are alluvial, deep and medium black, red and yellow, laterite, saline and desert, and forest and hill (Fig. 1.5). Almost all conceivable forms of vegetation, including tropical evergreen, littoral and swamp, tropical moist deciduous, tropical thorn, montane sub-tropical, Himalayan and alpine are present in various parts of the country.

The major physiographic divisions of the country are the Himalayas, the Indo-Gangetic plains, the Vindhyas, the Satpuras, the Western Ghats, the Eastern Ghats, coastal plains, the deltas and the riverine wetlands (Fig. 1.6). The alignments of hills and their elevation have profound influence on the prevailing winds and thereby the distribution of rainfall in the country. India receives, on an average, 105 cm of rainfall every year, which is one of the highest in the world for a country of comparable size. Total amount of rainfall received annually is estimated at 400 million hectare meters (mhm), out of which 230 mhm goes back to the atmosphere as evapotranspiration, leaving 170 mhm to impregnate the rivers through surface flow (110 mhm) and regeneration (60 mhm). The temporal and spatial distribution of rainfall exhibits wide variations within the country.

More than one million km^2 of the country's geographical area receives inadequate rainfall. This includes the deserts, the semi-arid regions of north India and the rain shadows of the Western Ghats (Fig. 1.7). Large rivers like the Godavari, the Krishna, the Pennar and the Cauvery pass through extensive tracts of low rainfall areas and hence carry much less water than the rivers passing through high rainfall areas like the northeast and the west coast. In the northeast, the Khasi and Jaintia hills receive a bountiful 1 000 cm of rainfall annually and the Brahmaputra valley gets precipitation to the tune of 200 cm. Rainfall up to 1 142 cm recorded in Cherrapunji and Mawsyngram in the region is one of the highest in the world. In the west coast of India, heavy rainfall occurs along the slopes of the Western Ghats, where during the southwest monsoon, rainfall of very high order is recorded on the windward side which rapidly decreases towards the leeward side. The Indo-Gangetic plains and the Himalayas also receive rainfall above the national average.

Seasonal distribution of rainfall in India is worth noticing. The Western Ghats, Assam, parts of sub-Himalayan West Bengal and some higher elevations of Himalayas up to Punjab have more than 100 rainy days a year, while in extreme west Rajasthan the number of rainy days are less than 10 (Rao, 1979). The south-west monsoon season extending from June to September is the principal rainy season in the country as a whole when 75% of the annual rainfall is received. In more than one third of the country, 90% of the rainfall and thereby the surface flow is limited to a very brief period of 2 to 3 months. This extreme seasonality in rainfall distribution makes the irrigation reservoirs a *sine qua non* for agriculture in India, especially in the rainshadows of the peninsular India. People inhabiting this area learned to store water by erecting barricades across minor stream and rivulets from time immemorial. In recent years, with the advent of modern hydraulic structures, larger and more complex dams came into being. The steep gradient and heavy discharge of water in the mountain slopes of Western Ghats, the northeast and the Himalayas offer ideal opportunities for hydro-electric power generation. A large number of such projects have come up in these regions in recent years. Thus, the reservoirs have become a common feature in the Indian landscape, dotting all river basins, minor drainages and seasonal streams.

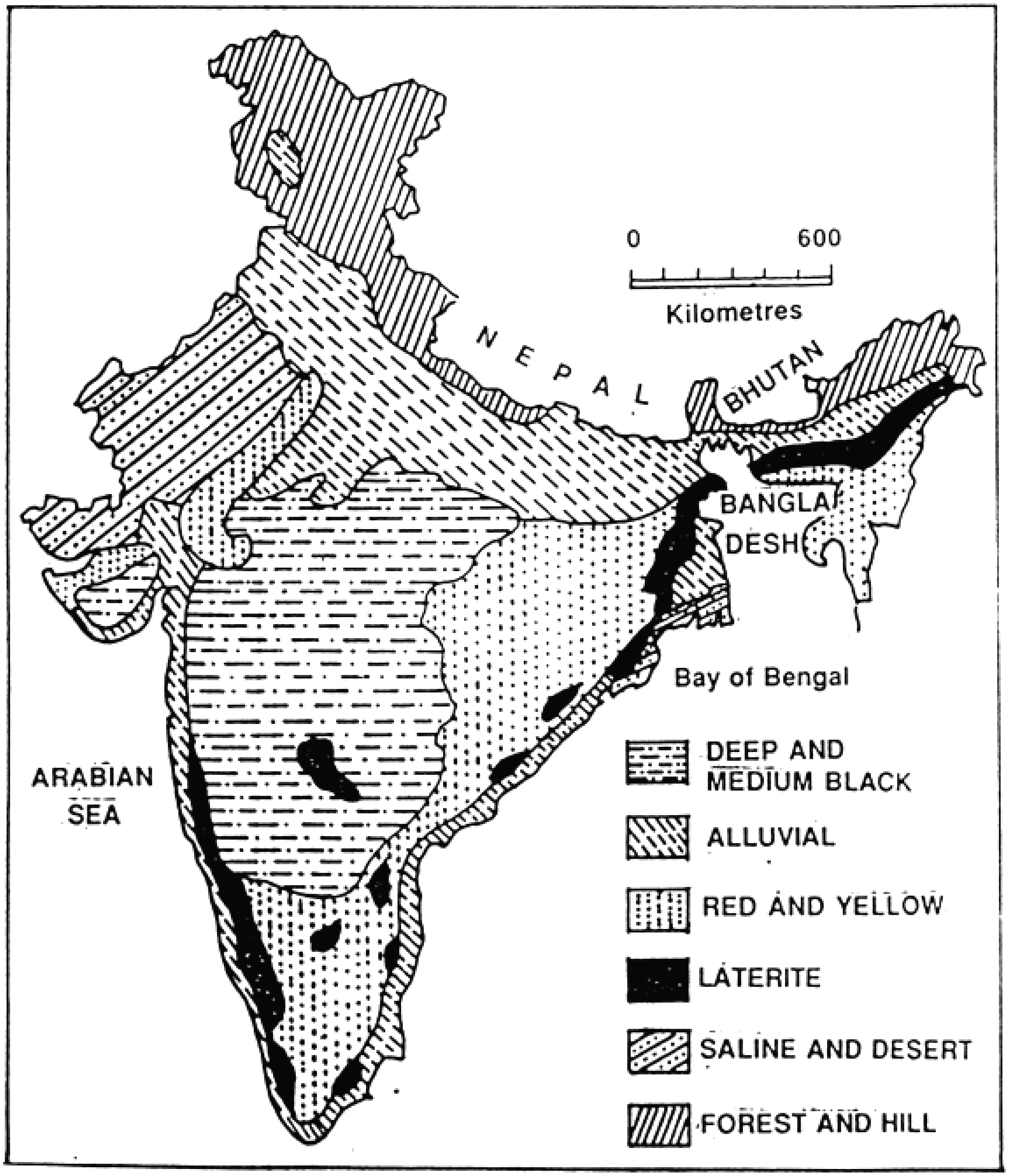


Figure 1.5 Soil msp of India

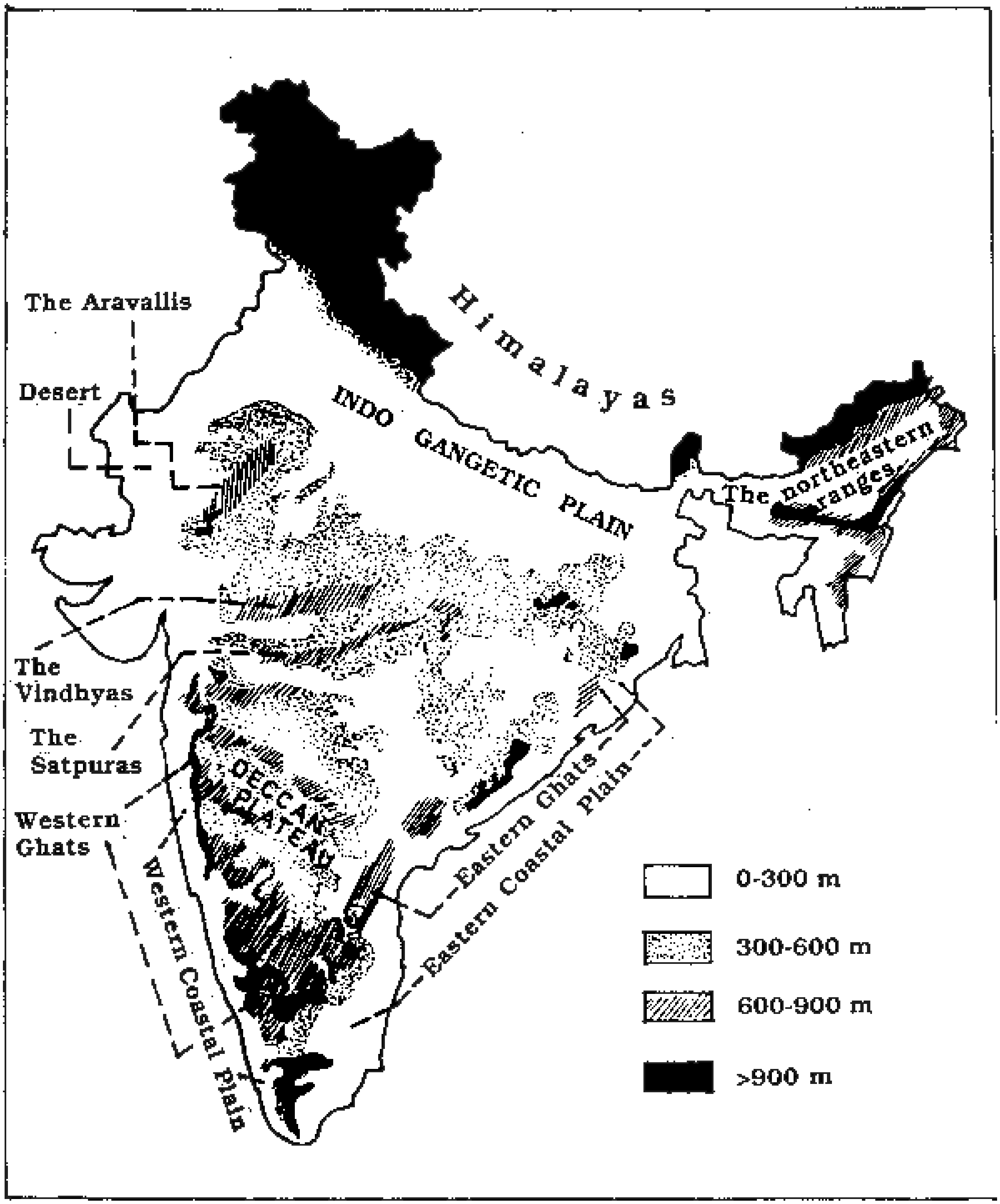


Figure 1.6 Phusiographic features of India

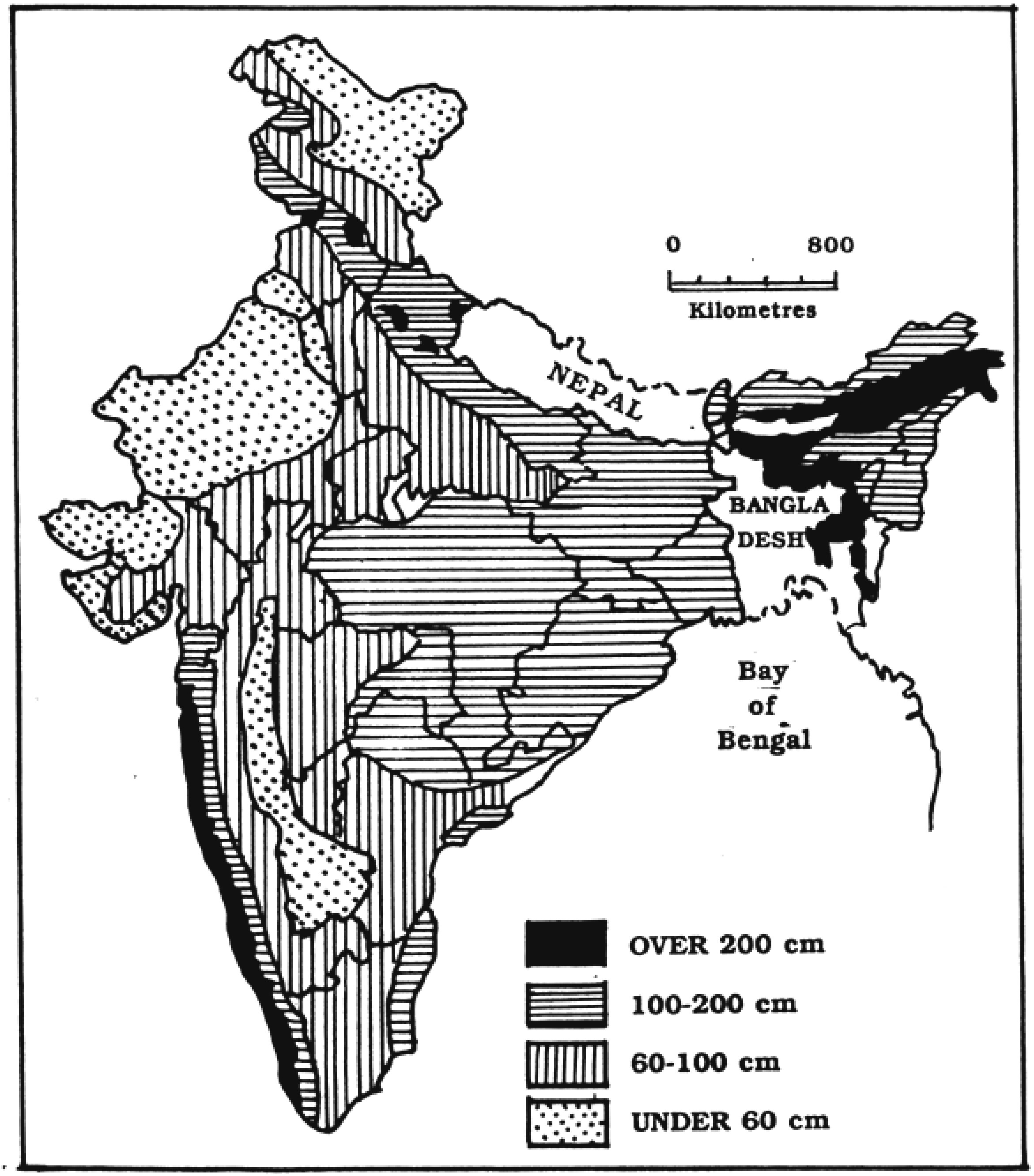


Figure 1.7 Rainfall map of India

1.4 RESERVOIR ECOSYSTEM

Reservoir is a man-made ecosystem without a parallel in nature. Though essentially a combination of fluviatile and lacustrine systems, a close examination of the biotope reveals that it has certain characteristic features of its own. The riverine and lacustrine characters coexist in reservoirs, depending on the temporal and spatial variations of certain habitat variables. For example, the lotic sector of the reservoir sustains a fluviatile biocoenos, whereas the lentic zone and the bays harbour lentic communities. During the months of heavy inflow and outflow, the whole reservoir mimics a lotic environment whereas in summer, when the inflow into and outflow from the reservoir dwindle, a more or less lentic condition prevails in most parts of it. Another unique feature of reservoirs that makes them distinctly different from their natural counterparts is the water renewal pattern marked by swift changes in levels, inflow and outflow.

In India, most of the precipitation takes place during the monsoon months which contribute substantially to the surface flow. During this period, due to a heavy inflow of water into the system, all outlets of the dam are usually opened, resulting in total flushing. This process dislodges a considerable part of the standing crop of biotic communities at the lower trophic level and disturbs the natural primary community succession. The sudden level fluctuations also affect the benthos by exposing or submerging the substrata. Factors determining the water and soil quality in reservoirs are different from those of natural lakes. In the latter, the basin soil plays a predominant role in determining the chemical water quality through soil water interphase. In the reservoirs, on the other hand, the nutrient input from the allochthonous source often determines the water quality, nutrient regime and the basic production potential. This is because of the fact that the catchment of parent rivers is very often situated far away from the reservoir, under totally different geoclimatic conditions. Deep drawdown, wind-mediated turbulence, locking up of nutrients in the deep basins, etc., are but some of the factors that impart the uniqueness to the reservoir ecosystem. Besides, the varying purpose and design of the dams make the reservoirs different in their hydrographic and morphoedaphic characteristics, with implications on the production potential. Some salient features of the reservoir ecosystem are depicted in Table 1.3.

The ecology of reservoirs is radically different from that of the parent rivers. Dams alter river hydrology both up- and downstream of the river. The obstruction of river flow and the consequent inundation trigger off sudden transformation of lotic environment into a lentic one. The riverine community is subjected to changes akin to the secondary community succession. A number of organisms perish, some migrate to more hospitable environs, and the more hardy ones adapt themselves to the changed habitat. There is usually an initial spurt of plankton and benthic communities due to the increased availability of nutrients released from the decay of submerged vegetation. This trophic burst is also on account of the saproxenic lacustrine species filling the vacant niches created by the disappearance of saprophobic riverine taxa. As the effects of trophic burst wean away, the reservoir passes into a phase of trophic depression and the final fertility is regained after a few years. Habitat variables responsible for a reservoir's productivity can be summed up into climatic, morphometric, and hydro-edaphic factors.

Table 1.3. Abiotic and biotic factors affecting productivity of reservoirs at various trophic levels

Positive/augmentative factors	Major effects unknown	Negative/reductive factors
High shoreline development (coves,bays,bays etc.)	Sedimentation of inorganic material	Low transparency in floods due to inorganic turbidity.
Low mean depth (less than 18 m)	High rate of evaporation	High mean depth
Existence and extent of marginal vegetation	Contributions of autochthonous nutrients	Erosion in the reservoir water shed area
Optimum nutrient levels	High surface temperature during summers (in northem India)	Reduction of quantity of water flowing into reservoir
Nutrient enrichment during floods	Low water temperature	Large water level fluctuations creating

	during winter (In northern India)	large aridal (barren littoral)
Moderate to long growing season	Aquatic community interrelationship	Low level of dissolved oxygen in parts of hypolimnion
High frequency of phytoplankton blooms		Pollution in the reservoir water- shed
Moderately developed macrophyte community		Phytoplankton biomass mainly blue greens
Periphyton abundant		Relative low fish species diversity indicating low stability and a potentially low resilience to stresses
Well established plankton and benthos		Unbalanced fish populations favouring predatory and trash species
Tree and bush cleared		Low abundance and diversity of terrestrial vegetation hence early successional stage
Conditions permitting passage of migratory fish		Relatively low environmental heterogeneity
Introduction of fishes adapted to lentic conditions		Low diversity of plankton and benthos
Employment of modern fishing gear and optimization of fishing effort		Low diversity of aquatic macro- phytes
Enforcement of fishery regulations		Exposure of fish nests during drawdowns

(After Jhingran, 1988)

1.4.1 Climatic factors

The Indian reservoirs are exposed to a wide range of climates from the temperate Himalayas in the north to the extreme tropical in the southern peninsula. From Gobindsagar in Himachal Pradesh to Chittar in Tamil Nadu, they spread over the southern slopes of Himalayas, the Indo-Gangetic plain, the Vindhyas, the Satpuras, the Western and Eastern Ghats and the Deccan plateau.

Apart from being the main factor influencing the prevailing climate of the region, the latitudinal location is important in determining the quantum of solar radiation available at the water surface for primary productivity. Natarajan and Pathak (1983) estimated the amount of solar radiation available at four reservoirs within 31° 25' N and 11° 28' N and the rate at which the solar energy was converted into chemical energy. Incident solar energy available at the surface varied from 213 x 10^4 cal m^{-2} yr^{-1} in Bhavanisagar (10° 28' N) to 172 × 10^4 cal $m^{-2}y^{-1}$ in Gobindsagar (31° 25' N). Jhingran (1990) observed that 0.2 to 0.68% of the incident solar energy was fixed as chemical energy by the primary producers in five reservoirs, *viz*., Gobindsagar (Himachal Pradesh), Ramgarh (Rajasthan). Rihand (Uttar Pradesh) and Bhavanisagar (Tamil Nadu). It is often the qualitative and quantitative abundance of the producer communities that determines the photosynthetic efficiency rather than the actual amount of solar energy available. For instance, Nagarjunasagar despite receiving solar energy at the rate of 205 x 10^4 cal m^{-2} yr^{-1}, fixes chemical energy to the extent of 0.29%, whereas in Gobindsagar 0.68% of the 172 × 10^4 cal m^{-2} yr^{-1} is being fixed by the producers (Table 1.4).

