ECOLOGY AND THE STATE OF FISHERY DEVELOPMENT IN SOME MAN-MADE RESERVOIRS IN INDIA

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Abstract

Ecological studies carried out in four reservoirs from Northern and Peninsular India include examination of climatic, edaphic and morphometric features; physico-chemical parameters that have relevance in the evaluation of the productivity characteristics of the reservoir biotope; biotic communities and their utilization by fishes; and factors that affect the productivity of economic fishes.

The qualitative composition and magnitude of the fishery in each of the reservoirs is presented. The present state of the fishery and the scope for ecology-orientated fishery development are indicated. The importance of stocking and the role of Gangetic major carps as stocking material are examined in depth. The paper also discusses management measures that are needed to raise the fish yield to optimum levels in the reservoirs under examination.

CONTENTS

1. INTRODUCTION

River Valley Development Projects have been given considerable importance in the successive Five Year Plans in India. These projects meet the twin purposes of agriculture and power generation. The country at present has an estimated 2 million hm^2 of impounded surface water, an area which increases year after year. The importance of developing fisheries in these impoundments is self-evident in the face of a galloping population growth (547 million, according to 1971 census) and the need to find additional sources of protein-rich food.

Fisheries development in reservoirs presupposes a knowledge of the ecology of these water bodies. Lack of understanding of the ecological transition from a lotic to a lentic environment, as well as improper management practices have resulted in a rather low yield (< 10 kg hm^{-2}) in most Indian reservoirs. In some of the well managed reservoirs, however, like Amaravathy (93 kg hm^{-2}) (Chacko, 1970) and Stanley (47 kg hm^{-2}) (Sreenivasan, 1969) the yield has been extremely promising. The full implications of ecology and fish capture-culture in these water bodies are examined here in respect of specific cases from North and Peninsular India based on observations in Konar (Bihar), Rihand (Uttar Pradesh), Nagarjunasagar (Andhra Pradesh) and Bhavanisagar (Tamil Nadu). Information collected on other Indian reservoirs is also drawn upon wherever necessary.

The observations reported here are based upon material collected under the All India Coordinated Research Project on Ecology and Fisheries of Freshwater Reservoirs in Bhavanisagar, Nagarjunasagar and Rihand, and material in Konar was collected by the Reservoir Sub-Station of Central Inland Fisheries Research Institute, studies under both of which were supervised by the author as project leader.

2. CLIMATIC, EDAPHIC AND MORPHOMETRIC FEATURES

The biological productivity of any water body is influenced by climatic, edaphic and morphometric features among other factors. The reservoirs examined here are at different latitudes ranging from 11°28′N in Bhavanisagar to 23°50′N in Konar (Table 1). Govindsagar, to which references are also made, is situated at latitude 31°25′N.

Rainfall was of the order of 35.1 cm in Bhavanisagar, 59.49 cm in Nagarjunasagar, 107.27 cm in Rihand and 113.39 cm in Konar reservoir. Yearly variations in rainfall and hence the degree of inflow have been found to have a great bearing on reservoir productivity. Studies carried out in recent years (1971-75) in Rihand reservoir clearly establish a relationship between inflow and plankton productivity, failure of rainfall and lesser inflow resulting in less abundant plankton.

The wind has great effects on the thermal regime of the aquatic biotope (Birge, 1961). It helps both in the distribution of heat within the lake and in the equalization of the temperature of the epilimnion. The wind velocity in monsoon and premonsoon months are of a high order in the reservoirs examined here. The wind velocity reaches a maximum speed of 26 km h^{-1} in Nagarjunasagar and 12.25 km h^{-1} in Bhavanisagar.

The reservoir fertility is very much influenced by the quality of the soil both of the reservoir basin as well as of the catchment. In Bhavanisagar the organic carbon value (1.5 - 2.6 percent) is optimal though the available phosphorus (0.25 - 10.0 mg per 100 g soil) is in the poor to average range. In Nagarjunasagar the organic carbon (average 0.66 percent) as well as available nitrogen (4.83 - 30.33 mg per 100 g) and available phosphorus (average 0.32 mg per 100 g) are of low order. In Rihand organic carbon (0.032 - 0.448 percent) and available phosphorus (0.65 - 1.73 mg per 100 g) are poor. Going by the index of organic carbon in Rihand it may be presumed that available nitrogen is also low. Organic carbon was low in Konar (0.37 - 0.60 percent). Though the soil quality in general is poor in Nagarjunasagar, Rihand and Konar the water quality in these reservoirs does not reflect the soil features of the basin and seems to be influenced more by the chemical nutrients of the soil of the catchment.

The reservoirs under consideration belong to different rivers; thus Bhavanisagar was constructed on the River Bhavani, Nagarjunasagar on the Krishna, Rihand on the Rihand (also known as Rend or Renu) and Konar on the Konar (a tributary of Damodar). These reservoirs show water level fluctuations from 30 to 69 ft. While the mean depth was 36.68 ft in Bhavanisagar it was as high as 133.2 ft in Nagarjunasagar. The high values of *shore development indices* in the range 7.04 to 8.78 in Nagarjunasagar, Rihand and Konar point to a high degree of shore irregularity. *The volume development index* being greater than unity (1.13) in Nagarjunasagar points to the fact that the basin wall in this reservoir is concave toward the water while the index being less than unity in the other reservoirs points to the convex character of their basin walls. For further details on location, dam design and related data, reference may be made to Table 1.

