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RESERVOIR FISHERIES IN INDIA

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Reservoirs are man-made lakes created by impounding river water for the purpose of irrigation, power generation, flood control, and industrial water needs. A large number of river valley projects have been commissioned since independence as a part of our development activities, resulting in a chain of such artificial impoundments. These water sheets, by virtue of their sheer magnitude and due to their high biogenic production potential, constitute one of the most important resources for inland fisheries development in the country. The National Commission on Agriculture has estimated the total area under reservoirs during mid-seventies as 3 m ha which was expected to swell to 6 m ha by 2000 A.D. Bhukaswan (1980) put the figure at 20000 km^2. According to a recent study conducted by the Indian Institute of Management, Ahmedabad (Srivastava *et al.*, 1984), the area covered by the 975 reservoirs in the size range of 1000 to 10000 ha was 1.7 m ha. The present rate of production from Indian reservoirs is frustratingly low; the various estimates of national average ranging from 6-14 kg/ha/yr. This leaves immense scope for development from this sector and calls for an accelerated drive to enhance their productivity. It is estimated that the reservoir fisheries development has the potential to generate additional national income to the tune of Rs. 100 crores per year and can provide employment to lakhs of fishermen and workers in the ancillary industries (Srivastava & Reddy, 1983).

The low fish yield from reservoirs is mainly due to unscientific management practices resulting from the inadequate knowledge of the ecology and production functions of this biotope. The studies conducted by the Central Inland Fisheries Research Institute (CIFRI) over the last four decades have virtually laid the foundation for the concept of scientific fisheries management of reservoirs in India. Reservoir is a man-made ecosystem without a parallel in nature. It exhibits both the fluviatile as well as lentic characteristics along with certain salient features of its own. The reservoir fisheries management strategy takes into account the prevailing environmental variables and it comprises both capture and culture norms.

FACTORS INFLUENCING THE BIOLOGICAL PRODUCTIVITY IN RESERVOIRS

Indian reservoirs are situated in different geoclimatic regions and they receive drainage from varying types of catchment areas. Moreover, the varying design and purpose of dams make reservoirs different in their morpho-edaphic characteristics. All these diversities make the reservoirs an interesting biotope. The habitat variables determining the productivity of reservoirs can be grouped into three main categories i.e., morphometric, climatic, and edaphic (Rawson, 1958).

Morphometric factors : Among the morphometric factors, depth is the most important single factor which can be correlated with productivity. Shallower lakes have a larger proportion of their substrates in the euphotic zone (Larkin, 1964). On the other hand, deeper lakes have most of their substrate locked up in the aphotic zone. Shore development which is another useful index in determiing the productivity denotes the degree of irregularities in the shoreline. Water level fluctuation is a characteristic feature of the reservoir ecosystem. It has been observed that plankton pulses coincide with the months of least level fluctuations. All biotic communities are in their lowest ebb during the months of maximum level fluctuations. A relatively stable reservoir level is more conducive to the growth of organisms. During the month of higher inflow and outflow rates, more or less fluviatile conditions prevail, compared to the seasons of lesser water movements when the reservoir is more lacustrine in nature. Percentage of shallow areas (littoral formation) vary at different reservoir levels and it is also an important factor to be reckoned with.

Climatic factors : Most important among the climatic factors that determine productivity of a lake is the latitudinal location which determines the quantum of solar energy available for photosynthetic activities. Bhavanisagar reservoir, situated at 11°50' N, receives solar energy at the rate of 213 x 10^4 cal/m^2/day compared to Govindsagar at 31°N receiving solar energy to the tune of 172 x 10^4 cal/m^2/day (Natarajan & Pathak, 1983). the latitude also determines, to a large extent, the air temperature. The prevailing atmospheric temperature plays an important role in the thermal and nutrient regimens of the reservoirs. For instance, in peninsular India the range of fluctuations in air and water temperature during the year is narrow and this prevent thermal stratificatin in the reservoirs. Thermal stratification is due to thermal resistance developed by the warmer and lighter layer of water in the upper stratum. High air temperature during summer warms up the upper layer and the thermal gradient is created. In peninsular India, there is no winter worth its name and temperature remains comparatively high during the whole year. During summer, when the surface water gets heated up, the prevailing high temperature at the bottom does notg offer any scope for thermal resistance by the warmer upper layer. Thermal stratification is limnologically important because in thermally stratified lakes, the water above and below thermocline does not mix up and thereby the rich nutrients at the bottom layer get locked up.