Table 1.4. Latitude-induced variations in availability of energy in Indian reservoirs				
Reservoir	**Area (ha) at FRL**	**Latitude**	**Available light energy (cal m^{-2} yr^{1})**	**Available chemical energy (cal $m^{-2}yr^{1}$)**
Bhavanisagar	7 285	11° 25'	213 × 10^4	8 781 (0.41%)
Nagarjunasagar	2 8474	16° 4'	205 × 10^4	5 959 (0.29 %)
Rihand	4 6538	24°	188 × 10^4	3 970 (0.20 %)
Ramgarh	1 265	27° 12'	183 × 10^4	8 236 (0.49 %)
Gobindsagar	16 867	31° 25'	172 × 10^4	11 696 (0.68 %)

(After Jhingran, 1990)

Prevailing climatic factors including air temperature, wind velocity, rainfall, etc. play an important role in the biological productivity of a water body. The wide seasonal variations in air temperature is the predisposing factor in the thermal features of the north Indian and peninsular reservoirs. In contrast to the reservoirs of the north, their southern counterparts are characterised by the narrow range of fluctuations in water and air temperature during different seasons, a phenomenon which prevents the formation of thermal stratification. Normally, the thermal gradient occurs when high air temperature during summer warms up the upper layer. In peninsular India, there is no winter worth its name and the air temperature remains comparatively high during the whole year. During summer, when surface water gets heated up, the prevailing high temperature at the bottom does not offer any scope for thermal resistance by the warm upper layers. Thermal stratification is limnologically important because in thermally stratified lakes, the water above and below thermocline does not mix up and thereby rich nutrients at the bottom layer get locked up. A warm bottom layer also facilitates rapid decomposition of organic matter, thereby accelerating the process of nutrient release.

The deep basin of Nagarjunasagar, despite 40% of its capacity being dead storage, does not favour the formation of thermocline. Apart from the high water temperature throughout the year, the continous drawdown from deeper layers and the wind and wave mediated turbulence facilitate mixing up of water column. This is true to most of the reservoirs in the States of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Orissa and Maharashtra. However, seven reservoirs in the upper peninsula comprising south Bihar, Gujarat and Madhya Pradesh undergo transient phases of thermal stratification during the summer stagnation, depending upon the other parameters such as the depth of the basin, water abstraction pattern and the wind. Konar reservoir situated beyond the Tropic of Cancer has distinct epi-and hypolimmon during the summer months. Similarly, a well-defined thermocline is reported from Gobindsagar. Apart from the solar warming of the top layer, which remains as a separate thermal regime, the inflowing Beas water that joins the reservoir at the lotic sector does not get mixed up, retains its cool character and remains as a separate layer at the bottom.

The amount of rainfall determines the rate of inflow into the reservoir, and hence plays a crucial role in bringing in the water replenishment and nutrient enrichment. More often, rainfall in the catchment of the river situated hundreds of km away from the reservoir affects the inflow rate. Another important climatic factor with implications on thermal and chemical regimes of the reservoir is the wind. It helps distribution of heat and equalisation of temperature in the water column. Wind velocity is very high in monsoon and premonsoon months in most reservoirs in India (Natarajan, 1979). Wind-induced turbulence is important in churning of the reservoirs and thereby facilitating the availability of nutrients at the trophogenic zone.

1.4.2 Morphometric factors

Reservoir morphometry is a function of the height of the dam and the topography of the impounded areas. Apart from the nature of the basin and the characteristics of the terrain, it is the design of the dam and the water use pattern that decide the influence of morphometric and hydrographic features on the aquatic productivity. Most of the hydel reservoirs on the mountain slopes of Western Ghats, Himalayas and the other highlands are deep, with steeper basin walls than the irrigation impoundments.

One of the most important morphometric considerations is the mean depth, that is believed to determine the productivity of reservoirs (Hayes, 1957, Rawson, 1952). This is based on the well known dictum that the shallower lakes have greater part of their water in the euphotic zone, facilitating greater mixing and circulation of heat and nutrients and hence higher productivity. A large portion of water in deep lakes serves as a *nutrient sink* at the bottom, where organic matter accumulates and thus the nutrients become unavailable at the photosynthetic zone. Mean depth calculated from the capacity and area varies from 5.2 in Panchet to 58 m in Gobindsagar among the large reservoirs. Medium reservoirs in the country have mean depth ranging from 2.3 m (Poondi) to 24.0 m (Bhatghar). Hope Lake in Tamil Nadu has an exceptionally deep basin of 37.7 m, while the small reservoirs in India have a mean depth range of 2.1 m (Vidur) to 14.57 (Badua). Mean depth in case of hydel reservoirs of the mountain slopes is invariably high, compared to the irrigation reservoirs of the plains and plateaus. The two largest impoundments in the country *Viz.*, Hirakud and the Gandhisagar have very low mean depths of 11.3 which is one tenth of Gandhisagar in area has a mean depth of 32 m.

The mean depth, however, does not show any direct correlation with productivity, either at primary or fish level. Vidur, despite being one of the shallowest (mean depth 2.1 m) of all reservoirs in the country, does not support rich plankton community. Likewise, Kulgarhi and Govindgarh reservoirs in Madhya Pradesh exhibit propensities towards oligotrophy in spite of their shallowness. On the other hand, Gobindsagar, the deepest reservoir, has the highest productivity among large reservoirs. Medium deep reservoirs like Amaravathy (13.7 m), Aliyar (16.8 m), and Tirumoorthy (11 m) develop regular blooms of plankton.

Shoreline and volume development indices

A highly crinkled shoreline, as indicated by the high values of shoreline development index, is believed to be indicative of productive nature of the water body. An irregular shoreline encompasses more littoral formations and areas of land and water interface. High shoreline indices of Hirakud (13.5), Gobindsagar (12.26), Tilaiya (9.12), Konar (8.78), Nagarjunasagar (7.89) and Rihand (7.04) are accompanied by a moderate to rich plankton community.

Ratio between the maximum depth and mean depth, often described as volume development index denotes the depth of basin in relation to the nature of basin wall. An index value less than 1 suggests basin wall convex towards water. No perceptible relation exists between this parameter and the productivity of Indian reservoirs.

Hydrographic changes have a direct bearing on productivity, as sudden changes in water level, inflow and outflow directly affect the biotic communities. It has been observed that plankton, benthos, and periphyton pulses coincide with the months of least level fluctuations and all these communities are at their ebb during the months of maximum level fluctuations and water discharge. Percentage of shallow areas (littoral formation) which varies at different levels, depending on the contour, is also an indicator of productive nature of the lakes.

Storage and release of water from dams are dictated by the requirements of irrigation, power generation and other primary purposes of the dam, rather than any considerations related to fisheries. The spillway discharge, apart from dislodging the standing crop of plankton, removes the oxygenated clear water at the top layer, leaving the oxygen-deficient, turbid bottom water. Similarly, the deep drawdown removes the decomposing material including nutrients.

1.4.3 Hydro-edaphic factors

The oligotrophic tendencies shown by some of the reservoirs are mainly due to the poor nutrient status and other chemical deficiencies. In most of the cases, poor water quality is a direct reflection of the catchment soil. All reservoirs in Kerala portray a low status in terms of specific conductivity (<50 µmhos) and total alkalinity (<50 mg 1^{-1}) with the attendant low primary productivity and plankton. The rivers of Kerala drain the hills of Western Ghats with lateritic and humus soils deficient in N, P and Ca. The eastern slopes of these hills drain the rivers feeding Hope Lake, Manimuthar, Pechiparal and Peruchani, all deficient in ions. Sathanur, Krishnagiri and Vidur reservoirs receiving drainage passing predominantly through cultivated area have higher levels of alkalinity and hardness. Similarly, in Madhya Pradesh the water is soft to medium soft with less mineral salts, due to geo-chemical reasons. Even small lakes with shallow bottoms, more often than not, do not show signs of productivity due to the poor chemical make up of the catchment. Soils in Madhya Pradesh are normally deep black, medium black, shallow black and mixed red and skeletal, low in nitrogen and phosphorus.

Catchment of Ravishankarsagar comprises rocky, denuded forests and upstream rivers are intercepted by impoundments, which further deprive the water of the suspended matter. Allochthonous enrichment with minerals and nutrients of the reservoir is very low, resulting in low standing crop of plankton. Limestone and other calcareous rocks underlying the water course in the Deccan plateau are responsible for the predominantly hard water character of many of the reservoirs on the Krishna and Cauvery in Andhra Pradesh and Tamil Nadu. The acidic nature of the water of the north eastern reservoirs Kyrdemkulai, Nongmahir and Barapani is attributable to the acidic soil of the reservoir bed and in the catchment.

Nutrient budget

Most of the Indian reservoirs are characterised by low levels of phosphate and nitrate. Phosphate very seldom exceeds 0.1 mg 1^{-1} in reservoirs free from pollution. However, the reservoirs of Rajasthan have particularly high levels of phosphate, ranging from traces to 0.929 mg 1^{-1}. They receive phosphate from the rain washings derived from soils types like brown hills, grey brown hills, red and yellow and desert soils. In the highly eutrophic reservoir of Mansarovar in Madhya Pradesh, phosphate levels of 4 to 13 mg 1^{-1} were recorded.

Nitrate nitrogen in water in Indian reservoirs is mostly in traces and seldom exceeds 0.5 mg 1^{-1}. Lack of nutrients in water, especially the nitrate nitrogen and phosphate, does not seem to be indicative of low productivity. In many cases, despite their virtual absence, the production processes are not hampered. In Amaravathy, Bhavanisagar, Gandhisagar, Ravishankarsagar and many other reservoirs, moderate to very high primary productivity is reported, although the phosphate in water is either absent or present in a very low concentration. In the tropical reservoirs, phosphate level in water has limited scope as an indicator of productive traits. This phenomenon is attributed to rapid turnover of nutrients (Ehrligh, 1960; Abbot, 1967) and their quick recycling, as seen from the high metabolic rates. Hayes and Phillips (1958) showed that 95% of the phosphorus could be taken up by the phytoplankton within 20 minutes, while some algae could convert inorganic phosphate into organic state in less than one minute.

Unlike the nutrients like phosphate and nitrate, the measure of total dissolved solids in the form of total alkalinity and the specific conductivity reflects the production propensities of reservoir satisfactorily, with the exception of Amaravathy which, despite very low levels of specific conductivity (38 to 63 µmhos), total alkalinity (7 to 84 mg 1^{-1}) and total hardness (18 to 50 mg 1^{-1}), supports a very rich plankton community and a good stock of fish.

The ranges of notable abiotic factors indicating their productivity status are given in Table 1.5. A close examination of physico-chemical data pertaining to more than 100 reservoirs in the country leads to the conclusion that none of the morphometric, edaphic, and water quality parameters can be used as a dependable yardstick to predict the organic productivity to any degree of accuracy, production propensities of each reservoir being determined by a variety of factors. The vertical gradient of some of the chemical parameters, especially the dissolved oxygen, however, conveys the status with a higher level of accuracy.

Table 1.5. Physico-chemical features of Indian reservoirs (range of values)

Parameters	**Overall range**	**Productivity**		
		Low	***Medium***	***High***
A. WATER				
pH	6.5–9.2	<6.0	6.0–8.5	>8.5
Alkalinity (mg 1^{-1})	40–240	<40.0	40–90	>90.0
Nitrates (mg 1^{-1})	Tr.-0.93	Negligible	Upto 0.2	0.2–0.5
Phosphates (mg 1^{-1})	Tr.-0.36	Negligible	Upto 0.1	0.1–0.2
Specific conductivity (µmhos)	76–474		Upto 200	>200
Temperature (°C)	12.0–31.0	18	18–22	>22
		(with minimal stratification : *i.e.*,>5°C)		
B. SOIL				
pH	6.0–8.8	<6.5	6.5–7.5	>7.5
Available P (mg/100 g)	0.47–6.2	<3.0	3.0–6.0	>6.0
Available N (mg/100 g)	13.0–65.0	<25.0	25–60	>60.0
Organic carbon (%)	0.6–3.2	<0.5	0.5–1.5	1.5–2.5

(After Jhingran, 1990)

The bacterial decomposition of organic matter at the bottom is well reflected by the high rate of oxygen consumption. A corresponding increase in oxygen at the trophogenic upper zone gives clues of the high rate of photosynthesis. Almost all productive reservoirs in the country, irrespective of their geographic location, have a klinograde oxygen curve.

In most of the cases, the oxycline is accompanied by a vertical stratification of other chemical parameters such as pH, carbon dioxide, total alkalinity and specific conductivity. The tropholytic zone has a steady supply of free carbon dioxide, which reacts with carbonate to produce bicarbonates. This results in an increase of bicarbonates towards the bottom. Similarly, due to the increase in the hydrogen ions, the pH drops rapidly. Thus, the increase in total alkalinity, specific conductivity and CO_2 and the decrease in pH values towards the bottom layers act as useful indicators of productivity.

Rate of primary productivity in reservoirs is very high due to the warm tropical conditions available in most parts of the country . Many workers consider 1% of the total carbon produced at the phytoplankton phase as the potential fish production from a water body, although almost all reservoirs produce much less fish than their potential.

1.4.4 Biotic communities

The highly seasonal rainfall and heavy discharge of water during the monsoons result in high flushing rate in most of the reservoirs which does not favour colonisation by macrophytic communities. Similarly, inadequate availability of suitable substrata retards the growth of periphyton. Plankton, by virtue of drifting habit and short turnover period, constitutes the major link in the trophic structure and events in the reservoir ecosystem. A rich plankton community with well-marked seral succession is the hallmark of Indian reservoirs.

Plankton

Blue-green algae from the mainstay of plankton community in vast majority of the man-made lakes studied. The overwhelming presence of *Microcystis aeruginosa* in Indian reservoirs is remarkable. The productive water of Gangetic plains, Deccan plateau, south Tamil Nadu and Orissa invariably have good standing crop of *Microcystis*. A common feature of all these reservoirs is the bright sunshine, isothermal water column, klinograde oxygen curve and an extensive catchment area, draining a calcium rich, forested or cultivated land. The species is almost ominipresent in the southern peninsula, except in the reservoirs of Karnataka and Kerala, which tend to be oligotrophic and have poor plankton count with desmids and other green algae as the main constituents. Reservoirs of Rajasthan receiving scanty rainfall and poor flushing rate favour macrophytes and despite being productive do not harbour blooms of *Microcystis.* The oligotrophic lakes of the northeast have a desmid-dominated plankton community (Fig. 1.8).

Altitude plays a decisive role in the distribution of *Microcystis*. Gobindsagar, the highly productive high altitude temperate reservoir, supports a rich community of *Ceratium* sp. instead of *Microcystic*. Similarly, the tropical Markonahalli situated at an altitude of 731 m above MSL, has *Ceratium* sp. as the major constituent of plankton.

Most of the reservoirs have three plankton pulses conciding with the post-monsoon (September to November), winter (December to February) and summer (March to May) seasons. The monsoon (June-August) flushing disturbs and often dislodges the standing crop of plankton. However, no sooner the destabilising effects wean away (as the dam outlets are closed), the allochthonous nutrient input favours an accelerated plankton growth. As the post-monsoon merges into winter, the turbulence decreases and water becomes clean, the plankton community progresses through a series of seral successions to culminate in a peak. The summer maxima coincide with the drastic drawdown, bringing the deep, nutrient-rich areas into the fold of tropholytic zone. The temperature, bright sunlight and rapid tropholytic activities also accelerate the multiplication of plankton during summer. In some cases, only two pulses(*i.e.*, the post-monsoon and summer) are seen. However, the shallow, nutrient-rich reservoirs in the southern tip of the peninsula, by virtue of the fast turnover of nutrients and availability of sunshine and warmth, sustain a permanent bloom of plankton.

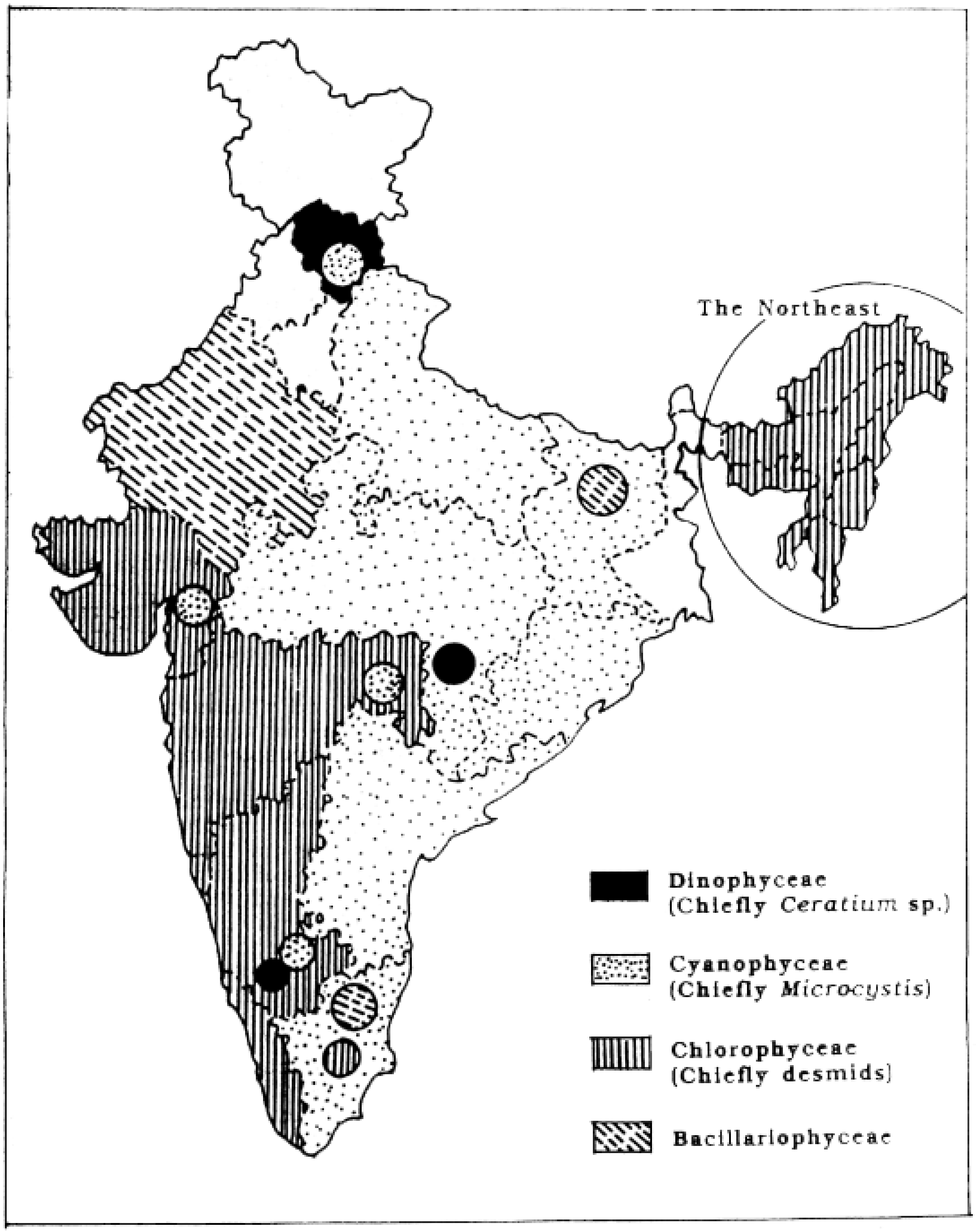


Figure 1.8. Dominant phytoplankton in reservoirs (State-wise)

The ubiquitous blooms of *Microcystis* in reservoirs in peninsular India are an example of a lacustrine biocoenose giving way to fluviatile ones in an impoundment. Studies have indicated that Chlorophyceae and Bacillariophyceae constituted the main components of riverine plankton. On reservoir formation and the consequent transformation of lotic environment into the lentic system, saprophobes disappear from the scene giving room for the rapid multiplication of saproxenes. *Microcystis*, finding a favourable note with the new environment, bursts into blooms, outnumbering all other forms into in significance. In many reservoirs, orientation of lacustrine and fluviatile plankton can be clearly discerned from the composition of plankton in lotic, lentic and the cove sectors. The fluviatile lotic sector, although recording a lower plankton density, often shows better diversity and evenness indices, compared to the lentic and bay sectors, the still waters of which are characterised by higher concentration of dominance (C) and low evenness(J') (Sugunan, 1991).

Macrovegetation

Aquatic macrophytes do not figure prominently in the community structure and trophic events of the reservoirs in India, barring some exceptional circumstances, such as low water renewal, ageing of reservoir and pollution stress. In most of the reservoirs they are totally absent or their population is too insignificant to be taken into account. Mostly, they are restricted to isolated patches of *Vallisneria, Hydrilla* and mats of *Spirogyra*, found in the protected bays and coves. Yerrakalava in Andhra Pradesh, Ramgarh in Rajasthan and Sayajisarover in Gujarat are the examples of macrophytic growth due to low flushing rate. Small irrigation reservoirs in Uttar Pradesh. *viz*., Bachhra and Baghla are also known for the luxuriant growth of macrophytes.