3. PHYSICO-CHEMICAL CHARACTERISTICS OF RESERVOIR BIOTOPE

Limnologists have attempted from time to time to classify lakes according to thermal characteristics (Welch, 1952; Hutchinson, 1957), although such classifications are intended primarily for lakes, they may be extended to reservoirs. Many of the reservoirs especially in the North Indian belt like Konar and Rihand, are monomictic with thermal stratification in summer. But the original definition of monomictic lakes as lakes which show winter circulation does not apply to these reservoirs as both wind action and the inflow of monsoon floods upset the summer stagnation in July/August and produce isothermal conditions. This is very well depicted in observations made in Konar reservoir (Natarajan *et al.*, 1971, MS). In the Nagarjunasagar reservoir situated in Peninsular India, there is little thermal stratification in summer and the temperature difference between the surface (30.0°C) and the bottom at 45 m depth (26.5°C) is only of the order of 3.5°C. Thermal stratification was not noticed in Bhavanisagar which is also situated in Peninsular India. This is to be expected as the seasonal difference in air temperature is less marked at lower latitudes. In Konar reservoir in 1970, the epilimnion extended to 9 m depth, the metalimnion from 10 to 17 m depth and the hypolimnion from 18 to 23 m depth. In Rihand the epilimnion ranged from 0 to 5 m, the thermocline from 6 to 11 m and the hypolimnion from 12 to 43 m in the deep zone in 1975.

The internal circulation of water assists in bringing the chemical nutrients locked in the tropholytic zone up to the trophogenic zone. In the reservoirs considered here, turbulence as well as monsoon inflow are more important factors in the vertical mixing of water than convection currents.

Table 2, which gives certain of the chemical and physical properties of the lakes, shows that chemical stratification is poor both in Rihand and Konar, as opposed to the strongly stratified Bhavanisagar and Nagarjunasagar. The chemical indices also indicate that Bhavanisagar and Nagarjunasagar are productive reservoirs. Rihand and Konar, where chemical stratification is feeble, are reservoirs of low productivity, and in Konar uniform distribution of oxygen was observed in some years which is a further symptom of low productivity. The amount of oxidizable substances in the reservoir is a reflection of the degree of development of the biota. A reservoir with a rich biota develops oxygen deficiency in the tropholytic hypolimnion. The stratification of dissolved oxygen is a useful chemical measure of the degree of productivity of a reservoir.

The net primary production was of the order of 250 mg C m^{-2} day^{-1} in Bhavanisagar, 225 mg C m^{-2} day^{-1} in Nagarjunasagar, 95 mg C m^{-2} day^{-1} in Rihand and 81 mg C m^{-2} day^{-1} in Konar. These values confirm the earlier chemical deductions of the productivity of the above reservoirs. Greater primary production was noted in lentic and intermediate zones in Bhavanisagar. But in Nagarjunasagar the intermediate one showed higher values. The respiratory coefficients were high in the bays of Bhavanisagar (0.82 in gross primary production) and Nagarjunasgar (0.92 in gross). They varied in the range 0.61 - 1.00 in Bhavanisagar and 0.75 - 0.92 in Nagarjunasagar. It was 0.68 in Rihand.

4. BIOTIC COMMUNITIES

4.1 Temporal and spatial distribution of plankton

Impoundments bring about qualitative changes in the plankton population, rheophil species giving way to limnophil species. Studies carried out immediately after impoundment in Bhavanisagar revealed Chlorophyceae dominant among phytoplankters followed by diatoms and blue-green algae (Pankajam, 1956). This pattern has since changed with blue-green algae replacing Chlorophyceae as the dominant element. In the reservoirs examined here Mydophyceae, Chlorophyceae, diatoms and Dinophyceae constitute the phytoplankters and copepods, cladocerans, rotifers and protozoans the zooplankters. Myxophyceae is represented by *Microcystis*, Chlorophyceae by *Pediastrum*, *Mougeotia*, *Spirogyra*, *Oedogonium*, *Botryococcus*, *Volvox*, *Pleodorina* and *Eudorina*, diatoms by *Synedra*, *Fragilaria*, *Gyrosigma*, *Melosira*, *Tabellaria* and *Navicula*, Dinophyceae by *Ceratium*, copepods by *Diaptomus* and *Cyclops*, cladocerans by *Diaphanosoma*, *Chydorus*, *Daphnia*, *Ceriodaphnia*, *Macrothrix*, *Sida*, *Bosmina* and *Leptodora*, rotifiers by *Keratella*, *Brachionus*, *Polyarthra*, *Filinia*, *Lecane* and *Trichocera* and protozoans by *Arcella*, *Actinosphaerium* and *Colpidium*. In general blue-green algae among Phytoplankters and copepods among zooplankters dominate the plankton in Bhavanisagar, Nagarjunasagar, Rihand and Konar reservoirs.