Wind is an important meteorological factor that helps mixing up of water facilitating nutrient transport. The rainfall at catchment areas is more important than the rainfall at the reservoir site due to obvious reasons. The soil status of the catchment area affects the nutrient status of the reservoirs. Thus, in many of the Indian reservoirs, in spite of poor soil quality of the basin, the productivity is high by virtue of allochthonous nutrients.

Edaphic factors : The physico-chemical characteristics of water and soil are the major determinants of biogenic productivity of a reservoir. Apart from temperature, transperency is a physical variable significant to production. The poor light penetration may be due to suspended matters like slit and clay or due to living organisms. Turbidity due to suspended particles retards productivity while poor visibility due to planktonic organisms is a positive index of production. The main source of dissolved oxygen in water is absorption from the atmosphere and through photosynthesis. The two main sources of its removal are respiration and the putrefaction of organic matter. The available dissolved oxygen in water at a given time depends on the balance of the above two processes. Dissolved oxygen below 5 ppm can be lethal to biota. A pH slightly above alkaline and not above 8 is considered to be conducive to productivity. A total alkalinity over 50 ppm and hardness above 70 ppm are indicators of better productivity. The electrical conductance reflects the total dissolved solids and it gives a reliable indication of the edaphic quality of water (Table 1).

TABLE 1: RANGE OF PHYSICO-CHEMICAL FEATURES IN RESERVOIR ECOSYSTEMS

Parameters	Range of Values		
	Low Productive Reservoirs	Medium Productive Reservoirs	Highly Productive Reservoirs
A. WATER			
pH	< 6.0	6.0-8.5	> 8.5
Carbonates (ppm)	< 35.0	35-80	>80.0
Alkalinity (ppm)	< 40.0	40-90	>90.0
Nitrate (ppm)	Negligible	Upto 0.2	0.2-0.5
Available phosphates (ppm)	Negligible	Upto 0.1	0.1-0.2
Total dissolved solids (specific conductivity micromhos/cm)		Upto 200	>200
Temperature (°C)	18	18-22	22
	(with minimal stratification: i.e. > 5.0)		
B. SOIL			
pH	6.5	6.5-7.5	> 7.5
Available P(mg/100g)	3.0	3.0-6.0	>6.0
Available N (mg/100g)	25.0	25-60	>60.0
Organic carbon (%)	0.5	0.5-1.5	1.5-2.5

Some of the biotic and abiotic factors affecting productivity of reservoirs of various trophic levels are given in Table II.

The upper water column where photosynthetic activities take place is *trophogenic zone* as distinguished from the lower *tropholytic zone* characterised by the breakdown of organic matter. Productive reservoirs having high rates of the above processes show sharp changes in the parameters like O_2, CO_2, pH, CO_3, and HCO_3 from surface to bottom while low productive reservoirs have near uniform distribution. Thus, high photosynthetic production of oxygen in the trophogenic zone and its high rate of consumption in the tropholytic zone causes klinograde oxygen curve and, therefore, the oxygen curve is a useful indicator of productivity. The decomposition of bottom organic sediments

TABLE 2 : ABIOTIC & BIOTIC FACTORS AFFECTING PRODUCTIVITY OF RESERVOIR AT VARIOUS TROPHIC LEVELS

Positive/augmentative factors	Negative/reductive factors
1 High shoreline development (coves, bays, etc.)	Low transparency in floods due to inorganic turbidity
2 Low mean depth (less than 18 m)	High mean depth
3 Existence and extent of marginal vegetation	Erosion in the reservoir watershed area
4 Optimum nutrient levels	Reduction of quantity of water flowing into reservoir
5 Nutrient enrichment during floods	Large water level fluctuations creating large aridal (barren litoral)
6 Moderate to long growing season	Low level of dissolved oxygen in parts of hypolimnion
7 High frequency of phytoplankton bloomp	Pollution in the reservoir watershed areas
8 Moderate macrophytes	Phytoplankton biomass mainly blue-greens
9 Periphyton density increasing markedly	Relative low fish species diversity indicating low stability and a potential by low resilience to stresses
10 Well established plankton and benthos	Unbalanced fish populations favouring predatory trash species
11 Tree and bush clearing	Low abundance and diversity of terrestrial vegetation, hence early successional stage
12 Conditions permitting passage of migratory fish and their economic worth, if to be created	Relatively low environmental heterogeneity
13 Introduction of fish adapted to lentic conditions	Low diversity of plankton and benthos
14 Utilization of modern fishing gear and optimization of fishing effort	Low diversity of aquatic macrophytes
15 Enforcement of fishery regulations	Exposure of nests of catfish, Mystus sp. due to severe drawdowns.