Hussainsagar in Andhra Pradesh and Mansarover in Madhya Pradesh harbour thick vegetation which thrives due to the hyper-eutrophication. These reservoirs are well-advanced on their way to change to swamps. Age of the reservoir seems to have an influence on the macrophyte community. Vanivilas Sagar, and Markonahalli reservoir in Karnataka formed in 1901 and 1939 have a luxuriant growth of macrophytes. Similar age-related macrophyte growth can be observed in Yerrakalava, Ramgarh, Jaisamand, Hussainsagar and Fatehsagar reservoirs. Reservoirs of Rajasthan exhibit a seasonal rhythm in aquatic weeds, their population peaking in summer and declining during the monsoon season.

In the irrigation tanks of Karnataka, the qualitative and quantitative distribution of macrovegetation depends, to a large extent, on the physiographic divisions and the soil types. Thick vegetation comprising the littoral, submerged and emergent types is the characteristic feature of the tanks of the costal plains and the Malnad region. In the transitional zone between plateau and hills, marked by the presence of laterite and red soil, the tanks are fertile and plankton-rich. Weeds are sparse and whenever present, do not choke the water. In the tanks in the black soil zones, the weeds are mostly submerged and emergent types such as *Hydrilla, Chara Nitella* etc. In most of the tanks in the red soil area, which are seasonal, the vegetation is limited to littoral areas.

Macrophytes offer substrata for an array of insects, molluscs and other invertebrate fauna, and thereby contribute to the species diversity of a water body. Nevertheless, the presence of weeds is considered to be undesirable from fisheries point of view. They accumulate large quantities of inorganic nutrients early in the season, depriving the phytoplankton of their share of nutrients. The floating vegetation utilizes the incident solar radiation for its photosynthesis and makes it unavailable to the phytoplankton communities. Submerged weeds provide shelter for minnows and weed fishes which compete with major carps for food. Excessive growth of macrophytes cause high rate of decomposition of dead plants at the bottom, creating anaerobic conditions. Problems are further confounded, if the water surface is matted by the floating vegetation which prevents light penertration. Instances of fish mortality in summer under such circumstances are reported from Hussainsagar and the reservoirs of Rajasthan. A major deleterious effect of weeds is its physical obstruction they cause to a variety of fishing gear.

The submerged plants commonly encountered in Mansarovar are *Ceratophyllum demersum, Potamogeton crispus, P. perfoliatus, P. pectinatus, P. natans, P. nodosus, Najas graminaea, N. minor, Hydrilla verticillata, Vallisneria spiralis, Chara intermedia, Nitella gracilus.* Floating weeds comprising *Eichhornia crassipes, Lemna sp*.. and *Spirodela* and the emergent *Ipomoea aquatica, I. reptans, Polygonum glabrum, Typha angustata*, and *T. elephantia* are reported. Hussainsagar is choked mainly with the water hyacinth, while the reservoirs of Rajasthan harbour a rich flora, dominated mainly by *Hydrilla, Ceratophyllum, Potamogeton, Najas, Azolla* and *Ipomoea*. The marginal areas of Yerrakalava reservoir in Andhra Pradesh have *Hydrilla* and *Chara*, while the deeper zones harbour *Vallisneria* and *Spirogyra*

Benthos

Benthic invertebrates fauna show an erratic distribution in Indian reservoirs. The main factors that retard this community are the predominantly rocky bottom, frequent water level fluctuation and the rapid deposition of silt and other suspended particles. In spite of this, a number of reservoirs harbour rich communities of benthic invertebrates. The sequence of dominance of benthic communities closely follows the soil fertility pattern, the pre-impoundment debris often providing suitable habitats. The benthic community succession especially that of chironomids is sometimes used to characterize habitat changes. High shoreline development, variable slopes and vegetation act as favourable factors for the development of a rich assemblage of benthic organisms.

Small, shallow reservoirs of the Gangetic basin, such as Bachhra and Baghla are particularly rich in benthic fauna mainly due to the favourable substratum, rich in organic matter and the absence of swift changes in water level. In Bachhra reservoir, the standing crop of benthos registered a steady growth from 490 to 1 894 individuals m^{-2} during the last 10 years. Baghla, another small reservoir in Uttar Pradesh, has a population of benthic invertebrates represented by *Chironomus*, annelids and molluscs. The deep Rihand reservoir in the Ganga basin has a poor benthic community.

Reservoirs of Karnataka, such as Tungabhadra, Markonahalli, Hemavathy, Vanivilas Sagar and Krishnarajasagar have impressive populations of benthic organisms. So are the reservoirs of Himachal Pradesh and Rajasthan. Trends in Tamil Nadu and Madhya Pradesh are erratic. The local conditions, rather than a general geo-climatic features of the area, determine the density of benthic populations in their reservoirs.

Chironomid larvae, being a saprophobic, quickly fill the niches vacated by the saproxenes during the tranformation of habitats. They form the most important constituent of benthos, reported from all soil types and geographic locations and depths. Gastropods and annelids from the next important groups. *Viviparus bengelensis* enjoys country-wide distribution.

Among the biotic communities of the reservoir ecosystem, periphyton is the least reported upon. It constitutes an important component of food for the browsing fishes which contribute substantially to the total fish biomass of the tropical reservoirs. Apart from the limited littoral region in reservoirs, it is the frequent level fluctuations that prevent the growth of periphyton on natural substrata. Significantly, rich periphyton, whenever reported, coincides with relatively stable reservoir levels. There are reports of rich periphyton deposits on anchored boats, rafts, *etc.* that move down along with the receding water level. The fixed substrata either get totally exposed when water level decreases or they are submerged too deep for the communities to survive when level goes up. Propensities for rich settling rates of periphyton have been established through experiments with the artificial substrata, such as glass slides (David *et al*., 1975; Jha, 1979; Sugunan and Pathak, 1986).

Ichthyofauna

Despite the cataclysmic faunistic changes associated with the impoundment, Indian reservoirs preserve a rich variety of fish species. The ichthyofauna of a reservoir basically represents the faunal diversity of the parent river system. On the basis of studies conducted so far, large reservoirs, on an average, harbour 60 species of fishes, of which at least 40 contribute to the commercial fisheries. The fastgrowing Indo-Gangetic carps, popularly known as Indian major carps, occupy a prominent place among the commercially important fishes. More recently, number of exotic species have contributed substantially to commercial fisheries. Broad categorisation of the species is as follows:

The Indian major carps: *Labeo rohita, L. calbasu, L. fimbriatus, Cirrhinus mrigala, Catla catla*,

The mahseers : *Tor tor, T. putitora, T. khudree, Acrossocheilus hexagonolepis*

The minor carps including snow trout and peninsular carps: *Cirrhinus cirrhosa, C. reba, Labeo kontius, L. bata, Puntius sarana, P. dubius, P. carnaticus, P. kolus, P. dobsoni, P. chagunio, Schizothorax plagiostomus, Thynnichthyes sandkhol, Osteobrama vigorsii*,

Large catfishes: *Aorichthys aor, A. seenghala, Wallago attu, Pangasius pangasius, Silonia silondia, S. childrenii*,

Featherbacks : *Notopterus notopterus, N. chitala*,

Airbreathing catfishes: *Heteropneustes fossilis, Clartas batrachus*,

Murrels : *Channa marulius, C. striatus, C. punctatus, C. gachua*,

Weed fishes : *Ambassis nama, Esomus danrica, Aspidoparia morar, Amblypharyngodon mala, Puntius sophore, P. ticto, Oxygaster bacaUa, Laubuca laubuca, Barilius barila, B. bola, Osteobrama cotio, Gadusia chapra.*

Exotic fishes : *Oreochromis mossambicus, Hypophthalmichthys molitrix, Cyprinus carpio specularis, C. carpio commun, Gambusia affinis, Ctenopharyngodon idella*.

Most of the catfishes, featherbacks, air breathing fishes,murrels and the weed fishes enjoy a country-wide distribution, while that of the major carps, minor carps and mahseers (*Tor putitora, T. tor, Acrossocheilus hexagonolepis*) varies according to river basins. The Indian major carps, catla (C. *catla*), rohu (L. *rohita*) and mrigal (C. *mrigala*) constitute the important native ichthyofauna of the rivers of the Gangetic system. These rivers also harbour *Labeo bata, P. sarana, P. chagunio*, and *C. reba, Tor putitora, Labeo dero* and the snow trouts (*Schizothorax* spp.) form the dominant riverine fish fauna of Indus system. Mahseers, especially the chocolate mahseer. *Acrosscheilus hexagonolepis* are also found in the streams associated with all the major river systems of the country. Indigenous fishes of the peninsular rivers include *Cirrhinus cirrhosa, C. reba, Labeo kontius, L.fimbriatus, P. dubius, P. sarana. P. carnaticus, P. kolus, P. dobsoni, T. tor, T. sandkhol and 0. vigorsii.*

Fish faunistic diversity of a reservoir at a given time is the result of the impact of a series of man-made and natural changes on the native fauna of the parent river. Riverine fish fauna is subjected to a series of habitat changes such as water current, turbidity levels, fishing pressure, loss of breeding grounds and the changes in fish food organisms due to lake formation. The original fauna changes and hardy fish species take advantage of the vacant niches. In many reservoirs, transplantion of fishes from other basins and introduction of exotic species have led to further radical changes in the species set up.

The three Indian major carps have been stocked extensively in reservoirs all over the country for many decades and, in many instances, they have established themselves in reservoirs far away from their original habitat. Sathanur reservoir in Tamil Nadu has a naturalised population of catla that contribute 80 to 90% of the total catch. This Indo-Gangetic carp has eclipsed all indigenous fish fauna including Labeo fimbrtatus, which dominated the scene by contributing 36% of the catch during the mid 1960s. Similarly, introductions of the silver carp in Gobindsagar, common carp in Krishnarajasagar and tilapia (*Oreochromis mossambtcus*) in Amaravathy are examples of man induced changes in fish communities.

1.4.5 Impact of reservoir formation on the native Ichthyofauna

Formation of reservoirs have affected especially the following Indigenous fish stocks:

1. The mahseers, snow trouts and *Labeo dero* and *L dyocheilus* of the Himalayan streams.
2. The anadromous hilsa, the catadromous eels,and freshwater prawns of all major river systems.
3. *P. sarana, T. tor,Tor mahanadtcus, T. mosal, L.fimbrtatus, L calbasu*,and *Rhinomugil corsula* of the Mahanadi river,
4. *P. dobsoni, P. dubius, P. carnaticus, C. drrhosa* and *Labeo kontius* of the Cauvery basin.
5. *P. kolus, P. dubius, P. sarana, P. porcellus, L.fimbrtatus, L. calbasu, L. pangusia and Tor kudree of the Krishna river system*, and
6. The mahseers, eels and *Osteobrama belangiri* of the northeast (Fig. 1.9).

The pristine streams of the river Sutlej harboured at least 51 species of fishes including the (exotic) trout, *Salmo trutafario*, the snow trouts, *Schizothorax* spp. and several species of hillstream fishes (Anon.. 1989b). Most of them were unique due to the sub-temperate climate and the zoogeographic affiliations to the Himalayan region. The upper reaches of the Sutlej and its tributaries were particularly rich in *T. putltora, L. dero, L dyocheilus* and *Schizothorax* spp. A decline in the number of species and their populations has been reported on account of changed ecological conditions especially the silt deposition at the bottom and the stratification of water body. Apart from minnows, many native species, such as, *Schizothorax plagiostomus, T. putitora, L. dero, L. dyocheilus* are on the decline. Proliferation of the exotic carps, *H. molitrix and C. carpio* in recent year has further to the local species.

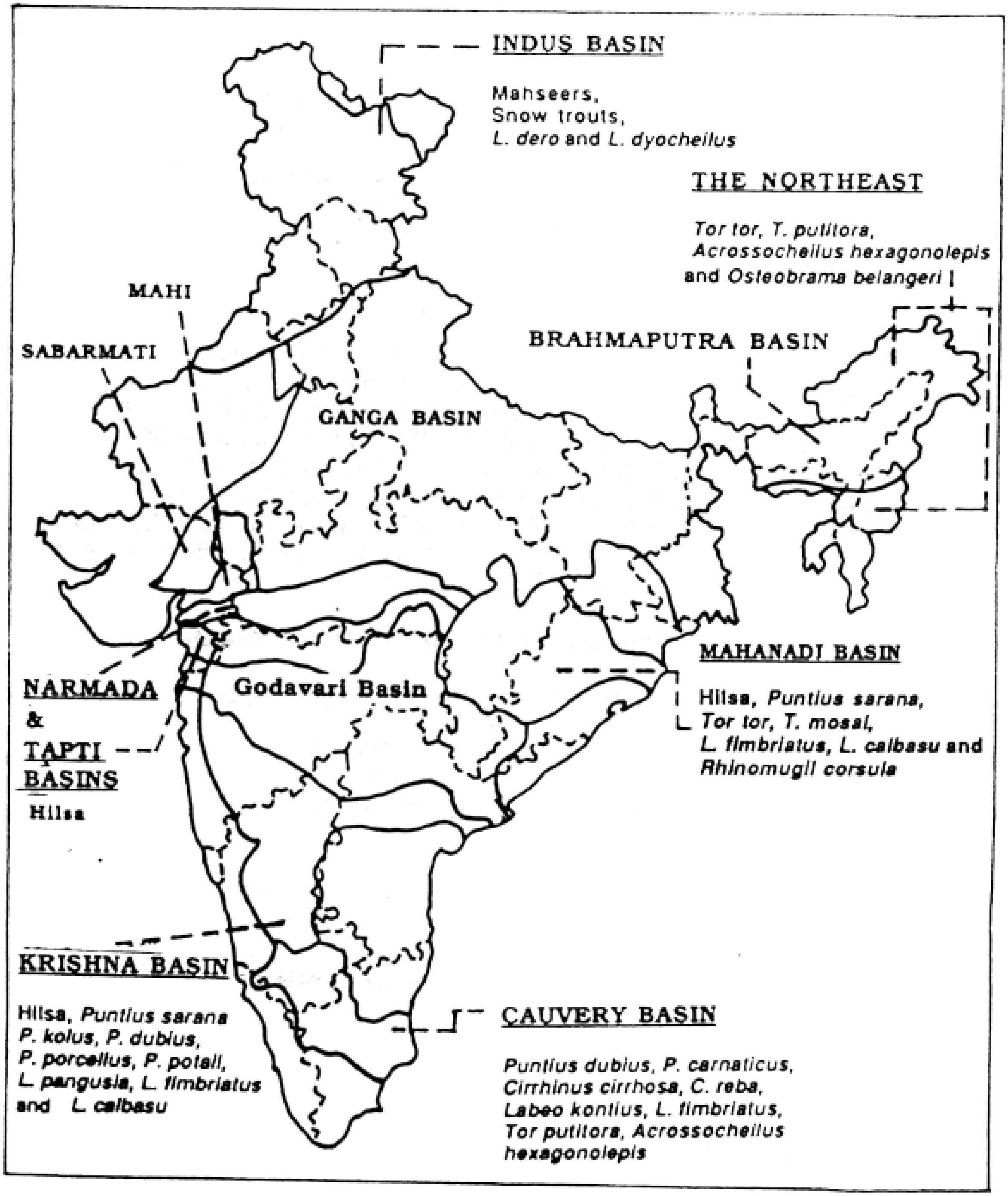


Figure 1.9. Indigenous fish species affected by reservoir formation in India

Before the creation of Hirakud reservoir, the parent river Mahanadi had a rich fish fauna of 103 species, comprising both plain and sub-montane forms with sizeable representation of carps and catfishes. The common species of the river were *P. sarana, T. tor, T. mahanadicus T. mosal, L. fimbriatus* and the Indo-Gangetic major carps. The endangered *T. mosal* and *T. mahanadicus* were protected in the temple tanks that were submerged during reservoir formation. Presently, the number of species has declined to 40, of which many may disappear. The worst affected are *Tor mosal, Rhinomugil corsula* and the freshwater prawn *Macrobrachium malcolmsonii*.

Fishes affected in the two reservoirs in the Krishna river system *viz.*, Tungabhadra and Nagarjunasagar are *P. sarana*, and *Labeo* spp. Soon after the impoundment, the Tungabhadra reservoir harboured a good population of indigenous *P. kolus* that contributed up to a third of the total fish landings. *P. dubius, P. sarana, P. porcellus, P. potail* and *Labeo pangusia* were also present in large numbers. Most of these native species have either disappeared or declined drastically due to the absence of fluviatile environment and the changed trophic structure. The vacant niche has been filled by minnow-predator combination, due to the management lapse of not inducting the fast-growing species into the system.

Nagarjunasagar reservoir on the mainstream Krishna harboured rich populations of *Labeo fimbriatus, Labeo calbasu* and *T. khudree* in the earlier years of impoundment. On account of recurring breeding failure and habitat loss, these species have declined over the years, giving way to minnows which have shared the common niche with them. In the absence of any commercial fish to utilize the rich planktonic resources of the reservoir, they are mainly channelled through the detritus-molluscs chain to favour *Pangasius pangasius* and through grazing-predator chain to help the *Silonia childreni* populations. Thus, finally, these two catfishes have established a firm hold on the fish fauna.

Cauvery river system is the original abode of a number of fish species including *P. dubius, P. carnaticus, C. cirrosa, C. reba, L. kontius, L. fimbriatus, Tor putitora* and *Acrossocheilus hexagonolepis* which have been affected in various degrees by the impoundments, chiefly, Krishnarajasagar, Mettur, Bhavanisagar and Amaravathy reservoirs. During the last 25 years, the indigenous economic carps in Krishnarajasagar *viz., Labeo spp., P. dubius* and *P. carnaticus* have suffered setback due to the changed ecological conditions, especially the components of fish food biotic communities. These species, contributing more than 60% of the total catch during the 1950s, have given way to the transplanted exotic common carp, *C. carpio*, which found a favourable environment in the reservoir *vis-a-vis* feeding and breeding. At present, most of the energy transfer is channelled through the detritus/benthos chain, giving considerable edge to the common carp which is a prolific breeder and competitor to *Cirrhinus* spp. for food.

One of the earliest casualties of hydraulic structures is the Indian shad *Tenualosa ilisha* (the hilsa) which was affected as early as mid 19th century when the Upper and Lower Anicuts were constructed on Cauvery. These barrages had severly restricted the migration of hilsa by obstructing their pathways and construction of Mettur dam (Stanley reservoir) in 1935 completely stopped the hilsa run in Cauvery. Several fishes were affected by the Mettur dam. *Puntius* spp. which used to form 28% of the landings in 1943–44 faded out in the mid 1970s. Although the indigenous *Cirrhinus cirrhosa* took some initial advantage, it also could not survive. Low water levels during July for three consecutive years have most probably caused its decline. Similarly, *Labeo kontius* which was next only to *C. cirrhosa* in Cauvery also disappeared from the reservoir. The Gangetic carps transplanted into the reservoir also did not find roots there. *C. mrigala* was stocked in 1950–51 and appeared in catch during 1957–58, contributing up to 13.9% in 1966–67, only to fade into insignificance later. The some fate met *Labeo rohita*. Recruitment failure, water level changes, and predator pressure are the main reasons for the failure of Indian major carps in Stanley reservoir. In 1993, the total catch of 115 t in the reservoir comprised *L. rohita (19%), Wallago attu* (15%), other catfishes (14%), *Puntius spp* (14%) and *C. catla* (10%).

Bhavanisagar is the only reservoir in the Cauvery basin, where the indigenous species like *Puntius spp., Tor putitora, T. tor, A. hexagonolepis, P. dubius, P. carnaticus, L. kontius* and *C. cirrhosa* still hold together well. Their survival is mainly due to the uninterrupted breeding activities at Moolathurai and Nellithurai, especially when water is released from the upstream Pilloor reservoir. *P. dubius* ascends the river Moyar during the northeast monsoon and lays eggs in batches of 1 000 to 2 000 on the gravel beds. Similar breeding success has been confirmed in case of *Cirrhinus reba, Labeo fimbriatus, Labeo calbasu, L. kontius* and *Puntius carnaticus.*

Amaravathy and Sathanur with their prime fishes of tilapia and catla respectively are the examples of introduced fishes finding a favourable environment and propagating themselves into a dominant position

Positive impact of reservoirs on fish fauna

Many species of fish not only manage to adapt to the reservoir ecosystem but also find it congenial and flourish there, which is the main reason for the rise in the biomass of reservoir in the early stage of impoundment. However, most of the fishes that manage to multiply in the reservoir system are not very high in priority from the commercial and ecological point of view. Stocks of the small clupeid, *Salmostoma phulo phulo* and *o. vigorsii*, which support a flourishing dry fish trade in Nagarjunasagar and Tungabhadra reservoirs, multiply in a much higher scale than they do in the riverine ecosystem. The catfish, *P. pangasius* which was believed to be a catadromous migrant, has not only adapted itself to become a resident population in Nagarjunasagar, it has also become a very important component of the population. Ramakrishniah (1994) described many instances where reservoirs acted as sanctuaries by citing examples of *Barilius bola* in Tilaiya (Damodar), *Mystus krishnensis, Osteobrama vigorsii*, and *Pseudeutropius taackree* in Nagarjunasagar (Krishna), *T. sandkhol* in Nizamsagar (Godavari), *Tor khudree* and *T. mussullah* in Shivajisagar (Krishna), *A. seenghala* and *T. putitora* in Pong (Beas) and Vallabhsagar (Tapti).

1.5 RESERVOIR FISHERIES

A realistic evaluation of fish production from reservoirs in India is elusive. Compared to the impressive volume of data generated by the individual research workers and various institutions on limno-chemical variables and biotic communities, the estimates on fish catch remain grossly inadequate. Reliable fish catch statistics and yield estimates remain as the weakest link in the database on reservoirs. More discomfitting is the fact that the production figures available on most of the reservoirs are inaccurate and unreliable. This lacuna is imputable to a large number of factors, chiefly:

1. the multiplicity of agencies owning the fishing rights that pose difficulties in some States to gather data.
2. highly scattered and unorganised market channels, mostly under the clutches of illegal money lenders.
3. Ineffective cooperative set up,

4. diverse licensing/royalty/crop sharing systems practised by different State Governments, some of which include a *free for all* system, providing little scope for recording catch statistics, and
5. inadequate and poorly trained manpower at the disposal of State Governments/Cooperatives to collect catch data, follow statistically sound sampling procedures, unable to cover the whole reservoir.

The All India Coordinated Project on Reservoir Fisheries took the lead in evolving a collection methodology on the basis of stratified random sampling during 1971 to 1985. However, many State Governments were not able to follow the procedure and to continue with recording of catch data after the project wound up in 1985. Nevertheless, some States like Tamil Nadu and Madhya Pradesh, despite the enormity of the resource size, have a streamlined machinery to record catch statistics. Similarly, Himachal Pradesh has good documentation on catch. On the contrary, Karnataka, has very little information on the catch structure of its reservoirs. Figures of Andhra Pradesh seem to be off the mark, due to the free fishing system and inadequate methods of data collection. For instance, system followed in Nagarjunasagar virtually allows anybody to catch fish in the reservoir and freely sell it anywhere. Considering the size of the lake and the large number of remote landing centres, an effective monitoring of catch is almost impossible. This is equally true with regard to many reservoirs of Kerala, Maharashtra, Orissa, Karnataka and Uttar Pradesh.

Based mainly on the data obtained from various State Governments, the fish production particulars from 422 reservoir have been presented in Table 1.6. Fish yield figures of small reservoirs of Andhra Pradesh, as given by the State Fisheries Department are very impressive (188 kg ha^{-1}), followed by those of Kerala, Madhya Pradesh, Tamil Nadu and Rajasthan in the range of 46.43 to 53.5 kg ha^{-1}. Medium reservoirs of Rajasthan, on an average, produce fish at the rate of 24.47 kg ha^{-1}, while Tamil Nadu, Maharashtra, Madhya Pradesh and Orissa record about half this yield. The two large reservoirs in Himachal Pradesh produce 35.55 kg ha^{-1} which is remarkably high, compared to other States.

The estimated fish yield of 291 small, 110 medium and 21 large reservoirs of the country are 49.90, 12.30 and 11.43 kg ha^{-1} respectively. Based on the catch of 422 reservoirs belonging to 10 states during 1992–93, the national fish production rate of Indian reservoirs is estimated as 20.13 kg ha^{-1}. Applying this national average yield rates into the 1 485 557 ha of small, 527 541 ha of medium and 1 140 268 ha of large reservoirs in the country, their current production rate can be estimated as 74 129, 6 488 and 13 033 trespectively. A modest increase in yield rate up to 100, 75 and 50 kg ha^{-1} in respect of small, medium and large reservoirs, would ensure production of 148 556, 39 565 and 57 013 t. This would increase the production by 2.5 times *i.e.*, from the present 93 650 t to 245 134 t (Table 1.7).

1.5.1 Reservoir fisheries management in India

The present low level of fish production in Indian reservoirs can be attributed to inadequate management inasmuch as many of them have high propensities of production from a limno-chemical point of view. In many of the reservoirs, the high rate of the primary and secondary productivity is not channelled to fish production. Insufficient understanding of the reservoir ecosystem often comes in the way for adopting effective management measures.

Table 1.6. Fish production in different categories of reservoirs in India

State	Small reservoirs	Medium reservoirs	Large reservoirs	Pooled

	Number	Production (t)	Yield (kg ha^{-1})	Number	Production (t)	Yield (kg ha^{-1})	Number	Production (t)	Yield (kg ha^{-1})	Number	Production (t)	Yield (kg ha^{-1})
Tamil Nadu	52	760	48.50	8	269.0	13.74	2	294.0	12.66	62	1323.0	22.63
Uttar Pradesh	31	168	14.60	13	156.0	7.17	1	50.0	1.07	45	374.0	4.68
Andhra Pradesh	37	2224	188.00	29	306.0	22.00	3	800.0	16.80	69	4330.0	36.48
Maharashtra	6	72	21.09	12	313.5	11.83	4	794.0	9.28	22	1179.6	10.21
Rajasthan	78	970	46.43	17	599.7	24.47	2	120.0	5.30	97	1690.0	24.89
Kerala	7	118	53.50	2	17.3	4.80	-	-	-	9	135.0	23.37
Bihar	25	22	3.91	3	7.2	1.90	1	0.8	0.11	28	30.0	0.054
Madhya Pradesh	2	24	47.26	20	624.9	12.02	3	1184.0	14.53	25	1833.1	13.68
Himachal Pradesh	-	-	-	-	-	-	2	1453.0	35.55	2	1453.0	35.55
Orissa	53	349	25.85	6	163.0	12.76	3	925.0	7.62	62	1437.0	9.72
Total	291			110			21			422		
Average			49.90			12.30			11.43			20.13

Table 1.7. Present and potential production from reservoirs of India

Category	Yield (kg ha^{-1})	Area (ha)	Present Production	Potential Production
Small	49.90	1 485 557	74 129	148 556
Medium	12.30	527 541	6 488	39 565
Large	11.43	1 140 268	13 033	57 013
Total		**3 153 366**	**93 650**	**245 134**

Since fish production from reservoirs is essentially extractive in nature, the essence of management strategy lies in exploitation of natural stocks. Nevertheless, the ecosystem management provides different degrees of freedom for stock maniputation, depending on the size and class of the water body (Table 1.8). One of the possible criteria that can be used to differentiate between capture and culture fisheries is the extent of human intervention in the ecosystem management. While aquaculture systems provide maximum avenues for the man to monitor and change the habitat variables and the biotic communities at will, this freedom attenuates as we proceed from aquaculture to the culture-based and capture fisheries. In a large water body, managed on capture fishery norms, there is little room for altering the habitat variables and the scope for effecting change in biotic communities is limited to stocking and ranching, which have uncertain chances of success.

Relative contribution of culture and capture norms in management vary, depending on the category of the reservoir. Medium and large reservoirs are predominantly capture fisheries systems and the management norms are based on the principle of stock manipulation, adjustment in fishing effort, observance of conservation measures and gear selectivity. Selective stocking is resorted to for correcting imbalances in species spectrum and to fill the vacant ecological niches. The small reservoirs, on the other hand, are generally managed as culture-based capture fisheries, akin to extensive aquaculture, where the main accent is on stocking, fattening and harvesting. An imaginative stocking and harvesting schedule and right species mix hold the key for effective management of small reservoirs.

1.5.2 Stocking

Inducting fast-growing extraneous species into the ecosystem to colonise the diverse niches is a necessary prerequisite of reservoir management. Since one of the primary aims of stocking is to ensure utilization of the enhanced food reserves, the ideal time to stock new species is the period of trophic burst. Any lapse in this important management measure causes the proliferation of trash fishes by taking advantage of the increased availability of fish food organisms, which in turn, may provide forage base for catfishes. Nagarjunasagar, Tungabhadra, Hirakud and a number of other large reservoirs in India are examples where the minnows, catfishes, murrels and other uneconomic fishes gained grounds in the early years, leading to establishment of long food chains. These reservoirs harbour good standing crops of plankton and benthos, which are not reflected in the fish output. Even intensive stocking at a later stage has failed to reverse the situation.

Table 1.8. The broad distinguishing features of small and large reservoirs

Small reservoirs	Large reservoirs
Single-purpose reservoirs mostly for irrigation.	Multi-purpose reservoirs for flood-minor control, hydro-electric generation, large-scale irrigation, etc.
Dams neither elaborate nor very expensive. Built of earth, stone and masonry work on small seasonal streams.	Dams elaborate, built with precise engineering skill on perennial or long seasonal rivers. Built of cement, concrete or stone.
Shallow, biologically more productive per unit area. Aquatic plants common in perennial reservoirs but scanty in seasonal ones.	Deep, biologically less productive per unit area. Usually free of aquatic plants. Subjected to heavy drawdowns.
May dry up completely in summer. Notable changes in the water regime.	Do not dry up completely. Changes in water regime slow. Maintain a conservation-pool level (= dead storage).
Sheltered areas absent.	Sheltered areas by way of embayments, coves, etc. present.
Shoreline not very irregular. Littoral areas with a gentle slope.	Shoreline more irregular. Littoral areas mostly steep.
Oxygen mostly derived from photosynthesis in these shallow, non-stratified reservoirs, lacking significant wave action.	Although photosynthesis is a source of dissolved oxygen, the process is confined to a certain region delimited by vertical range of transmission of light (euphotic zone). Oxygen also derived from significant wave action.
Provided with concrete or stone spillway, the type and size	Provided with more complex engineering

of the structure depending on the size of the runoff.	devices.
Major carps breed in the reservoirs.	Breeding mostly observed in the headwaters or in other suitable areas of the reservoir.
Can be subjected to experimental manipulations for testing various ecosystem responses to environmental modifications.	Cannot be subjected to experimental manipulations.
Trophic depression phase can be avoided through chemical treatment and draining. Cycle of fish production can be repeated as often as the reservoir is drained.	Trophic depression phase sets in.
The annual flooding during rainy season may be compared to overflowing of floodplains. Inundation of dry land results in a release of nutrients into the reservoir when it fills up, resulting in high production of fish food through decomposition of organic matter, predominantly of plant origin, leading to higher fish growth and survival.	Loss of nutrients occurs as they are locked up in bottom sediments. Rapid sedimentation will reduce benthos production.
Through complete fishing or overfishing of seasonal reservoirs, no brood stock is left. Fish stock has to be rebuilt through through stocking. There is thus established a direct relationship between stocking rate and catch per unit of effort.	Prominent annual fluctuations in recruitment occur and balancing of stock number against natural mortality requires high density stocking of fingerlings. Their capture requires efficient capture methods.

(Jhingran, 1988)

Since large and medium reservoirs are to be developed on the principles of capture fisheries, it is desirable to stock the species that may breed and ultimately get naturalised in the system through autostocking. This is imperative to meet the long-term objective of obtaining a sustained yield rate. Management involving persistent stocking in large water bodies not only pushes up the input cost, such systems also create many practical difficulties in raising the stocking material in adequate quantities. However, naturalisation of introduced species is quite often beset with many problems. The alien species should find the habitat conducive to its biological and physiological requirements. It should have an edge in the competition for food and finally, the environmental conditions should favour its requirements of spawning and larval development. Recruitment failure due to the erratic hydrographic conditions that break the breeding rhythm have been found to be the single major factor responsible for the failure of stocked fishes to hold out in reservoir.

In Konar, strong currents wash down the carp eggs into the deep zones of the reservoir leading to their destruction and resultant recruitment failure (Parameswaran *et al*., 1969). But more often, the fishes do not find suitable spawning grounds as in the case of many south Indian reservoirs. Since the breeding of major carps is governed to a great extent by the magnitude of monsoon floods, annual variations in this parameter affect their breeding and recruitment.

Selection of species for stocking

Jhingran (1988) has summarized the principles to be followed in the selection of species for stocking as:

1. The species should find the environment suitable for growth and reproduction.
2. It should be quick growing, ensuring high efficiency in food utilization.

3. A fishery comprising herbivores with a short food chain is preferable, as they have a better conversion of primary production to fish flesh.
4. The stocking density should be such that the food resources of the ecosystem are fully utilized and optimum population maintained, consistent with normal growth.
5. The size of the fingerlings to be stocked should be so chosen to get the desired results.
6. Seed should be readily available with minimal transportation cost.
7. Cost of stocking and managing the species must be such that the operation is economically viable.

One of the important considerations is to know the amount of food available in the new environment. This factor has a considerable bearing in determining stocking rates and hence production. Fish production from unit area is a product of individual growth rate and population density. From a study of growth rate of various species in a particular body of water, it is possible to assess their optimal stocking density. Efficient utilization of fish food communities increases the carrying capacity and therefore calls for a higher population density which is achieved by addition of species to the original fish populations. In addition, information on differences, if any, in the growth rates of the endemic and introduced species, and the time taken by the introduced species in attaining harvestable size would provide insight into the production dynamics of the system.

Competition

Both intra- and inter-specific competitions are to be considered in the stocking programme. Situations where two or more species use a similar resource, such as food or space, lead to overcrowding and poor growth rate. Under a higher than optimum stocking rate, though production may be high, the individual growth rate will be so small that to attain a marketable size a long growing period will be needed. On the other hand, if bigger fishes are needed, the rate of stocking should be lowered and a low production will have to be accepted. Similarly, when a marketable size is to be attained in a shorter period, stocking rate will have to be lowered to allow faster growth. Thus, a desired balance among stocking rate, population density and growth is to be maintained with enough flexibility so as to swing it to suit the changes in environmental factors. Such a plan must determine tentative stocking rates and population thinning, depending on the need(Jhingran, 1988).

The sizes of fingerlings that are stocked in Indian reservoirs come under the pre-recurit phase and so, up to the size of entering the exploited phase they are prone only to natural mortality. Therefore, a knowledge of the natural mortality rate is essential as due compensation can be provided for it while computing optimum stocking rates. Jhingran and Natarajan (1969), while evaluating the stocking rates of Damodar Valley Corporation (DVC) reservoirs, arbitrarily recommended a compensation factor for natural mortality @ 25% for reservoirs with no large predaceous fishes and 50% for those harbouring large predators. While estimating optimum stocking rates for such populations, about which no reliable estimates of natural mortality are available, it is felt that assumption of higher natural mortality rate would be desirable as a little overstocking would be less harmful than understocking. Fish Seed Committee of the Government of India (1966) recommended the stocking rate for reservoirs at about 500 fingerlings ha^{-1} of the size range 40 to 150 mm.

Stocking measures adopted in Indian reservoirs

The policies hitherto adopted in Indian reservoirs mainly consisted of stocking fingerlings of a species or a combination of species without any definite density levels or ratios based on the biogenic capacity of the reservoir. Rate of stocking and the species-mix are often determined by their availability, as can be seen from the case studies in the chapters ahead.

Basic productivity of the reservoir is dependent on the amount of solar energy available and the efficiency of the system to transform it into chemical energy. Besides, the energy conversion efficiency at trophic levels of consumers differs considerably from one reservoir to another, depending on the qualitative and quantitative variations in the biotic communities. Any conversion rate above 1% can be considered as good. In an ideal situation, the commercial species share the ecological niches in such a way that trophic resources are utilised to the optimum. At the same time, the fishes should belong to short food chain in order to allow maximum efficiency in converting the primary food resources into harvestable materials. But in reservoirs, such conditions seldom prevail.

Indian reservoirs, by and large, have a wide ranging representation of biotic communities. Phytoplankton comprising Cyanophyceae, Chlorophyceae, Dinophyceae and Bacillariophyceae dominate over the zooplankton such as copepods, cladocerans, rotifers and protozoans. Benthos is represented by insect larvae and nymphs, oligochaetes, nematodes and molluscs. There is a rich growth of periphyton on the submerged objects. The large magnitude of water level fluctuations does not favour the establishment of aquatic macrophytic communities. Significantly, many of the above niches with the exception of insects, Cyanophyceae and molluscs are shared between Indo-Gangetic major carps and trash fishes, focussing the need for controlling carp minnows and weed fishes. The ecosystem-oriented management policy places due emphasis on trophic strata in terms of shared, unshared and vacant niches. Two main pathways through which primary energy finds its way to fish flesh are the grazing chain and the detritus chain. Contribution by both the pathways to the total availability of the energy needs to be assessed for determining the species combination, most suited to the ecosystem. A large number of Indian reservoirs exhibit the detritus chain of energy transfer.

Prior to the development of carp seed production technology in India, natural spawn collected from rivers were stocked in reservoirs. Thus, the seed of *Puntius* spp., *Cirrhinus* spp. and *Labeo* spp. collected from the Cauvery were extensively stocked in the reservoirs of Tamil Nadu along with euryhaline species such as *Chanos chanos, Etroplus suratensis* and *Megalops cyprinoides*. *Labeo fimbriatus, Cirrhinus cirrhosa*, tilapia and *Etroplus suratensis* were the common stocking material in Kerala during the early years. With the advent of induced breeding, most of the States in India were able to raise the carp seed in large numbers by the 1970s and this resulted in a shift in species-mix in favour of catla, rohu and mrigal. Today, reservoir fisheries in India largely centre on development of carp fisheries. Their unmistakable role has been demonstrasted in the Gangetic as well as peninsular reservoirs. Major carps, by virtue of their feeding habits and fast growth rate are indispensable in reservoir management. However, the Indian major carps are ill-suited to utilize phytoplankton, the most dominant fraction of plankton. The remarkable ability of silver carp in efficient conversion of phytoplankton into fish flesh has been demonstrated in Kulagarhi and Getalsud reservoirs, despite the persisting doubts about the digestibility of *Microcystis*. However, introduction of exotic fishes in open waters is still a subject of controversy due to its possible deleterious effects on indigenous populations.

Development of endemic candidates as stocking material has not made much headway in the country although some of them have a proven track record in ensuring an efficient energy transformation rate. *P. pangasius*, subsisting on a molluscan diet is a species to be considered in the detritus-based, mollusc-rich reservoirs of the country. *Puntius pulchellus*, the peninsular species is a well-known macrophyte feeder and *Thynnichthys sandkhol* consumes *Microcystis*, the common alga in Indian waters. Diversification of stocking material is essential for establishment of a multi-species fish stock that utilize all food niches of the ecosystem. In reservoirs, where annual drawdown is not pronounced and water level fluctuations are not steep, phytobenthos and macrovegetation develop in various degrees. The grass carp, *Ctenopharyngodon idella* can be considered for such water bodies. The common carp is being stocked in many reservoirs. This sluggish fish does not survive normally in the warm, deep-basin reservoirs of the south, especially when infested with predators. However, this prolific feeder could carve out a place for itself in the reservoirs of the northeast, in Gobindsagar and in some of the peninsular reservoir like Krishnarajasagar. The fish being a mud-stirrer, is considered to be unsuitable for already turbid waters.

Tilapia, due to its records of rapid proliferation and consequent stunted growth in pond ecosystem, does not find favour with many fishery managers, although in Amaravathy and Malampuzha it has performed well. Stocking of prawn, *Macrobrachium malcolmsonii* has been tried in Tungabhadra and Konar (Natarajan, 1979b), where they could not survive and contribute to the commercial fisheries. Ahmed (1993) emphasised the need for extensive stocking of this prawn, by quoting instances of its self-sustaining populations in many reservoirs. However, the prawn's ability to complete its full life cycle in the freshwater phase is yet to be proved. *T. putitora, L. dero*, and the exotic species such as mirror carp, silver carp, grass carp, *Tinca tinca* and *Carassius carassius* are advocated for the high altitude reservoirs (Natarajan, 1979b).

Impact of stocking

The most important objective of stocking, *i.e*., to augment the yield, can be achieved only if the stocked fishes survive, grow and get caught in the fishing gear. This is achieved, to a large extent, in small reservoirs where the management centres round the stocking and recapture system. However, in larger water bodies, the recapture is uncertain on account of many reasons as mentioned earlier.

Impact of stocking in medium and large reservoirs

Experience in a number of medium and large reservoirs prompts us to conclude that the stocking programme can be termed as successful, only when the stocked fishes breed in the reservoir and contribute towards autostocking. In many cases, despite persistent stocking, the transplanted species did not show up in the catch, thereby rendering the expenditure incurred in stocking as waste. Only in a few instances the resources mobilised for stocking operation were compensated by generation of income through recapture of the stocked fishes.