is always associated with accumulation of carbon dioxide, decrease in pH, and increase in HCO_3.

While definite relationships could be established between the morphometric characters of the lake and its productivity (Rawson, 1955), the edaphic factors have also occupied a prominent position in the statistical analysis. There have been persistent attempts to evolve a reliable index to predict the productivity of lakes in terms of fish. The morphoedaphic index as evolved by Ryder (1961) took into account a large number of physico-chemical and morphometric characters of the lake. Later, the morpho-edaphic index has been simplified (Ryder *et al.*, 1974) as :

$$MEI = \frac{TDS}{\bar{d}}$$

where, TDS = total dissolved solids, and $\bar{d}$ = mean depth.

MEI has been proved to be a useful tool in predicting the fish productivity of man-made lakes. However, its application in Indian reservoirs has been inherent limitations due to the high rate of level fluctuations and water renewal.

ENERGY TRANSFORMATION THROUGH PRIMARY PRODUCTION

Reservoirs differ considerably not only with respect to the incident light energy available at the waterphase, but also the efficiency with which this energy is converted into chemical energy. The studies indicated that only 0.2-0.68% of the available light energy is transformed into carbohydrate. Moreover, out of the total energy fixed only 41.7 - 65.2% is stored by the primary producers, the remaining being used up for metabolic activities and ultimately getting lost through respiration. The efficiency of energy flow from producers to different levels of consumers differ considerably from reservoir to reservoir depending upon the qualitative and quantitative variations and the patterns of community metabolism of the organisms inhabiting the lake. It is indicated that in Indian reservoirs, 0.034 (Rihand) to 0.28% (Bhavanisagar) of the energy fixed by producers is obtained as fish.

BIOTIC COMMUNITIES

In the aquatic ecosystem plankton, benthos, periphyton, and nekton form the major biotic communities. Normally, the members of nekton constitute the harvestible biological products which, in their turn, depend on plankton, benthos, and periphyton for their food. In a complex chain of community metabolism the energy fixed by the primary producers passes through the different trophic strata, a fraction of which ends up as fish flesh. Therefore, the structure of different fish food biotic communities assumes greater significance to reservoir fisheries management.

When a reservoir is formed, riverine environment is suddenly transformed into a lacustrine habitat upsetting the life habits of the vast majority of the riverine communities. Many of the flora and fauna perish, some animals escape to more homely environment and the rest adjust themselves to the new environment. This catastrophic change in the riverine community at the time of the first impoundment is comparable to the second ary community succession (Knight, 1966). This phase is also characterised by the rich nutrients emanating from the decaying vegetation of the newly submerged land, triggering rich blooms of plankton and benthic communities. Eventhough the effects of this trophic burst wean away in due course, the lentic sectors of Indian reservoirs are known to hold a very rich plankton community. Monospecific blooms of *Microcystis aeruginosa* is a common feature of peninsular reservoirs and the Dinoflagellate blooms occur in reservoirs of higher latitude. Rich species spectra of Chlorophyceae, Myxophyceae, and Bacillariophyceae are recorded from Indian reservoirs. Copepods, the main constituent of zooplankton, are mainly represented by *Cyclops* and *Diaptomus*. Species diversity is maximum in rotifers.

Benthos formation in a newly formed body of water progresses under unstable environmental conditions. Preimpoundment vegetation and associated debris offer varied nutrient and substrate relations. The high shoreline development, variable slopes, and vegetation associations produce a large number of possible benthic habitats in reservoirs. The chironomids are highly responsive to change in the bottom biotope. Benthic communities are subjected to the impact of rheotactile deprivation, water level fluctuations, hypolimnetic oxygen deficiency, increased hydrostatic pressure, light and other impoundment associated factors. Frequent level fluctuations often retard a rich growth of periphyton and macrobenthos in reservoir environment.

ECOSYSTEM APPROACH TO RESERVOIR FISHERIES MANAGEMENT

Reservoir fisheries is essentially extractive in nature and the strategy for its development is mainly formulated on capture lines. However, in smaller irrigation impoundments characterised by the near-total draw down of water extensive aquaculture practice is followed. The emphasis here is on artificial recruitment and a total harvesting every year, with little scope for sustained natural populations of commercial fishes. Stock monitoring, stocking support, and effort monitoring are the three cardinal principles of ecosystem oriented management norms. In an ideal situation, the commercial species of fishes share the ecological niches in such a way that the trophic resources are utilized to the optimum. At the same time,the fishes should be of short food chain in order to obtain maximum efficiency in converting the primary food resources into harvestable materials. But this ideal situation seldom exists in reservoirs. By and large, species diversity at all trophic levels are relatively high. Phytoplankton comprising Myxophyceae, Chlorophyceae, Dinophyceae, and Bacillariophyceae dominate over the zooplankton like copepods, cladocerans, and rotifers. Benthos is represented by insect larvae, nymphs, oligochaetes, nematodes, and molluscs. Significantly, many of the above niches with the possible exception of insects, Myxophyceae and molluscs, are shared niches between Gangetic major carps and trash fishes, focussing the importance of controlling carp minnows and weed fishes. The ecosystem-oriented management policy envisages due emphasis on trophic strata in terms of shared, unshared, and vacant niches.

Stocking : Stocking becomes necessary to enlarge species spectrum and to correct the imbalances in utilization of different ecological niches by the commercial species. During the first 2-3 years of impoundment, the reservoirs pass through a transient phase of trophic burst characterised by an abundant supply of fish food organisms. This is the ideal time for implanting desirable species to build up stocks. Any lapse in this important management measure may result in the proliferation of trash fishes on account of the trophic burst and these fishes in their turn may provide forage base for catfishes. The whole situation becomes undesirable because of considerable energy dissipation at all levels from primary trophic resources to catfishes. Stocking also becomes necessary to correct situations arising out of erratic breeding of desirable fishes. Sometimes even after successful breeding, the offsprings fail to survive due to certain unfavourable features of lake morphometry, as has been observed in some DVC reservoirs.

Selection of fishes for stocking : Basic objective of artificial recruitment is to channelise the energy at an unshared trophic niche into fish flesh. Therefore, selection of fishes for stocking is based on an assessment of existing biotic communities and their efficiency in converting primary trophic resources to harvestable products. Our country is bestowed with a variety of fast growing fishes feeding at different trophic niches that can be suitably employed for reservoir fisheries management. For instance, Indian major carps, by virtue of their feeding habits close to primary producers and their fast growth rate, are indispensable in reservoir stocking. However, the Indian trio-catla, rohu, and mrigal are ill-suited to utilize the blue-green algae, the most dominant component of plankton. The remarkable ability of silver carp in the fast and efficient conversion of phytoplankton into fish flesh has been demonstrated in Kulgarhi, Getalsud, and Govindsagar reservoirs. However, the introduction of exotic fishes in Indian waters is still a subject of controversy due to the possible deleterious effects on indigenous populations.

Stocking rate : Based on the studies of different waters, quite a number of stocking formulae have been proposed by different workers like Hey (1952) :

No. of fish to be stocked = Total production/acre x area x No. of fish required to weigh one lb + % loss.

Huet (1960) :

$$\text{Rate of stocking} = \frac{\text{Growth or total production in k+loss (Nos.)}}{\text{Individual growth rate in k}}$$

A similar formula for computing the number of fishes/ha to be stocked in reservoirs has been proposed by Jhingran *et al.* (1969) which reads :

$$N = \frac{S_1 - S_0}{G} + M$$

when, N = number of fish/unit area/unit time; S_1 = the fish biomass/unit area at the end of unit period; S_0 = the fish biomass/unit area at the beginning of the unit period; G = average increase in weight per fish; and M = anticip;ated mortality.