Sreenivasan (1984) reviewed the impact of stocking in 10 reservoirs of Tamil Nadu. The stocked catla built up a naturalised population in Mettur reservoir. Just 10 000 fingerlings were stocked during 1922 to 1935, which formed the nucleus of a self-propagating stock and dominated the catch during the 1960s. Catla fisheries, however, suffered periodic setback due to breeding failures. The current contribution is as low as 10%. Recapture of two other stocked fishes *viz., L. rohita* and *L. calbasu* is reported to be adequate (Sreenivasan, 1984). However, stocking of *L. fimbriatus* (over 2 million), common carp (1 million), *L. kontius* (0.4 million), *P. carnaticus*(0.4 million), *C. reba* (several hundred thousands) and *P. dubius* (several hundred thousands) is believed to be wasteful, since they were never recaptured in any appreciable quantity.

In Bhavanisagar, although the transplanted catla showed up in the catch, they could not make any impact on the catch structure. As opposed to this, *L. calbasu*, another transplant, found the environment congenial for breeding and established itself in the reservoir, supporting a lucrative fishery for the last few decades. More than 2 million common carp fingerlings were stocked in the reservoir, of which only a few hundreds were recaptured. Intensive stocking of *L. fibriatus* did not make any dent on the fisheries, despite the fact that the fish was native to the system.

In Sathanur, a breeding population of catla has been successfully established through stocking and the fish contributes more than 80% of the total catch. The species has also eclipsed the indigenous *L. fimbriatus* by reducing its contribution from 36% to 1%. It is pertinent to note that the stocking done over 12 years involving 2 million fingerlings of indigenous species such as *C. cirrhosa, L. kontius, C. reba* and *L. fimbriatus* could not make any impact on restoration of their fisheries, primarily due to the inability of the fishes to breed and propagate themselves.

In Krishnagiri, although the increase in percentage of the stocked major carps has resulted in some initial increment in their contribution in the catch, the recapture was not commensurate with the stocking rate. Stocking of Gangetic carps, common carp and *L. fimbriatus* done in Vaigai, so far, has been described as wasteful (Sreenivasan, 1984), where presently, catla contribute 20% of the catch.

In Malampuzha and Peechi, the two medium reservoirs in Kerala not register any substantial increase in yield rate despite sustained stocking with Gangetic major carps, mainly on account of their failure to breed. In Malampuzha, despite a sharp increase in stocking density from 52ha^{-1} in the 1970s, and a corresponding increase in the percentage of major carps in the stocked fishes, the yield rate remains at a low level of 5.0 kg ha^{-1}. Although catla grows to an impressive size, the contribution of major carps never exceeded 20% of the total catch. Considering the low yield rate, the quantity of major carps harvested does not commensurate the stocking effort. Similarly, in Peechi, 90% of the fingerlings stocked belong to the Indian major carps, especially *L. rohita.* But they are not reflected adequately in the catch and the yield rate remains at a low level of 4.5 kg ha^{-1}.

In Nagarjunasagar, Andhra Pradesh, regular annual stocking at the rate of 50 000 to 833 000 fingerlings comprising catla, rohu and mrigal during the 1970s had little impact on the catch structure, as none of the stocked fishes could breed and contribute to recruitment. Similarly, stocking as a management option has failed in Tungabhadra reservoir situated on the same basin and Krishnarajasagar in the Cauvery basin. In Tungabhadra, the stocking rate during 17 years ranged from 1 to 11 ha^{-1}, while it varied from 0.15 to 67 ha^{-1} in Krishnarajasagar. In both the reservoirs, the selection of species has always been arbitrary, the stocking density was inadequate and the stocked fishes failed to breed in the reservoir.

Gandhisagar in Madhya Pradesh is an example of the stocked fishes contributing to fish catch in a sustained manner through breeding and recruitment. During the 1950s through 1970s, on account of steady stocking of catla (2 million), rohu (1.3 million), and mrigal (1.1 million), the fish yield rose to 20.33 kg ha^{-1} from the initial 0.51 kg ha^{-1}. Among the stocked fishes, catla contribute 60 to 70%, while mrigal and rohu form only 1 to 20%. Mrigal, despite being a part of the indigenous ichthyofauna, is on the decline. Ravishankarsagar in the same State was stocked, on an average, with 1.77 million fingerlings every year and yet the yield rate could not be raised above 8.3 kg ha^{-1}, primarily due to the non-establishment of the carps. The amount spent on stocking has been much higher than the cost of recaptured fishes. Rihand reservoir in U. P. could build up a breeding population out of the initial stocking. Although the yield rate of 0.58 kg ha^{-1} is not impressive, 73 to 99% of the catch comprises *C. catla.*

The success of stocked Indian major carps in Ukai reservoir in Gujarat can also be attributed to their breeding in the reservoir. Apart from augmenting the reservoir fisheries through recruitment, the young ones of Indian major carps are also reported to escape through the outlet of the dam and contribute to stocking of downstream impoundments. In all the DVC reservoirs, *viz.*, Konar, Tilaiya, Maithon and Panchet, stocking did not have any impact (Sreenivasan, 1984). Some breeding activities in respect of catla and mrigal have been reported, though low survival rate of the spawn and frequent breeding failure due to erratic monsoon prevented proper recruitment of the planted species.

Indian experience of stocking medium and large reservoirs suggests that by and large, the stocking becomes effective only when the stocked fishes propagate themselves. Moreover, this breeding population can be built up only if the stocking is resorted to during the early phase of the reservoir formation.

Impact of stocking in small reservoirs

In sharp contrast to the large and medium reservoirs, stocking has been more effective in improving the yield from small reservoirs as success in the management of small reservoirs depends more on recapturing the stocked fish rather than on their building up a breeding population. The smaller water bodies have the advantage of easy stock monitoring and manipulation. Thus, the smaller the reservoirs, the better are the chances of success in the stock and recapture process. In fact, an imaginative stocking and harvesting schedule is the main theme of fisheries management in small, shallow reservoirs. The basic tenets of such a system involve:

1. Selection of the right species, depending on the fish food resources available in the system.
2. Determination of a stocking density on the basis of production potential, growth and mortality rates.
3. Proper stocking and harvesting schedule including staggerred stocking and harvesting, allowing maximum growout period, taking into account the critical water levels.
4. In case of small irrigation reservoirs with open sluices the season of overflow and the possibilities of water level falling too low or completely drying up, are also to be taken into consideration.

Aliyar is a standing testimony to the efficacy of the management based on staggered stocking. The salient features of the management options adopted in Aliyar are:

1. stocking is limited to Indian major carps (earlier, all indigenous, slow-growing carps were stocked)
2. Increasing the size at stocking to 100 mm and above.
3. reducing the stocking density to 235–300 ha^{-1} (earlier rates were erratic ranging between 500–2 500 ha^{-1}).
4. staggering the stocking, and

5. regulating mesh size strictly and banning the catch of Indian major carps < 1 kg in size

A direct result of the above management practice was an increase in fish production from 1.67 kg ha^{-1} in 1964–65 to 194 kg ha^{-1} in 1985.

Effective recapture of the stocked fishes renders the stocking more remunerative in small reservoirs. Successful stocking has been reported from a number of small reservoirs in India. In Markonahalli, Karnataka, on account of stocking, the percentage of major carps has increased to 61% and the yield increased to 63 kg ha^{-1}. Yields in Meenkera and Chulliar reservoirs in Kerala have increased from 9.96 to 107.7 kg ha^{-1} and 32.3 to 275.4 kg ha^{-1} respectively through sustained stocking. In Uttar Pradesh, Bachhra, Baghla, and Gulariya reservoirs registered steep increase in yield through improved management with the main accent on stocking. An important consideration in Gulariya has been to allow maximum growout period between the date of stocking and the final harvesting, *i.e.*, before the levels go below the critical mark. The possible loss due to the low size at harvest was made good by the number. Bundh Beratha in Rajasthan, stocked with 100 000 fingerlings a year (164 ha^{-1}) resulted in a fish yield of 94 kg ha^{-1}, 80% of which constituting catla, rohu and mrigal (Table 1.9).

Table 1.9. High yields obtained in small reservoirs due to management

Reservoir	**State**	**Stocking rate (number ha^{-1})**	**Yield (kg ha^{-1})**
Aliyar	Tamil Nadu	353	194
Meenkara	Kerala	1 226	107
Chulliar	-do-	937	316
Markonahalli	Karnataka	922	63
Gulariya	Uttar Pradesh	517	150
Bachhra	-do	763	140
Baghla	-do-	?	102
Bundh Beratha	Rajasthan	164	94

Instances where intensive stocking of Indian major carps became ineffective in small reservoirs are very rare. In Govindgarh, despite stocking of Indian major carps at the rate of 19 to 390 fingerlings ha^{-1}, the yield remained at 15.92 kg ha^{-1}, during the '60s and the '70s. Large-scale escapement of fishes through the open weir is believed to be the main reason for this low fish yield. An estimated 1.1 million fingerlings of catla, rohu and mrigal were stocked into Badua reservoir, Bihar during the period 1975 to 1979. However, the fish yield from the reservoir during the period remained within 4 to 7 kg ha^{-1}. Other management measures taken in the reservoir are not known. Sreenivasan (1984) reported disappointing recapture of major carps after their heavy stocking in Manjalar reservoir (Tamil Nadu). Proliferation of the tilapia, *O. mossambicus* is the main factor that prevented the major carps from getting a foothold in the fishery, probably due to their competition for food.

1.5.3 Removal of predators and weed fishes

Presence of predatory and weed fishes poses impediments in survival and growth of economic species in many Indian reservoirs. Keeping these unwanted population under check is a very difficult management problem, especially in large reservoirs. A small population of predators helps to crop the trash fishes which compete for food with the economic species. A small predator population of Gobindsagar which keeps the minnows under check is a good example.

However, no scientifically sound methods are available to keep a limited population of predatory species. Repeated use of gill nets of appropriate mesh size, use of long lines, traps, etc. are suggested for control of the uneconomic and undesirable populations. Manipulation of reservoir level with a view to checking the breeding and destruction of the young ones of predators and the minnows has been tried in several countries. However, this is not practicable in many Indian reservoirs since water release pattern is dictated by priority sectors like irrigation and power generation. Poisoning of selected sheltered areas arms and coves as practised abroad has also limited use in India due to the multiple use of water and objections from the other water users. David and Rajagopal (1969) reported that non-selectivity of shore seines helped in reducing catfish population in Tungabhadra reservoir by 76 to 81%. *Alivi*, the giant shore seine of Tungabhadra also removes the trash fish in large numbers. Judicious use of this gear, with a condition that the juveniles of economic species are released back, can go a long way in containing the trash fish population.

Recent findings of Kartha and Rao (1990) with regard to the efficacy of trawling in checking predators and trash fishes are of interest. Bottom trawling in Gandhisagar was found to catch 64 to 91% of the unwanted fishes and this has been recommended as a method to crop the predators and carp minnows. Nevertheless, applicability of this method is limited to places where the bottom is free from obstructions. Natarajan (1979b) suggested biological control of trash fishes by stocking two euryhaline species *viz., Megalops cyprinoides* and *Lates calcarifier*. Since these predatory fishes do not breed in freshwater, they cannot go out of control.

1.5.4 Exotic fishes and their role in the reservoir fisheries of India

In spite of an already rich and diverse fish genetic resource of India, more than 300 exotic species have been introduced into the country so far (Jhingran, 1989a). While a vast majority of them are ornamental fishes which remain, more or less, confined to the aquaria, some others have been introduced in aquaculture and open water systems with varying degrees of success. Three larvicidal fishes *viz., Lebistes reticulatus, Nothobranchus* sp. and *Gambusia affinis* were introduced for containing the insect larvae in confined waters. Silver carp and the three varieties of common carp were brought into the country with the objectives of broadening the species spectrum in aquaculture and increasing the yields through better utilization of trophic niches. In recent years, the bighead carp *Hypophthalmichthys nobilis* and *O. niloticus* have been reported from the culture systems of eastern India. After unauthorised introduction, these two fishes are becoming popular among the aquaculturists of the region. While a few of the introduced species proved to be a boon in aquaculture and acted as an instrument for yield optimisation from ponds, the accidental and deliberate introduction of some of the exotic fishes into the open-waters has generated a lot of debate in recent years. There is a growing concern in India about the possible deleterious impact of the exotic fishes on the fish species diversity of the Indian rivers.

Oreochromis mossambicus, Hypophthalmichthys molitrix, Ctenopharyngodon idella, Cyprinus carpio communis, C. carpio specularis and *C. carpio nudus* have gained entry into the reservoir ecosystem through accidental or deliberate introduction. Among them, tilapia, silver carp and common carp could make a negative impact on the fisheries in various reservoirs in the country. Instances of *Gambusia affinis* getting naturalised in reservoirs are rare. In Markonahalli reservoir, the fish has established itself as a breeding population and reported to be affecting the larval stages of commercially important fishes.

Tilapia

The tilapia, *O. mossambicus* was first introduced into the pond ecosystem of the country in 1952 and soon it was stocked in the reservoirs of south India. By the end of 1960s, most of the reservoirs in Tamil Nadu and those in the Palakkad and Trissur districts of Kerala were regularly stocked with tilapia. Performance of tilapia in ponds of south India has been discouraging mainly due to its early maturity, continuous breeding, over-population and dwarfing. It is reported to mature at 6 cm length at an age of 75 days and to breed at an interval of one month under the tropical conditions.

Performance of tilapia in reservoirs

The warm waters of the tropical reservoirs in India have provided a conducive habitat for the tilapia and it has established a secure position in a number of south Indian reservoirs. The fears of its stunted growth have been allayed as the average size of tilapia did not decline as much as it did in ponds. Sreenivasan (1967) stated that the fluctuating water levels affected the breeding pits of the fishes and the predators took a heavy toll of their young ones. These two factors are believed to keep check on the excessive proliferation of tilapia in reservoirs.

Size of tilapia in the commercial catches of reservoirs has been very good, as opposed to the unmarketable size reported fromthe ponds. The average size of tilapia from Tamil Nadu reservoirs has been 1.5 kg during the 1960s, with the minimum size of 500 g. Similarly, tilapia weighing 2.5 kg was very common in Malampuzha reservoir, Kerala during the 1960s, with an average size of 1.5 to 1.75 kg. The present size of 0.5 to 0.7 kg in Malampuzha and 0.68 kg in Tamil Nadu reservoirs are well within the limits of market preference, their continuous slide in size over the years is a cause of concern as it is feared that if the fall in size continues, it may become unmarketable.

Tilapia has dominated and virtually eliminated all other fishes including the stocked Gangetic carps in a number of reservoirs in Tamil Nadu. Vaigai, Krishnagiri, Amaravathy, Uppar and Pambar reservoirs in Tamil Nadu are harbouring sizeable populations of tilapia since 1960s, contributing substantially to commercial catches. While its contribution has declined since 1979–80 in Vaigai, it continues to form a major fishery in all the other reservoirs. In Krishnagiri, the fish has a changing fortune on account of competition with the mullet, *Rhinomugil corsula*. From the predominant position in the 1960s the percentage of tilapia came down to 4.3% in 1983–86, only to increase in the year 1989–90 to 69% (Jhingran, 1991). At present, tilapia forms 24% of the catch.

Chulliar, Meenkara, Peechi and Malampuzha reservoirs in Kerala have been stocked with tilapia in the early sixties and the fish contributes substantially to the catch. In the relatively large (2 313 ha) Malampuzha reservoir, tilapia is reported to have registered a fast growth rate and large size, contributing 10 to 70% of the catch in different years. Tilapia also found its way into Kolleru lake in Andhra Pradesh and Sondur reservoir in Raipur district, Madhya Pradesh. Jhingran (1991) examined the yield of tilapia in different classes of reservoirs in the size range 50 to 10 000 ha and came to the conclusion that, by and large, small reservoirs in the size range of 50 to 200 ha showed a better yield (44 to 101 kg ha^{-1}), than the larger ones. Relatively large reservoirs such as Malampuzha and Amaravathy have a better size of tilapia, although documentation is not sufficient to attempt any correlation between the size attained by the fish and the area of reservoirs.

Distribution of tilapia is more or less restricted to the tropical belt as the fish is constrained with slow growth and winter mortalities in the higher latitude. Attempts to introduce the fish in Baghla, a small irrigation impoundment in the Gangetic plain have not succeeded (Jhingran, 1991). The ongoing debate on the introduction of tilapia centres round its:

1. suitability to enhance yield through niche utilization,
2. propensity for affecting or even replacing the native ichthyofauna, and
3. consumer preference.

One of the main considerations in determining introduction of exotic fishes is their feeding habits. Since none of the Indian culturable carps feeds on Cyanophyceae blooms like *Microcystis aeruginosa*, tilapia is often cited as a welcome addition to the blue-greens-dominated water bodies. Although Sreenivasan (1967) and many workers abroad expressed their reservations about the ability of tilapia to digest and assimilate *Microcystis*, Jhingran (1991) believed that the sodium-calcium ratio in alkaline reservoirs broke down the cell walls of blue-greens, facilitating their digestion by tilapia. *Oreochromis mossambicus* has wider omnivorous food spectrum, compared to many other species of tilapia.

Tilapia versus indigenous carps

The apprehensions about tilapia affecting the native ichthyofauna seem to be valid, going by its track record in India and abroad. In a number of reservoirs in India, introduction of tilapia has resulted in poor growth rate or even elimination of the indigenous species and the transplanted Gangetic carps. Sreenivasan (1967) found that the growth rates of *C. catla, L. fimbriatus* and *C. mrigala* were adversely affected by tilapia in Ayyamkulam pond. He also observed that growth of *Chanos chanos* was restricted to less than 100 g yr^{-1}, against the usual 500 g yr^{-1} in many water bodies of Tamil Nadu due to its co-existence with tilapia. In Kabini reservoir tilapia has adversely affected the indigenous *Cirrhinus reba*. During the period from 1980–81 to 1984–85, tilapia has caused decrease of *C. reba's* share in the catch from 70% to 20% (Murthy et al., 1986). Tilapia and the Indian economic species sharing a common food niche, the success of one in competition with the other is determined by the ability to breed and propagate. Given the propensities of tilapia for autostocking, the indigenous species, which are prone to breeding failure, have a definite disadvantage in its struggle to coexist with the former.

Introduction of *O. mossambicus* and *Tilapia zillii* for weed and insect control in Californian reservoirs has affected the native ichthyofauna (Moyle, 1976). A more devastating effect on indigenous fish fauna has been reported from Kyle reservoir in Zambia, where a valuable local species *Paretopus petite* has been eliminated from the ecosystem (Lamarque *et al*., 1975).

Consumer preference

Tilapia of right size has a good consumer preference. Tilapia is also known as a species affordable by the poor. In Palakkad and Trissur districts of Kerala, where the fish is an important component of reservoir catch, tilapia enjoys a consumer preference over the Indian carps even when sold at an equal price (Jhingran, 1991). *Relevance of tilapia in reservoir fisheries*

Tilapia (*O. mossambicus*) has entered the Indian scene, when the inland fisheries contributed negligibly to the total fish production in the country and the ecosystem management was in its infancy. Today, a number of indigenous species are available for stocking to broaden the species spectrum, bridge the gaps in niche utilization and increase the yield. Barring a very few reservoirs, tilapia-dominated fishery invariably leads to low yields. In many reservoirs like Krishnagiri and Vaigai, the production has been found to be erratic due to the unpredictive behaviour of tilapia population due to competition from other fishes. Fishery managers of India are striving hard to change the fish from its dominant position, wherever, they occupy one. Thus, in the present context, tilapia does not figure among the species preferred for stocking in Indian reservoirs.

Oreochromis niloticus has not yet entered the reservoir ecosystem in India. Confined to the estuarine and freshwater wetlands of the eastern India, the fish has registered an impressive growth of 250 g in 6 months. Since this fish is not reported to have problems of stunted growth and prolific breeding, it may probably have a more positive role to play in Indian reservoirs, compared to *O. mossambicus*.

Silver carp

Silver carp, *Hypophthalmichthys molitrix* was introduced in India in 1959 and unlike tilapia, it has not strayed into many reservoirs. However, silver carp has attracted more attention from the ecologists and fishery managers, generating a more animated debate. Importance of silver carp in reservoirs emanates mainly from:

1. its reported ability to utilise *Microcystis*
2. the impressive growth rate, and
3. its propensities for affecting the indigenous species, especially *Catla catla*.

The silver carp has a specialised structure of gill rakers adapted to microplankton feeding (Inaba and Nomura, 1956). Gut analysis of the fish carried out at the Central Inland Fisheries Research Institute revealed a wide feeding range including Chlorophyceae, Cyanophyceae, Chrysophyceae, Bacillariophyceae, Dinophyceae, Protozoa, Rotifera, Cladocera, Ostracoda, and Copepoda (Jhingran and Natarajan, 1978).

Performance of silver carp in reservoirs

An experimental consignment of 239 fingerlings of silver carp was stocked in Kulgarhi reservoir (Madhya Pradesh) in 1969. Based on the recapture of 8 specimens, growth rates ranging from 597 mm in 783 days (0.76 mm day^{-1}) to 404 mm in 293 days (1.4 mm day^{-1}) have been recorded (Rao and Dwivedi, 1972). The fish was also introduced in Getalsud reservoir, Bihar in 1974, where it has recorded growth rates ranging from 2.20 to 5.79 g day^{-1} (Table 13.4). In both reservoirs, the fish did not breed. There are reports about the stocking of silver carp in a number of reservoirs across the country ranging from Gumti in the northeast to Aliyar in Tamil Nadu. However, it did not get established as a breeding population anywhere.

The most spectacular performance of silver carp has been reported from Gobindsagar reservoir, where after an accidental introduction, the fish formed a breeding population and brought about a phenomenal increase in fish yields. (see the chapter on Himachal Pradesh). Silver carp is instrumental in enhancing the fish production from the reservoir from 160 t in 1970–71 to 964 t in 1992–93 (Fig. 1.10). Many workers have suggested the over-intensity of feeding in respect of silver carp, as reflected by the *gorged* and *full* conditions of gut all through the year. Jhingran and Natarajan (1978) pointed out that the silver carp, being a cold-water fish, when introduced into a warm regime, consumed food much in excess and grew faster as expected of a true poikilotherm. A similar latitude- induced change worth noticing is the age at maturity. The fish mature when they are 5 to 6 years old in North China, 4 to 5 years in Central China and 2 to 3 years in south China. In India, it breeds just at the age of one year under optimum conditions.

Silver carp versus catla

Pond culture experiments conducted in the country have unmistakably established the superior performance of silver carp when cultured along with catla (Sukumaran, *et al*., 1968). Jhingran and Natarajan (1978) expressed the view that this need not hold good for large water bodies like reservoirs. They argued that the silver carp short-circuited the food-web, resulting in the poor performance of catla. For instance, silver carp showed preference for smaller zooplankters especially rotifers and nauplii. It was quite likely that too much of grazing on copepode nauplii by silver carp could disturb the life cycle of copepodes in a small water body like pond, causing poor performance of catla. While advocating a cautious approach, they advocated stocking of silver carp in closed reservoirs like Gobindsagar and Nagarjunasagar which are blocked by dams, both down- and upstream and no connected with the Ganga river system, the original abode of *C. catla*. The fish was not stocked in either of the reservoirs. However, in Gobindsagar, stocking of silver carp has since become irrelevant as the fish has already carved out a niche for itself in the reservoir. In the process, the lurking fear that the exotic fish is deleterious to the populations of indigenous catla has been proved beyond any doubt. Ever since silver carp gained a stronghold in the reservoir, catla which constituted an annual fishery of the magnitude of 200 to 300 t has declined considerably (Fig. 1.10)

Karamchandani and Mishra (1980), while evaluating the co-existence of silver carp and catla, established that the two fishes shared a common niche and compete with each other for food in a reservoir ecosystem. Percentage composition of phytoplankton in the guts of both the fishes caught during the same time from Kulgarhi reservoir was more or less the same. Zooplankton, the favourite menu of catla, formed 21% of the gut contents of silver carp. The authors concluded that silver carp hampered the growth of catla in the reservoir and advocated caution before its stocking in Indian reservoirs.

It is significant to note that despite its entry into a number of Indian reservoirs, by accident or otherwise, silver carp failed to get naturalised anywhere except Gobindsagar. Considering that the reservoir, with its temperate climate, is closer to the original habitat of the fish and has a distinctly cold water hypolimnion due to the discharge from Beas, the silver carp seems to have found a congenial habitat for growth and propagation. Although introduction of silver carp was never cleared by the Committee of Experts constituted by Govt. of India, the fish is being stocked in a number of reservoirs in the country. Nowhere did the fish make an impact as it did in Gobindsagar. Therefore, fears regarding the threat of extinction of catla from the Gangetic and peninsular India posed by silver carp are perhaps misplaced.

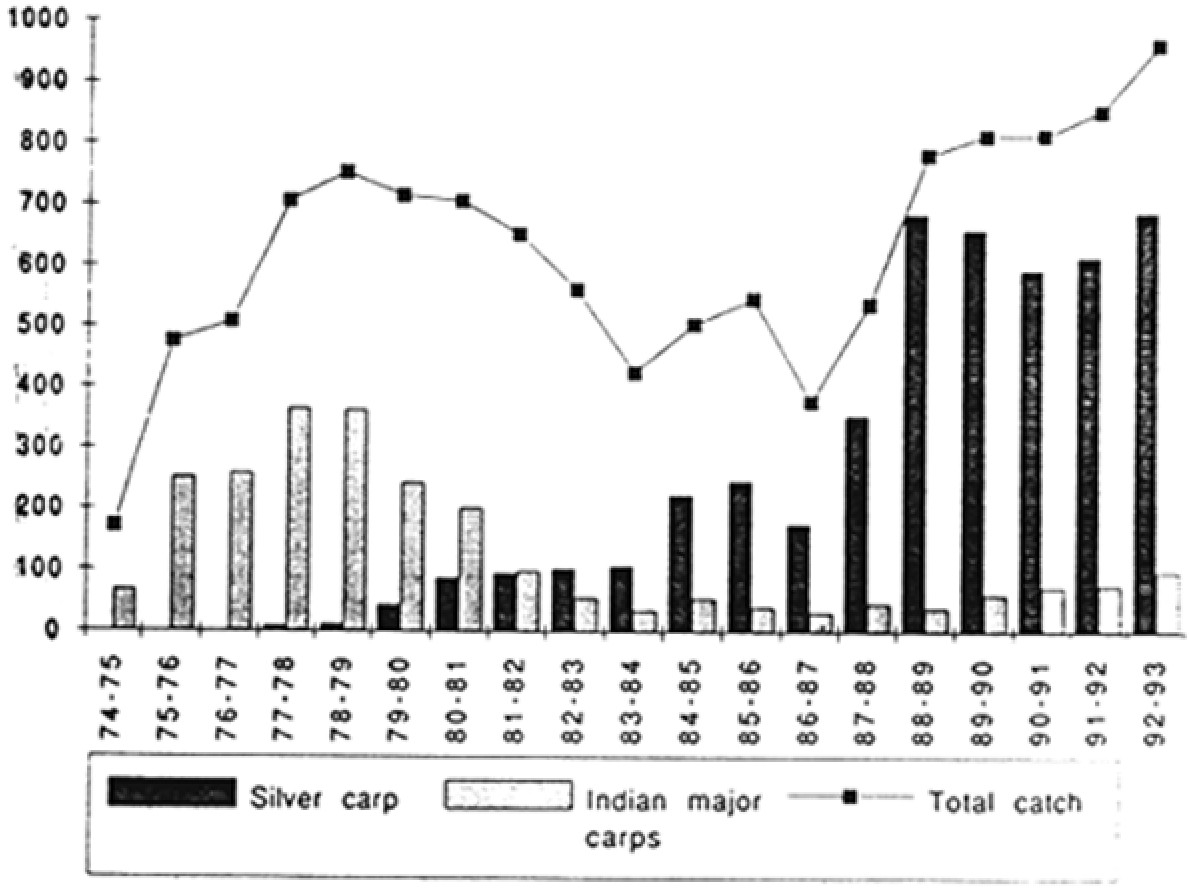


Figure 1.10. Catch of silver carp in relation to the total fish catch in Gobindsagar (in t)

Common carp

The three varieties of the Prussian strain of common carp, *viz.*, the scale carp *(Cyprinus carpio communis)*, the mirror carp *(C. carpio specularis)* and the leather carp *(C. carpio nudus)* were introduced in India during 1939. They were stocked in several high altitude ponds and lakes during the 1950s. Later, in the 1957, the Chinese (Bangkok) strain of the common carp was brought into the country, primarily for aquacultural purposes, considering its warm water adaptibility, easy breeding, omnivorous feeding habits, good growth and hardy nature.

Like tilapia, common carp soon found its way to all types of reservoirs in the country. Relative ease at which the fish could breed in controlled conditions prompted the departmental fish farms throughout the country to produce the seed of common carp in large numbers and to stock them in the reservoirs. However, such stocking attempts were devoid of any ecological reasoning. The Bangkok strain of common carp has been stocked in a large number of reservoirs in the plains and European strain was introduced in the reservoirs of temperate zones and high altitudes. But their performance in reservoirs is erratic, despite heavy stocking.

Common carp is not a suitable fish for stocking in Indian reservoirs, especially the larger ones, for diverse reasons. Being a sluggish fish, its chances of survival in a predator-dominated reservoir are very poor. They are not frequently caught in a passive fishing gear like gill net, due to its slow movement and bottom dwelling habit. It is no wonder, despite a regular stocking for 13 years (involving 537 000 fingerlings), not a single common carp was ever caught from Nagarjunasagar. Obviously, the stocked fishes failed to survive among the marauding predators. This has been the fate of common carp stocked in all the deep reservoirs, with a few exceptions such as Krishnarajasagar. A more important disqualification is its propensities to complete with some important indigenous carps like *Cirrhinus mrigala* and *C. cirrhosa* and *C. reba* with which common carp shares food niche. Instances where the presence of common carp has resulted in the decline of *Cirrhinus* sp. are available in Girna and Krishnarajasagar.

The mirror carp has a dubious distinction of jeopardizing the survival of a number of native fish species, after its introduction in some of the upland lakes of Kumaon Himalayas, the Dal lake in Kashmir, Gobindsagar, and the reservoirs of the northeast. In the Dal lake, common carp found a favourable environment by virtue of the shallow lake basin, extensive submerged vegetation, and rich food resources. By virtue of the specific ecological advantage, the fish propagated itself profusely to the perli of indigenous snow trouts like *Schizothoraichthys niger, S. esocinus*, and *S. curvifrons*. The snow trouts had the twin disadvantages of low fecundity and the stream breeding behaviour. Mirror carp has caused similar damage to the snow trouts in Gobindsagar reservoir and *Osteobrama belangeri* in Loktak lake of the northeast. Analogy of events related to the common carp and snow trouts sends out enough signals regarding the potential harm the former can do to the ichthyofauna in the plains.

Other exotic species

Three exotic carps, being considered for introduction in the country are the bighead carp, *H. nobilis* (already gained entry unofficially) the mud carp, *Cirrhinus molitorella* and the snail carp, *Mylopharyngodon piceus*, feeding on zooplankton, detritus and molluscs respectively. Natarajan (1988), after a thorough probe into the ecological implications of their introduction, considered their introduction as an irrational step, as all of them infringe on the food niche of economic carp species of India and the alien species possessed all propensities for causing extinction of their native counterparts.

1.5.5 Artificial eutrophication

Fertilization of reservoirs as a means to increase water productivity through abetting plankton growth has not received much attention in India. Multiple use of the water body and the resultant conflict of interests among the various water users are the main factors that prevented the use of this management option. Surprisingly, fertilization has not been resorted to even in reservoirs which are not used for drinking water and other purposes. Documentation on fertilization of reservoirs in India is scarce. Sreenivasan and Pillai (1979) attempted to improve the plankton productivity of Vidur reservoir by the application of super phosphate with highly encouraging results. As soon as the canal sluice was closed, 500 kg super phosphate with P_2O_5 content of 16 to 20% was applied in the reservoir when the waterspread was 50 ha with a mean depth of 1.67 m. As an immediate result of fertilization, phosphate content of water increased from nil to 1.8 mg 1^{-1} and that of soil from 0.242 to 0.328%. Similar improvements in organic carbon and Kjeldal nitrogen has been reported from soil and water phases on account of fertilization. Experiments were also conducted with urea in the same reservoir.

Application of lime was tried in some upland natural lakes for amelioration of excessive CO_2 and acidity at the bottom (Sreenivasan, 1971). This measures, together with the application of superphosphate in Yercaud lake, raised the pH of water from 6.2 to 7.3 and decreased the

CO_2 in bottom water from 38 to 6.5 mg 1^{-1}. There was a corresponding increase in species number and biomass of plankton.

The basic objective of fertilization is to increase the plankton density and thereby accelerating primary productivity. Fertilization in Vidur reservoir resulted in a marked increase in benthic and plankton communities and doubling of the primary production rate. After two successive applications of fertilizers, significant limnological changes took place including the presence of free carbon dioxide and decrease in pH and dissolved oxygen at the bottom layer of water. The methylorange alkalinity increased from 44 to 108 mg 1^{-1} from the surface to bottom, indicating a high organic productivity. Phosphate fertilization triggered the tropholytic activities mineralising the organic matter and producing carbon dioxide. As a direct benefit from the fertilization, a 50% increase in fish production, along with three-fold increase in the size (average weight) of catla, rohu, mrigal, *L. fimbriatus* and *L. calbasu* were achieved.

Experiments on fertilization is in progress in the 90 ha Naktra reservoir in Madhya Pradesh, under a research project of the Central Inland Capture Fisheries Research Institute. Organic and inorganic fertilisers are being applied to improve the water and soil quality status. Artificial eutrophication as a decisive management option was tried in India for the first time in Kyrdemkulai (80 ha) and Nongmahir (70 ha) reservoirs of the northeast (Sugunan and Yadava, 1991a, b) by applying poultry manure (10 t ha^{-1}), urea (40 kg ha^{-1}) and single superphosphate (20 kg ha^{-1}).

Fertilization can play a key role in many small reservoirs of India, which require correction of oligotrophic tendencies. A number of reservoirs in Madhya Pradesh, the northeast and the Western Ghats, receiving drainage from poor catchments show low productivity, necessitating artificial fertilization. Chinese experience in fertilizing the small reservoirs for increasing productivity has been reassuring (Yang *et al*., 1990). In Shishantou reservoir, a management strategy comprising fertilization by organic and inorganic manures and feeding resulted in phenomenal production hike from 1 500 kg ha^{-1} to 6 000 to 7 000 kg ha^{-1} during 1985 to 1989. Before fertilization, the plankton biomass in Shishantou was 1.5 mg 1^{-1}, which was raised to 6.5 mg 1^{-1} through application of organic fertilizers at the rate of 6.375 t ha^{-1}. The plankton biomass, after dropping during the peak precipitation period, picked up to 20.51 mg 1^{-1} during the post-rainy season months, with corresponding increase in fish production.

1.5.6 Pollution

Ecodegradation of reservoirs has been on the increase due to the rapid pace of industrialisation, poor environment management in the catchment and a variety of other factors. Apart from the direct entry of industrial, municipal and thermal wastes, the pollution load carried by the upstream rivers is also accumulated in the reservoirs. The environmental degradation in reservoirs is caused mainly by the waste discharge from industrial, municipal and agricultural sources and the thermal power plants (Table 1.10). High rate of siltation due to poor catchment management also affects the biological productivity.

Table 1.10. Pollution in reservoirs

Reservoir	Name of river	Sources of pollution
Getalsud	Subarnarekha	Heavy engineering, chemicals and sewage.
Gandhisagar	Chambal	Textile, chemicals, trade effluents from Indore, Ujjain and Kota.
Tungabhadra	Tungabhadra	Paper, iron and steel, rayon, chemicals and sewage.

G.B.Pantsagar	Rend	Thermal power plant, coal washery, chemicals.
Bhavanisagar	Bhavani	Viscose factory effluent.
Hussainsagar	Musa	Trade effluents and sewage from Hyderabad city.
Hirakud	Mahanadi	Paper mill
Byramangala	Vrishabhavati	Industrial effluents and city sewage
Sandynulla	-	Animal products

(*Modified from Joshi, 1990*)

Thermal pollution

A number of reservoirs have been selected, of late, as sites for thermal power plants due to their dual utility as perennial source of water supply and disposal point for heated effluents. Thermal power generation capacity of the country has been registering a steady growth of 8% per annum and by the turn of the century, the installed capacity is expected to reach 84 000 MW. Various thermal plants in the country are estimated to generate 10 billion m^3 of hot water (40° to 5°C) and 17 million t of fly ash every year. Fly ash is known to contain heavy metals such as Zn (6%), Ba (12.2%), Cu (1.3%), As (0.02%), V(0.08%), Ti(0.02%) and Mn (0.23%), which may find their way to the nearest river stretch or a reservoir.

Rihand is a large man-made lake of 46 000 ha, into which converge cooling waters from four super thermal power plants under the public sector*viz*., Singrauli (2 000 MW), Vindhyachal (2 260 MW), Anpara (3 130 MW) and Rihand (3 000 MW), besides the private sectors Renusagar thermal power plant with a capacity of 210 MW. All these power generating plants are located within a small area of 30 km^2. Chandra *et al* (1985) reported adverse effects of heated discharge on resident aquatic organisms. They recorded mortality of fish and decrease of aquatic life within 50 km of the discharge point, owing to high temperature (46 to 52°C) of the effluent. Deposition of fly ash has been reported up to 500 m downstream of the outfall point. Cooling waters of Renusagar power plant discharged into Rihand reservoir are acidic and high in chlorides. Although an increase in water temperature is known to cause deoxygenation, a rise within reasonable limit enhances photosynthetic activities resulting in supersaturation of water with oxygen.

The main ecological consequences of a heated water discharged into the aquatic ecosystem are increase in water temperature, change in chemical composition and change in metabolism and life history of aquatic communities. The heated discharge may elevate the water temperature by 8 to 10 °C which may cause mortality of fish and fish food organisms. Temperature also exerts direct influence on toxicity. Apart from the rise in temperature, discharged waters are often altered chemically during the cooling processes. Davies (1966) showed that cooling tower discharge has lower ammonia level, higher concentration of nitrate and TDS, and lower levels of organic nitrogen, when water is abstracted from a polluted water source.

Temperature above 40 °C has been reported to negatively affect the plankton and benthic communities. Generally, fishes avoid heated effluents discharge points by swimming away to safer places. They can also withstand wide fluctuation of temperature (8 to 10 °C). However, the reproduction of fish is affected due to deposition of fly ash in the marginal areas of the river/reservoir which act as their breeding grounds. All the power plants around Rihand reservoir are located near the intermediate and lotic sectors, where the fishes are known to congregate

(Desai, 1993). The most deleterious among the impacts of thermal pollution is the blanketing effect on the reservoir bed. Fly ash covers extensive areas of the bottom, blanketing off the substratum, resulting in retardation or total elimination of benthic communities. Thick mat of fly ash deposit at the bottom bed over the years may seal the nutrients away from the water phase and thereby affect productivity.

Domestic wastes

A number of reservoirs contiguous to towns and cities face threat from sewage pollution. Although from the fisheries point of view, organic loading within certain limits does not hamper the productivity, sewage load in excess can cause aseptic conditions, adversely affect the biotic communities, retard productivity and render the fish unfit for human consumption. Moreover, the problem needs to be addressed from public health and aesthetic points of view. The acute cases of hyper-eutrophication due to city sewage discharge in Hussainsagar, Mansarovar, Byramangala and Sandynulla reservoirs cause serious impediments in ecosystem management. Cases of heavy fish mortality is reported in Byramangala (Raghavan *et al*, 1977) and Hussainsagar (Hingorani *et al*, 1977).

The major adverse impact of sewage pollution can be assessed from deoxygenation, high BOD load, rapid eutrophication and accumulation of heavy metals in the environment. Sharp fall in dissolved oxygen in water puts the biotic communities under severe stress. While some species can tolerate a wide range of dissolved oxygen, many communities are highly sensitive to this parameter. As a chronic effect of oxygen depletion, some of the component populations are eliminated from the riverine community, causing far reaching changes in the trophic cycle. For instance, complete absence of zooplankton during January to August and its reappearance in September represented by *Keratella* sp., associated with abundance of phytoplankton like *Microcystis* sp. *Oscillatoria* sp., *Hormidium* sp., and *Nitzschia* sp., have been observed downstream of the sewage effluent outfall on the Ganga and Yamuna. The outfall area is dominated by *Chironomus*, followed by oligochaetes (*Tubifex* and *Nais*) in both the rivers, while areas below the outfall are characterised by the dominance of *Chironomus* followed by gastropods and bivalves.

Apart from affecting the organisms at lower trophic levels, intensive rate of pollution from municipal sources often causes direct fish kill, especially in small reservoirs where the problem gets aggravated due to reduced water flow rate. There are potential problems relating to the use of chlorine for disinfecting the sewage effluents for public health purposes. Owing to the increased use of synthetic detergents for domestic purposes, their incidence in the sewage effluents are on the increase. Synthetic detergents being absorbed into the body system of fish impair their growth and reproductive capacity. Detergents mixed with oil may be 60 times more toxic than the oil alone. Synergistic action of detergents with insecticides has also been recorded. Its sub-lethal concentration causes thinning and elongation of respiratory epithelial cells. Sodium lauryl sulphate is more toxic to freshwater teleosts, compared to alkyl benzene sulphonate (13-60 mg 1^{-1}). Impact of heavy metals is discussed later on in this document.