Most of the formulae for estimating the stocking rate are applicable to small reservoirs. In case of larger reservoirs the stocking rates vary depending on the specific requirements. However, due allowances should be made for loss due to predation and escapement through irrigation canals. Carps may be stocked @ 250/ha in case of large reservoirs free of predatory catfishes and @ 500/ha in catfish dominated. However, a rational stocking rate may be derived after estimating the potential fish yield of the reservoir and adjusting the rate so as to realize the potential.

Management of large and small reservoirs : Separate management norms are followed for large and small reservoirs; the former depending heavily on natural recruitment and the latter on intensive stocking. In larger lakes, the management measures centre round the deployment of optimum fishing effort and selection of the right kinds of tackle. Appropriate measures to conserve the desirable species and maintenance of the right balance in species mix is also ensured through stocking, mesh regulations, protection of breeders, etc. In such cases, stocking support is resorted to in order to correct the imbalances in utilization of trophic niches. Raising the fishing effort to the optimum, coupled with monitoring of stock abundance by catch per unit effort, is recognized as a tool for improving stock productivity. In Bhavanisagar, fishing effort was raised in a phased manner from 50×10^3 units (50 m hung length) in 1971-72 by 13-27% for a period of 5 years with a corresponding production hike of 29-211%. In Govindsagar, the three-pronged strategy of enlarging mesh size, increase in fishing effort and stocking has paid rich dividends. In 1973 the mesh size was enlarged from 65 mm to 100-180 mm bar and the fishing effort was increased by 120%. There was sustained stocking of common carp which responded well to the reservoir environment. All these measures helped to push up the production by about 200% (827 t in just five years).

Small irrigation impoundments which dry up in summer have much more production potential per unit area, compared to the larger ones. These waterbodies are intensively stocked (up to 1000-1500 ha) and harvested completely in summer. Proper stocking and harvesting schedules are the key to small reservoir management where it has to be ensured that the fish stock is not lost through the overflowing spillways and allowing a reasonable growout period.

Small reservoirs in the Ganga basin viz., Gularia and Bachhra, are ample testimony to the viability of small reservoir fisheries management system where production to the tune of 100-150 kg/ha has been obtained, Similar yield could be achieved in Aliyar reservoir in a west-flowing drainage of Tamil Nadu.

POLLUTION

Reservoir environment is subjected to the onslaught of insecticide carrying run off and a variety of lethal industrial effluents. Varying degrees of environmental degradation have been reported from reservoirs like Mettur, Bhavanisagar, Hirakud Rihand, and Panchet. Upstream spawning habitats are biologically sensitive zones for Indian major carps where discharge of pollutants need to be strictly prohibited in order to avert the serious ecological consequences.

OTHER SOCIO-ECONOMIC CONSIDERATIONS

Ownership of reservoir waters vests with the state, but there is no uniform policy governing the exploitation. Some states allow free fishing with or without licence. Free fishing hardly provides any motivation for the states to develop the fishery resources in reservoirs. Any licentious operation makes the system beyond management scrutiny and obviously reckless exploitation results. Moreover, royalty is essential as the reservoir fisheries management implies financial resources for developmental inputs by way of stocking, habitat improvement, enforcement of management measures, etc. Outright auctioning leads to indiscriminate exploitation.

Social problems arising out of exploitation by middlemen and improving the lot of fishermen are to be tackled at various levels of administration. Cooperative societies have a great role to play, eventhough they are yet to make an impact in reservoir fisheries. Development of infrastructure facilities and scientific post-harvest technologies will go a long way in realizing the maximum out of the reservoir fisheries resources.

A probe into cost and return functions of the fishing units in certain reservoirs does indicate the overall remunerativeness of the fishing operations. An investment level of Rs.632700.00 in a small reservoir of 3695 ha affords gainful employment to 76 fishermen at an annual income level of Rs.8175.00 per head.

Though the capture fisheries based on exploitation of natural population from open waters continue to constitute the mainstay of inland fish production in India, the riverine and estuarine sectors are under the mounting pressure of man-made habitat modifications. It is increasingly difficult to sustain the current level of production from these resources unless we compromise on other developmental needs. Reservoirs on the other hand still leave enough scope for fisheries development and any production hike from capture fisheries has got to be from the man-made lakes. However, in view of the multiple water use pattern of reservoirs, a careful management policy is needed to realise the full potential of this resource.

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