Industrial effluents

Wastes emanating from an array of industries such as chemical plants, textile mills, heavy engineering plants, paper mills, iron and steel factories, rayons, etc., cause pollutional hazards in Indian reservoirs. Several instances of ecosystem damage and fish kill due to industrial effluents have been documented. Effluents from the Kanoria chemicals discharged into Rihand reservoir are alkaline (pH 9.2) and high in total alkalinity (4 770 mg 1^{-1}), specific conductivity (12 816 umhos), chlorides (5 173 mg 1^{-1}) and free chlorine (1 924 mg 1^{-1}) (Chandra *et al*., 1983). These wastes have shown severe toxic effects on phyto - and zooplankton. Direct fish kills have also been reported in this reservoir due to high chlorine bearing wastes (Arora, *et al*, 1970). Effluents from a paper mill at Brajrajnagar are discharged into Hirakud reservoir and Sugar mill wastes finding their way to a small reservoir in Gorakhpur were the cause of complete replacement of carps by the uneconomic fishes (Natarajan, 1979b). Discharge of industrial wastes consisting of dissolved and insoluble solids, free chlorine and lime of Mettur chemical factory into the surplus water channel of Stanley reservoir is reported to have resulted in large-scale mortality of carps and catfishes in summer.

An industrial unit near Sandynulla reservoir manufacturing gelatin from animal bones and the effluents from this factory bearing high BOD and phosphate are discharged into the reservoir, which is already eutrophic on account of sewage wastes from the city of Ooty. The south India Viscose, manufacturing viscose rayon and staple fibre, discharges 16 000 m^3 of waste material into the river Bhavani at Sirumughai, causing pollutional hazard in Bhavanisagar reservoir, causing increase in bicarbonate and carbon dioxide and fall in dissolved oxygen and pH along with occasional fish kills. Another synthetic fibre manufacturing unit, Harihar Polyfibre discharges wastes into the tributaries of the river Tungabhadra, resulting in ecosystem degradation and fish kills (Joshi and Sukumaran, 1987). Several major and minor industries located on the river Bhadra in the industrial town of Bhadravati in Shimoga district are the source of heavy metals discharge in the inflowing water of Tungabhadra reservoir (Singit *et al*., 1987). *Impact of industrial pollution*

Industrial effluents, though comparatively less in volume, may cause considerable harm to the aquatic environment and the biotic communities including fish and ultimately affect man through food chain. Non-biodegradable and persistent types of pollutants like heavy metals, chlorinated hydrocarbon pesticides, oil components having high boiling points and radionuclides get more concentrated at higher trophic levels through biomagnification and pose threat to human health. Industrial effluents include a wide variety of chemical toxicants and heavy metals, apart from those contributing substantially to the BOD load such as pesticides which are used in processing the raw materials in many industries. In addition to the sub-lethal chronic effects on the environment, certain direct impacts are also discernible.

Natarajan (1979b) stressed the importance of protecting the upstream zones which are biologically sensitive areas. So are the head zones (*i.e*., that part of the reservoir into which river flows) of the reservoirs where fish concentration is much higher. Discharge of effluents into the upstream can throw up a chemical barrier for breeding migration of economic carps, apart from causing considerable mortality to spawn and hatchlings.

Chronic effects of effluent discharge

There are two general classes of effects of pollutants on water uses. Some of the dramatic effects of toxicity, including fish kills are often well-publicised. But the other class of effluxion which involves continuous chronic sublethal degradation needs a more demanding consideration. This degradation goes unnoticed except by ecologists, taxonomists and sometimes by fishermen. It is neither dramatic nor well-publicised. No gory pictures of heaps of dead fishes or large water areas covered with oil spill or debris, but the killer masquerades in the form of reduction in the rate of reproduction by aquatic species or subtle changes in the food chain pattern on which the fish populations depend. The contaminants get accumulated in the water, soil and detritus phases of the environment and get biologically magnified, as they enter into fish tissues.

The harmful industrial and municipal effluents are as diverse as they are obnoxious. There is a diversity of harmful chemical toxicants that emanate from different industrial units, the nature of substances varying, depending on the products, production processes and the raw materials used. Similarly, the agricultural runoff carry heavy load of non-biodegradable pesticides. Domestic wastes also contain a variety of chemicals, detergents and organic load. Unfortunately, the impact of these toxicants on the biotic communities is very complex and our knowledge in this regard is grossly inadequate. It is not even possible to prescribe a precise *safe* limit in respect of any of the chemical pollutants. The pre- 1960 literature in this regard was based on short-term studies and used mortality as an end point. This is no longer valid, as the emphasis has now shifted to a balanced ecosystem rather than prevention of fish kills. To prevent the ecosystem from gradual degradation, we must provide criteria that will protect the entire life cycle of the desirable species as well as the food chain on which these species depend. A significant reduction in available food or reproductive success will result in a condition similar to that after a fish kill. Criteria must, therefore, be based on chronic or life cycle studies that may also permit extrapolation to untested species or toxicants.

Where multiple discharges exist, many chemical reactions may occur in the receiving water that intensify or reduce the toxic effect of the original materials. Thus, apart from the information concerning the effluents, specific knowledge on the potential chemical and physical changes involved is imperative to estimate the effects of multiple effluents on the environment. Moreover, the potential of combined stress on aquatic life cannot be explained on the basis of a single contaminant. The problems involving pH and metal toxicity are common where toxicity increases due to decrease in pH values. Similarly, the environments barely acceptable with regard to dissolved oxygen become totally unacceptable if the temperature is permanently increased, resulting in an increase in oxygen demand by the aquatic life.

The validity of applying the existing *safe concentration limits* is rather limited, as they are generally determined under controlled laboratory conditions. In the laboratory, fish are fed *ad libitum*. They are treated prophylactically, if needed: there are no predators, no competition for spawning areas, and no exposure to extremes of natural water quality. The effect of 2, 4-D on fishes adequately illustrates the gradual unspectacular decline in the quality of aquatic life. A study conducted at the Bureau of commercial fisheries pesticide laboratory at Gulf Breeze, Florida (Brungs, 1972) indicated that fish exposed to 2, 4-D for 1 to 5 months grew and survived as well as the control animals. However, the exposure, apparently lowered the general body resistance to a microsporidian parasite and a massive invasion of the central nervous system of the fish resulted.

Pesticides and heavy metals

Hazardous and toxic substances such as pesticides and heavy metals are carried to the reservoirs through the effluents and the rain washings from the catchments. These substances are highly persistent and thereby contaminate the entire biogeochemical cycle of static systems like reservoirs. The problems are aggravated due to the capacity of toxic substances to get biomagnified in fish tissues, which otherwise exist in water in extremely low concentrations. Such a situation, apart from resulting in low fish, transports toxic metals and pesticides into the human body through the contaminated fish. Heavy metal accumulation in water, sediments and plant tissue has been reported from Byramangala, (Table 1.11), Stanley (Table 2.8), Hussainsagar (Table 5.12) and Rihand (Agarwal and Kumar, 1978) reservoirs and the Tungabhadra river (Joshi and Sukumaran, 1987).

Pesticide residues have been detected in the riverine ecosystems in all the river basins of the country (Joshi, 1990). High levels of BHC, methyl parathion, endosulfan and DDT and their biomagnification in biotic communities like plankton, benthos and fish have been reported from Cauvery, Ganga and Yamuna rivers. However, such observations from reservoirs are rare. Joshi (1990) recorded significant presence of residues of different isomers of BHC, and DDT and its metabolites (DDE, DDD) in fish and plankton of Rihand reservoir. Considering that the reservoir is situated in a relatively remote place far away from agricultural and industrial activities, the observation assumes importance.

Studies conducted in Panchet reservoir, Bihar (Gopalakrishnan *et al.*, 1966) showed adverse effects of effluents from coal washings on the recruitment of Indian major carps. Sinha (1986) reported rapid eutrophication in man-made lakes due to drainage from coal fields in south Bihar.

Table 1.11. Status of heavy metals in Byramangala reservoir

Metal	Concentration		
	Water *(µg l^{1}*	**Sediment *(µg ^{1}***	**Plant *µg g-^{1} dry wt.)***
Zn	87–130	50–197	76.5–207.8
Cu	28–52	38–64	33–143
Cd	nd-15	32–106	1.4–2.1
Cr	nd	0.88–1.32	0.42–0.7
Pb	16–22	53.4–101.2	5.3–9.0
Hg	0.08–0.12	0.14–0.4	0.29–0.63

(After Joshi, 1990)

Siltation

Excessive siltation leading to drastic decrease in the water holding capacity and even damage to concrete hydraulic structures is a common problem in reservoirs. Siltation also hampers the productivity of water body by affecting the life processes of biotic communities. Erosion of top soil in the catchment area is the main man-made factor that leads to increased sediment load in rivers. Vegetation cover on the slopes acts as an adherent of top soil during the surface runoff. Removal of forest cover through logging, grazing, road construction or for urban needs makes the soil susceptible to erosion. The entire suspended and bed load materials carried by the rivers, however, are not exclusively the contribution by man. The catchment areas, especially those of the Ganga river are characterised by a prolonged dry season followed by a turbulent monsoon, with river discharges up to 85 000 m^3 per second. Therefore, heavy erosion and high sediment load are characteristic of Indian rivers. However, the tampering of environment in catchment areas adds considerably to the sediment load and the problem needs to be addressed through appropriate conservation measures.

Suspended particles tend to settle down in the lentic waters of the reservoir causing many problems. It is estimated that in India 5 334 million t of soil is eroded every year from the cultivable land and forests. The Indian rivers carry about 2 050 million t of silt, of which nearly 480 million t is doposited in the reservoirs and 1 572 million t is washed away into the seas. Loss of storage capacity of the reservoirs due to siltation is one of the most serious consequences of soil erosion. Many of the reservoirs recorded siltation rates, much in excess of what was envisaged during the planning stage of the project, due to increased rate of sediment load in the incoming waters (Table 1.12).

Table 1.12. Rate of siltation in some selected Indian reservoirs

RESERVOIR	Rate of silting (in ha m 100 km^{-2} yr^{-1})	
	Assumed	***Actual***
Gobindsagar	4.29	6.00
Nizamsagar	0.29	6.57
Tungabhadra	4.29	6.11
Hirakud	2.52	3.98
Shivajisagar	3.24	15.24
Gandhisagar	3.61	10.05

(After, Joshi, 1990)

Apart from diminishing the water holding capacity of the reservoir and cutting its life, Siltation also affects the biota by blanketing the benthic and periphytic community. It also hampers the recruitment by destroying the breeding grounds and retards the overall productivity of the ecosystem.

1.5.7 Cage and pen culture

The unconventional production systems, such as cage and pen cultures have not become very popular in India, although they have a definite role to play in augmenting fish production from open water, especially the reservoirs. It is now widely accepted that the pen enclosures erected in the reservoir margins can be used as nurseries to raise stocking material to obviate the necessity for constructing concrete nursery farms which are cost-intensive. Similarly, the rearing of fish in cages and pens up to marketable size enables easier stock manipulation and total harvesting. However, non-standardization of farm practices and the materials to be used in the operation still acts as a major retardant for large-scale adoption of these culture systems in Indian reservoirs.

Species selection

Main criteria for the choice of candidate species for cage and pen culture are:

1. *fast growth rate*,
2. *adaptability to the stresses in enclosures due to crowded conditions*,
3. *ready acceptance of artificial feeds consisting mainly of cheap agricultural byproducts*,
4. *high feed conversion rates*,
5. *resistance to diseases, and*
6. *good market demand.*

The candidate species should preferably not breed in the cages and upset the population balance. Under the Indian conditions, the Gangetic major carps*(C. catla, L. rohita, C. mrigala)*, the chinese carps *(Hypophthalmichtys molitrix, Ctenopharyngodon idella)*, common carps *(Cyprinus carpio)*, the magur *(Clarias batrachus)* and tilapias satisfy these requirements to a great extent. Murrels *(Channa spp.)* also can be cultured in maritime States, where marine trash fish is available at a discount. Selection of species, however, is mainly dictated by the local demands and availability of quality seed and other inputs in adequate quantities.

Site selection

Appropriate site selection is important for successful enclosure aquaculture. Sheltered, weed-free, shallow bays are the ideal locations for installing pens and cages. The sites should have adequate circulation of water, with wind and wave action within moderate limits. Excessive turbulence may lead to wastage of fish energy for stabilizing themselves and loss of feed. The other major considerations are that the water should be pollution-free, availability of seed in the vicinity, easy accessibility to the site and a ready market for fish. Flowing waters with a slow current of 1.0 to 9.0 m per minute are considered ideal for cage siting. It is desirable to install cages a little away from the shore to prevent poaching and crab menace.

Water level fluctuation is the most important consideration in site selection for the pen culture operations in reservoirs. A scrutiny of the contour map and the monthly fluctuation patterns of reservoir levels will enable the location of suitable sites, which retain sufficient water for the required period of time. Sites which dry out during summer will be ideal, as it is easier to erect pens on dry land, to be inundated later as the water level increases. Similarly, some bays of the reservoir retaining water for sufficient period can be identified and cordoned off by erecting barricades.

Cage culture

Experiments on cage culture conducted in India have been exploratory in nature and the yields obtained, so far, are not impressive. The supplemental feeds given are oilcakes, ricebran, soy bean flour and silkworm pupae, which have great demand in cattle, poultry, pig rearing and other animal husbandry practices and hence command a good price in the market. The food quotient obtained in the cage culture of various species has not been high, except in the case of tilapia, making conventional supplemental feeding unremunerative. The low production and feed conversion rates are mainly due to the relatively low stocking density and many deficiencies in the feed. The feed is often not in a water–stable form and nutritionally balanced to promote growth. There is need for evolving suitable complete feeds for individual species of fish from the locally available raw materials, by experimentation.

One of the major constraints of the cage culture system is the lack of suitable cage designs to withstand severe wave action, common in Indian reservoirs. Mukherjee (1990) suggested a number of flexible, floating barriers, sheet barriers and rigid floats to protect the cage structures from wave action. The floats dampen the wave thrust and absorb the wave energy before the wave can propagate and strike the cage and cause damage. Kumaraiah and Parameswaran (1985) proposed a circular cage that could be used in reservoir with moderate wave action for culture of carps, tilapia and air breathing fishes. The cages can float at the surface, remain just submerged or rest at the bottom. Floating cages are considered to be most appropriate for Indian conditions and all the experiments conducted so far in the country for seed rearing, growout, nutrition and biomonitoring have been in such enclosures.

Cage materials

Floating fish cages can be constructed out of a variety of materials including metal, wood, bamboo and netting. Fairly fine-meshed nylon netting is used for nursery purposes. Cages made of monofilament woven material of 1.0 to 3.0 mm mesh size are light and easy to handle but last only for six months to one year, depending on their thickness. Knotless nylon webbing of 3 to 6 mm mesh size and knotted nylon webbing of 7 to 15 mm mesh have been found to be very durable as cage material. A battery of cages can be buoyed up within a bamboo catwalk which will serve as a working platform, floated by sealed empty barrels. Circular and boxlike cages of varying diamensions on conduit pipe structures which can be easily assembled, and suitable flotation systems have been designed in India. Similarly, self–floating cage with HDPP pipe structure has also been experimented with succesfully.

In Jari tank near Allahabad, nylon cages (20 mesh cm^{-1}; size 2.2×1.6×1.45 m) were stocked at a density of 8500 hatchlings m^{-2} (size 6.5 to 7.8 mm). These grew in 21 to 28 days to 30.2 to 45.6 mm with a survival of about 25% (Anon., 1979). In fry rearing, the stocking rate in the cages (mesh size 3 mm) was 700 to 2 500 m^{-2} and within 90 days they attained a size of 103.6 to 121.8 mm. The feed given was powdered soybean, groundnut cake and rice bran in equal proportions. Rearing of carp fry was done in Getalsud reservoir, where they (10 to 31 mm in size) were stocked in 2.4 × 1.5 × 1.5 m cages at the rate of 300 to 700 m^{-2}. The growth rate per month was 17, 25 and 20 mm in mrigal, catla and rohu respectively. The stock was fed with mustard and groundnut cake and rice bran in the ratio 3:1:1 at 30% of the body weight (bw) of the stock for 4 days and thereafter at 20% for the rest of the period. Summary of cage culture experiments conducted is presented in Table 1.13.

A series of cage culture trials have been reported from a 12 ha impoundment in Bangalore (Parameswaran, 1993). In an experiment conducted with monofilament cloth cages of size 10.5 m^{-2}, common carp and silver carp fry were reared at a ratio of 40:1 at a stocking density of 225 m^{-2}. Put ona diet of powered rice bran, defatted silkworm pupae, groundnut cake and soya flour in 12:5:2:1 ratio at 10 to 20% bw day^{-1}, the survival obtained at the end of 4 months rearing was 97.5% in common carp and 88% in silver carp. The stock attained average final weight of 20 and 8.6 g respectively. However, experiments conducted on catla gave erratic results with survival rate varying from 9 to 71.4%. In another trial, 30 000 spawn obtained from cage grown common carp parents were reared in 4.5 m^3 auto-floating (PVC frame) monofilament cloth (mesh: 15 cm^{-1}) cages. In 35 days, the fry attained a size of 25.4 mm with 38% survival. Restocked in 3.5 m^3, 8 mm mesh knotless nylon netting cages, at a density of 475 m^{-3}, they grew to 54.8 mm/4.9 in 75 days with a survival rate of 88.5%.

In a cage culture experiment reported from Tamil Nadu (Parameswaran, 1993), 10 days old fry (size 10 mm) stocked at a density of 500 m^{-2} were raised to a size of 50 to 60 mm in 40 days, with survival rates ranging from 45 to 85%. Department of Fisheries in Tamil Nadu has been undertaking rearing of spawn and fry of major carps in floating cages during July to September every year. However, data on the stocking density, nutrition, growth and survival are not available.

Rearing of the fry of Indian major carps was tried in Tungabhadra reservoirs in the year 1984–85 (Singit et al., 1985). Four floating cages, made of 16-P velon screen fitted on rectangular bamboo frame of 10×4×1 m, were stocked with rohu and mrigal. Although survival rates ranging from 37.5 to 87.5% were obtained at the end of the 3 months rearing period, the experiment was vitiated due to the destruction of cages due to heavy winds. At stocking densities ranging from 2 to 5 million ha-1, growth of about 100 mm (33 g) was obtained.

Dependent on the type of management input, fish production rates obtained for growout in cages vary greatly. Unlike the hi–tech system of saturated stocking and feeding on enriched formulated diets, the production recorded in cage culture of common carp is 35, 37.5 and 25 kg m^{-3} $month^{-1}$ respectively in Japan, Germany and the Netherlands. In Asia, in general, only semi–intensive and low cost technologies are adopted, mainly due to economic considerations. In India, the growing season is almost year round, except for December–January in northern parts, where the temperature is low during these winter months.

Table 1.13 Summary of growout experiments conducted in cages in India

Species cultured	Cage volume (m^3)	Stocking		Mean harvest size (g)	Culture period (months)	Production (kg m^{-2} $month^{-1}$)	Feed	Feeding rate (%bw	FCR	Reference
		density (m^{-2})	size (g)							
Cyprinus carpio	15.75	30–38	40–50	325	6	1.55–2.22S	WP, GNC, RB (8:9:3)	10–20	8.3–10.4	Govind(MS.) 1983
Catla catla	15.0–15.75	13–49	8–50	544–772	6–8	0.83–1.30	GNC,RB(1:1)	5–10	5.6–6.6	Govind*et al.*, 1988
Hypoph-thalmichthys molitrix	10	15	61	472	10	0.7	SWP,RB, GNC (1:2:3)	3–5	3.1	Kumaraiah*et al.*, 1991
Labeo calbasu	10	5	16.5	208	8	0.1	GNC, RB(1:1)	2	2.9	Kumaraiah *et al.*, (unpublished)
Ctenopharyngodon idella	3	33–67	7–10	350–400	6	2.0–3.3	Lemna, Hydrilla	80	-	Bandopadhyay *et al.*, 1991
Oreochromis mossambicus	5–10	100–200	6.0–7.6	32–62	2–5	09–1.6	RB, GNC, CFP (1:1:1)	3–5	1.8–2.3	Kumaraiah et al.,1986
Channa marulius	5	40	25.8	177	5.3	0.8	Trash fish	10–12	2.5	Kumaraiah Parameswaran; and (unpublished)
Clarias *batrachus*	2	100	7.4	36.9	3	1	-	-	-	Murugesan and Kumaraiah; 1972

SWP=Silkoworm pupae;

GNC= Groundnut cake;

RB=rice bran;

CFP=cattle feed pellets;

FCRfood conservation ratio

Pen culture

Pen culture has a special relevance in reservoir management, since it has been widely recognised as a means to rear, *in situ*, the fingerlings for stocking. The number of fingerlings required for stocking the reservoirs in the country is so enormous that it is impossible to raise all of them in land-based nursery farms which makes pen nurseries *sine qua non* for reservoir management. Nevertheless, pen culture on a regular basis has not been practised anywhere in India except at Tungabhadra reservoir. The factors that hamper the standardisation of pen culture technique are:

1. the steep level fluctuations,
2. wind and wave action,
3. lack of suitable pen materials,
4. weed infestation and the related harvesting problems, and
5. nonsynchronisation of suitable water levels and the spawn availability.

The water retention time is important, since the rearing has to be completed before the water level in the pen goes down the critical limit. In reservoirs with high drawdown, the water retention time is very limited. Sometimes the filling takes place so late that no spawn of desirable carps will be available when the water level attains the desirable limit. The pen walls limiting the water circulation to some extent, the accumulated feed and fertilizers case eutrophication leading to weed infestation fouling of water and fish kills.

Pen culture in Tungabhadra reservoir

Despite all the limitations, pen nurseries are used with remarkable success in Tungabhadra reservoir for the last 12 years. During 1992–93, 21 pens were erected in Ladakanabhavi, 25 km away from the dam site, covering a total enclosure of 3.3 ha. The pen site is situated at an elevation of 496 m above MSL and the installation was completed in the month of July, when the site was still exposed. Later, when the water level increased, the pen got inundated.

The pen area was pre-treated with organic manure that resulted in a rich growth of plankton after the filling. A total of 15 million spawn were stocked in the pens, comprising 6.75 million *Labeo rohita*, and 8.25 million *Cirrhinus mrigala*. After a rearing period of 90 days, 2. 41 million fingerlings were collected from the pen and released into the reservoir. This included 1. 085 million *L. rohita* and 1. 325 million *C. mrigala*, worth Rs. 495 875. Pen culture operations on similar lines are being in Kyrdemkulai and Nongmahir reservoirs of the northeast (see Chapter on the Northeast).

Seed rearing experiments were conducted in a split bamboo pen enclosure of 247 .5 m^2 reinforced with a nylon netting in Punjar swamp, adjoining the Bhavanisagar reservoir (Abraham, 1980a). The pen was stocked with the spawn of *C. mrigala* (size 7 mm) and *L. fimbriatus* (size 5 mm) at the rate of 4.6 million ha^{-1} and usual farm practices were followed. In 30 days, mrigal attained a size of 38 mm and L. fimbriatus, 28 mm. At the time of conclusion of the study after 3 months, the former had attained a size of 88 mm and the latter, 75 mm. The overall survival obtained was 27.8%.

A pen culture experiment for raising catla and rohu in Manika maun, a floodplan lake in Gandak basin yielded a (computed) production of 4 t fish ha^{-1} in six months. The experiment was conducted in a bamboo screen pen (1000 m^2) and the stock was fed with mixture of rice bran and mustard cake, apart from a feed formulated from the aquatic the weeds collected from the lake.

1.5.8 Crafts and gear

Gear

The presence of underwater obstacles restricts the use of active gear in reservoirs and the choice is often limited to passive gear such as simple gill nets. The most common among them is the *Rangoon* net, an entangling type of gill net without a foot rope. Another entangling type of net used in reservoirs is *uduvalai*, which has a reduced fishing height and is usually operated in shallow marginal areas to catch small fish. Shore seines of various dimensions and mesh sizes are employed in many reservoirs. Although a number of other fishing gear such as long lines, hand lines, pole and line, cast nets, dip nets, *etc.* are in use, their contribution to the total catch is very insignificant.

Unlike the marine fisheries, very little attention has been paid over the years towards improvement of gear in the inland sector, barring an attempt to upgrade the reservoir fishing gear by two experts under the aegis of FAO/UNDP programme during the 1960s (Gulbadamov, 1962). A number of improvements have been suggested by the experts to the fishing techniques followed by the reservoir fishermen. Apart from the introduction of frame net, they have suggested improvements on the design of gill nets, beach seines and long lines, Unconventional methods such as electrical fishing, use of light as fish lure, and the use of echosounder for fish detection and survey of bottom topography were also suggested.

The main emphasis of gear improvement was the modification of gill nets. Gulbadamov (1962) designed two nets *viz.*, Sebgul I and Sebgul II, which were gill nets with modified rigging patttern. While ensuring a proper fixing of webbing on head and foot ropes, a uniform hanging coefficient was ensured. Similarly, the sideways movement of the webbing was checked to maintain effective area of the net. Ranganathan and Venkataswamy (1967) conducted experiments in Bhavanisagar reservoir to check the efficacy of the new design and found no appreciable superiority for Sebgul nets over the *Rangoon* nets.

The Central Institute of Fisheries Technology has experimented with gill nets of various colours and found yellow and orange coloured nets yielding better catch than the white coloured ones(Table 1.14). It has been observed that 77% of the carps were caught by entangling and the rest by gilling. The usual method of increasing the entangling capacity of gill net is by decreasing the slackness of webbing, which can be achieved by suitable modifications in the hanging of the net (Nayar, 1979).

Alivi, the giant drag net of Tungabhadra reservoir is described in the chapter on Karnataka. This giant shore seine catch fishes of all hues in large numbers, including the juveniles of commercially important carp species. Similar nets are used in Rihand and Keetham reservoirs, where they are known as *mahajal*.

Table 1. 14. Fish catch by gill nets of different colours

Colour of net	Catch kg 1000 m^{-2}
White	38.9
Blue	55.1
Green	66.9
Orange	83.4
Yellow	85.5

(After Nayar, 1979)

Trawling

Trawling has been attempted only in two reservoirs *viz.*, Gandhisagar and Hirakud. The findings of Kartha and Rao (1990) with regard to species selectivity of different type of trawling are interesting. The findings suggest efficacy of various types of trawling in increasing the productivity of commercial carps and checking the predator and weed fish populations. After experimental trawling with *single-boat bottom trawling, two-boat bottom trawling* and *two-boat mid-water trawling* under different speeds, it has been found that more than 92% of the total catch consisted of economic varieties such as catla, rohu, murrels, mullets and featherbacks in two-boat mid-water trawling. This was in sharp contrast to the bottom trawling, of both single boat and two boat variety, which yielded mostly (64 to 91%) the noncommercial species of fish. The two-boat mid-water trawling at a speed of 3 to 4 knots have been recommended for exploitation of commercial species and single and two-boat bottom trawling at 2 to 3 knots for eradication of uneconomic species of fishes.

Fishing crafts

Coracle, a saucer shaped country craft, is the major fishing craft used in the reservoirs of peninsular India. It is made of a split bamboo frame, covered with buffalo hide. Apart from being simple and inexpensive, coracle is durable and has very good manoeuvrability in choppy waters. It is also a versatile craft used for laying and lifting of nets, besides navigation and transport of fish and other material. Coracles of Krishnarajasagar are prepared by wrapping HDPP over the bamboo frame with the help of coal tar as an external covering in place of hide. This modified version of coracle is cheaper and more durable (Anon., 1984b; Parameswaran and Murugesan, 1984).

Unlike Gobindsagar, where all the fishermen possess their boats, reservoir fishermen, in general, are too poor to own boats. In many reservoirs like Vallabhsagar and Hirakud, the fishermen could get their boats with the help of subsidy and other financial assistance from the Government or fundings agencies. In Vallabhsagar, boats are distributed by the State among the fishermen at a subsidy of 50%, while in Hirakud, they get it from various schemes under NABARD and NCDC. Wooden boats are used for fishing in a number of reservoirs, especially in the North India. Flat bottomed, locally fabricated boats ranging in length from 3 to 7m are used in Kyrdemkulai, Hirakud, Malampuzha, Gobindsagar, Gandhisagar and Rihand. A plank-built, flat bottomed canoe, 2 to 3 m in length is the most popular fishing craft of Gandhisagar. In the same reservoir the repatriates from the erstwhile East Pakistan used the Bengal type dinghy, which is 5 to 7 m in length and have the additional facility of setting sails for wind propulsion.

Mechanised boats are not used in reservoir fishing in any appreciable extent. A 9.1 m long wooden, mechanised boat has been introduced by the CIFT in Hirakud reservoir, but they are too expensive for the fishermen. It is significant to note that large water bodies like Nagarjunasagar, Tungabhadra and Krishnarajasagar have no motorised craft neither for fishing nor for fish transport.

Dugout canoes, carved out of palm trees are used in Yerrakalava reservoir. In most of the reservoirs in the country the fishermen rely on improvised materials. Reservoir fishermen show considerable ingenuinity in fabricating makeshift rafts out of discarded old tyres, logs, used cans *etc*. In a vast majority of Indian reservoirs, where the catch is not very remunerative, no boats are used and the fishermen depend entirely on these improvised devices.

1.5.9 Other management measures

Pre-impoundment surveys

Until recently, pre-impoundment surveys conducted in India in connection with dam construction invariably lacked a fisheries perspective. Faunistic surveys of the river stretches carried out before dam construction in Tungabhadra (Chacko and Kuriyan, 1948), Bhavanisagar (Chacko and Dinamani, 1949), Pipri and Rihand (Hora, 1949), Damodar Valley Corporation reservoirs (Job *et al.*,1952), Hirakud (Job *et al.*, 1955) and Gandhisagar (Debey and Mehra, 1959) were not comprehensive and did not help in any way the conservation and developmental efforts. A complete survey comprising the fish and fisheries, together with inventories of fishing villages and fishermen populations, and fishing craft gear for planned development is lacking in most cases.

The pre-impoundment surveys provide the framework for future development policies and should encompass:

i. the native ichthyofauna in the river stretch above and below the dam, and their likely chances of survival,
ii. breeding habits of fishes and the possible impact of impoundment on their recruitment.
iii. survey of breeding grounds in relation to submergence, both above and below the dam,
iv. hydrobiological characteristics of water and soil with special emphasis on the nutrient and thermal regime,
v. needs for creating infrastructure such as, hatcheries, nurseries, ice plants etc. ,
vi. site selection for pen nurseries, cages etc., and
vii. possibilities for cleaning the area of submergence of trees and other obstructions.

Holistic pre-impoundment survey for fisheries development is a new concept in India. A beginning in this direction has been made by the Narmada Control Authority. A recently concluded socio-economic survey of the Narmada basin tried to address the problem of fisheries development with a holistic approach.

Timber clearance

Opinion is divided on the wisdom of removing timber from the reservoir bed. While it is mostly appreciated that a reservoir bed free from obstructions facilitates the use of active fishing gear and leaves room for many other management options, many workers feel the necessity to leave at least the non-commercial timber intact for a variety of purposes such as, reducing wave action, flocculating the colloidal clay turbidity, providing habitat for fishes and substrata for periphyton deposition (Bhukaswan, 1980). Timber clearance has been tried in a number of reservoirs in India, both before and after the impoundment. In Chillar and Benisagar reservoirs of Madhya Pradesh, trees were cut from the lake bed and auctioned before the reservoirs were filled. Harsi, Jamoia and Ghatera reservoirs are examples of complete clearance of date palm trees from the marginal areas during the summer months. Forest area of about 61. 4 km^2 were cleared in Hirakud, when the bed was exposed during drawdown.

Exploitation systems

Fisheries being a state subject, management of reservoir fisheries vests with the State Governments. There is a great deal of divergence in the management practices followed by individual States which vary from outright auctioning to almost free-fishing. Cooperative societies (primary and apex) and the State level Fisheries Development Corporations are also involved in the fishing and marketing operations. Involvement of the above agencies and their role in fishery operations and market interventions often vary from one reservoir to another within the same State. Some sort of uniformity in fishery regulations among various categories of reservoirs as well as the need to monitor the socio-economic aspects of reservoirs fisheries.

Commercial exploitation systems followed in different States can be broadly classified under four headings *viz.*, 1) departmental fishing, 2) lease by auctioning, 3) issue of licences to cooperative societies or individuals and 4) fishing on a royalty basis (crop sharing). Direct departmental fishing being not an economic proposition, is followed only in a very few reservoirs. In some reservoirs like Hirakud, Nagarjunasagar, and DVC, this practice is partially resorted to for experimental and exploratory purposes. In most of the cases, the Department exerts its control over the exploitation by acting as a marketing link and controlling the fishing effort. In Rajasthan, Madhya Pradesh and Uttar Pradesh, the small reservoirs are mostly auctioned on an yearly basis. In a number of large reservoirs, free licences are issued to fishermen without any limit. This virtual *free for all* system has been found to be detrimental to the interests of the ecosystem and fishermen in Nagarjunasagar, Yerrakalava and a large number of other reservoris in Andhra Pradesh. Crop sharing is a very popular mode of exploitation in Tamil Nadu, where, the fishermen are provided with all fishing implements, in return of which they pay a royalty (sometimes up to 50% of the catch) to the Government.

Input-output relationship

Evaluation of the socio-economics of reservoir fisheries is a very tedious task due to the multiplicity of agencies involved in reservoir management. Reservoir fisheries is developed basically on capture fisheries lines, following the common property norm. Like the rivers, lakes and the seas, the biological wealth is considered as a nature's endowment and the State's intervention in developmental activities benefits the poor fishermen who toil in water. The investment made in developing reservoir fisheries shall be viewed in the light of the social benefits it accrues in the form of:

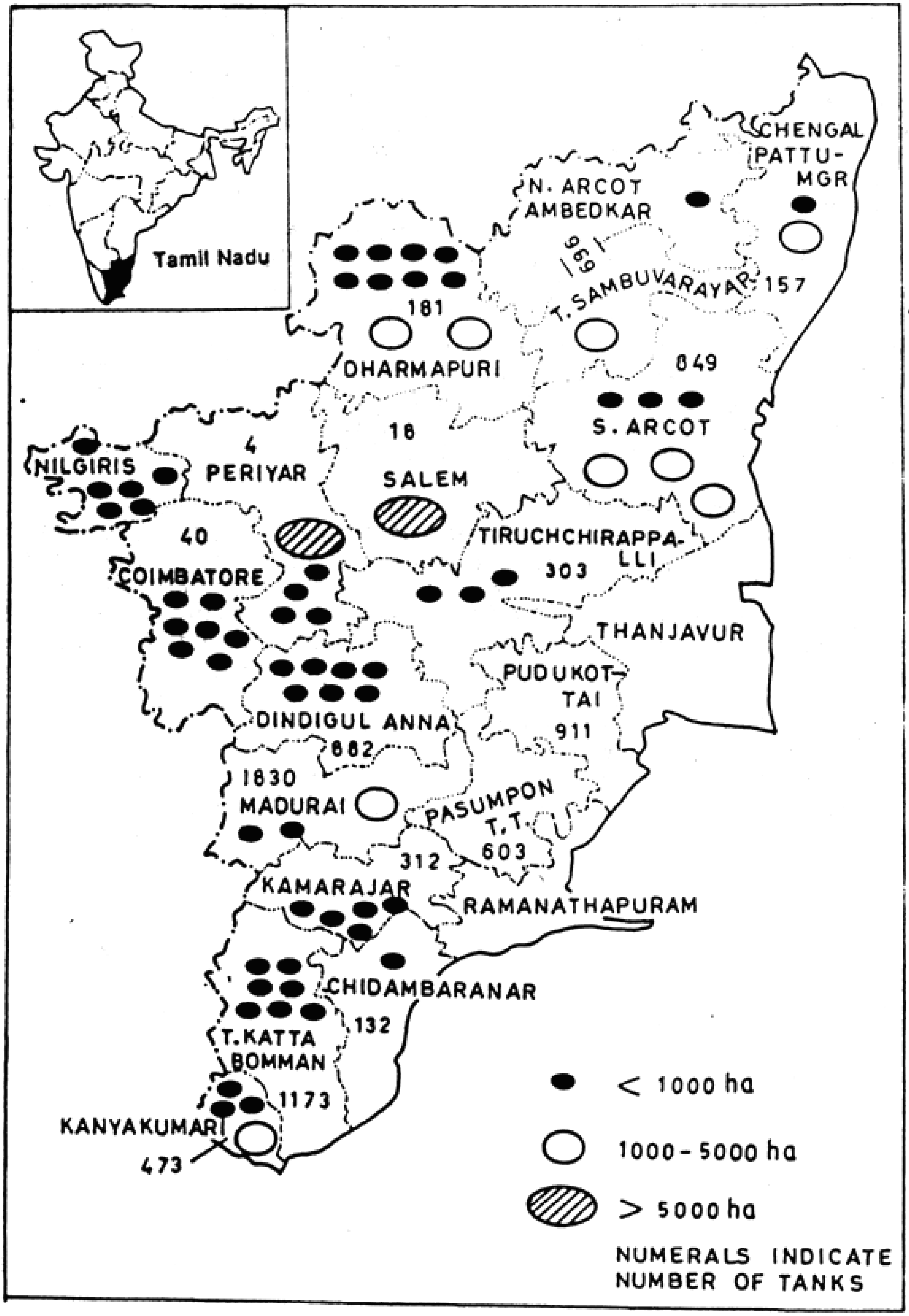
1. *rehabilitating the displaced population*,
2. *improving the living conditions of fishermen, and*
3. *providing employment opportunities.*

Capture fisheries activity of the reservoirs is akin to the extractive industries like coal, oil, iron ore *etc.*, where the yield depends on the state of technology involved and the quantum of labour and capital deployed. But the renewable nature of the resource and the intricate biological principles involved in the ecosystem management imparts a heavy element of challenge into the reservoir fisheries management. Human intervention being less intense in reservoirs, compared to the aquaculture operations, yields often display violent fluctuations, even if the effort in terms of labour and capital is kept constant. Therefore, production-function relationship is bound to be intricate and less precise. A certain measure of stability needs to be imparted in production by affecting sustained improvement in yield along with remunerative returns to fishermen by narrowing the price spread between the producer and the consumer.

In aquaculture, it is estimated that 77.23% of the price paid by the consumer is received by the producer (Paul, 1990). As opposed to this, a major chunk of the price is siphoned away by the wholesalers and other market intermediaries in reservoir fisheries. A study of seven reservoirs (Paul and Sugunan, 1990) for a period of six years has brought to light the major factors that determine the remunerativeness of fishing in reservoirs. Reservoir fisheries is a sector, where the chief input is labour, besides a marginal depreciation of crafts and gear. Even if the costs of stocking and other developmental measures are taken into account, this area does not call for heavy investment as in the case of pond culture.

A factor that can bring serious distortions in the income level of fishermen is the over–concentration of fishermen in the wake of low fish productivity. For instance, in Ukai reservoir, with an area of 36 525 ha, 306 boats with 3 400 gill nets (50 m each) were operated during 1985–86 to 1982–83. In a fishing year comprising 260 days, 1 836 fishermen netted out 174 t of fishes. In sharp contrast to this, 520 fishermen of Nagarjunasagar shared a catch of 170 t in a year. In lower Aliyar, 17 t of fishes were harvested by 14 fishermen, each of them, after meeting the royalty obligations, could take home only Rs. 1 000 to 1 400 a year. A better picture, however, emerged in Bhavanisagar, where 80 fishermen after sharing 150 to 300 t of fishes, earned an annual individual income of Rs. 8 175/ (Paul and Sugunan, 1983).

There is a need to dovetail the twin objectives of conservation and yield optimisation in reservoir fisheries management. While the fishermen and the fish merchants strive to increase the production for economic considerations, it is the responsibility of the State to ensure that economic expediency of development does not mar the ecological reasoning. Virtual free fishing, as followed in Andhra Pradesh is counter–productive to the norms of conservation and yield optimisation. Although there are fair possibilities of linking reservoir fisheries development with poverty alleviation programmes, the progress made so far in this direction is not very encouraging. Chances of creating additional employment are not much in majority of Indian reservoirs. On the contrary, many reservoirs have surplus manpower which can be diverted to others which can absorb more men without eroding the income level of the existing fishermen (Paul and Sugunan, 1990).



Tamil Nadu
CHENGAL PATTU-MGR
N. ARCOT AMBEDKAR
969
T. SAMBUVARAYAR
157
181
DHARMAPURI
849
18
S. ARCOT
4
NILGIRIS
PERIYAR
SALEM
40
TIRUCHCHIRAPPA-LLI
303
COIMBATORE
THANJAVUR
PUDUKOT-TAI
DINDIGUL ANNA
911
882
1830
MADURAI
PASUMPON T.T.
603
312
KAMARAJAR
RAMANATHAPURAM
CHIDAMBARANAR
132
T. KATTA BOMMAN
1173
KANYAKUMARI
473
< 1000 ha
1000 - 5000 ha
> 5000 ha
NUMERALS INDICATE NUMBER OF TANKS

Figure 2.1. Distribution of reservoir and tanks in Tamil Nadu.