A Myxophyceae pulse was noted in June in Bhavanisagar, during October-March in Nagarjunasagar and April-May in Rihand. A copepod pulse was observed in June and November in Bhavanisagar and November in Rihand. The intermediate zone showed a maximum standing crop of plankton in Bhavanisagar and Nagarjunasagar while the standing crop was equally well represented in all the zones (subject to seasonal variation) in Rihand. Bays in general are rich in plankton.

Botryococcus (Chlorophyceae) occurs normally only in reservoirs in the northern belt like Konar, and Rihand. Similarly *Microcystis* (a warm water species) is replaced by *Ceratium* (a colder water species) in Bakra reservoir.

The standing crop of plankton was of the order (ml m^{-3}) of 0.335 in Bhavanisagar, 0.65 in Konar, 1.08 in Nagarjunasagar and 1.42 in Rihand.

4.2 Benthos and communities of Aufwuchs

Morphometry, substrate characteristics and water fluctuations are some of the factors that have a bearing on the abundance, qualitative composition and bathymetric distribution of benthos in reservoirs. Rocky substrates do not favour benthic fauna as observed in Nagarjunasagar but in the same reservoir soil types having a high degree of decayed organic matter had a rich bottom biota. Clayey substrates supported more units of benthos in Rihand. The optimum depth for benthos decreases from lentic to lotic in Nagarjunasagar, thus, 6-10 m in lentic, 4-6 m in intermediate, 4 m in lotic and 2-4 m in bays. A similar distribution was observed in Rihand (Natarajan *et al.*, 1974).

The benthos is represented by insect larvae and nymphs (*Tendipes* and *Chaoborus* larvae of Diptera, caddis-worms of Tricoptera, mayfly nymphs of Ephemeroptera and dragonfly nymphs of Odonata), Oligochaetes, nematodes, bivalves (*Corbicula*) and gastropods (*Melanoides*). The larger population of *Tendipes*, oligochaetes and nematodes in the lotic zone in Bhavanisagar is attributable to pollution effects of effluents from the South India Viscose Factory which resulted in reduced oxygen level in bottom waters.

The abundance of benthos (in terms of units m^{-2}, was of the order of 143 in Nagarjunasagar, 118 in Bhavanisagar, 47 in Rihand and 43 in Konar.

Impoundment results in the submergence of trees, shrubs, etc., which serve as substrates for the development of the communities of Aufwuchs. The periphyton complex is represented in Konar by *Mougeotia*, *Hormidium*, *Oedogonium* among green algae, *Phormidium*, *Anabaena* and *Lyngbya* among blue-green algae and *Navicula*, *Pinnularia* and *Rhopalibia* among diatoms (Natarajan *et al.*, 1971, MS).

5. UTILIZATION OF FISH FOOD RESOURCES

The biotic communities described above are interlinked with one another. The complex relationship of food chain and energy flow in community metabolism are of great importance for a correct understanding of the trophic dynamics of the aquatic ecosystem, and is of vital importance in the study of the dynamics of fish stocks and their yield. The link between fish and other trophic strata is examined here in some detail on the basis of observations made in Konar (Natarajan *et al.*, 1975) and other reservoirs (Natarajan *et al.*, 1974).

In the reservoirs under consideration, blue-green algae, green algae, diatoms and the nanoplankton constitute the primary producers. Of this, the blue-green algae, the dominant element in net plankton, are little utilized though they occur occasionally in the diet of *Catla catla*, *Esomus danrica*, *Chela*, *Laubuca*, *Oxygaster bacaila*, *Amblypharyngodon mola*, *Labeo boggut*, *Cirrhinus reba* and *Rhinomugil corsula*. Chlorophyceae is taken by *C. reba*, *L. boggut*, *O. bacaila*, *Barilius barna*, *Puntius ticto*, *P. stigma*, *P. sarana* and *R. corsula*. This food item is also observed in small quantities in the gut contents of *Cirrhinus mrigala*. Bacillariophyceae, which constitutes an important segment of periphyton, is taken occasionally by *E. danrica*, *A. mola*, *O. bacaila*, *B. barna*, *P. ticto*

P. stigma, *P. sarana*, *L. boggut* and *R. corsula*. Among economic fishes, *C. mrigala*, *Labeo calbasu*, *C. reba* and *Labeo fimbriatus* also utilize this food. Copepods constitute a dominant part of zooplankton in reservoirs. They are taken by *A bassis nama*, *Osteobrama cotio* and *O. bacaila*. Among major carps this biotic element constitutes a dominant percentage in the diet of zooplanktophagic *C. catla*. Cladocerans occur in the diet of *A. nama*, *O. cotio*, *O. bacaila* and *P. stigma*. Insects and insect larvae are taken by *A. nama*, *O. cotio*, *E. danrica*, *C. laubuca*, *O. bacaila*, *B. barna*, *M. cavasius*, *N. notopterus*, *G. giuris*. This item of biota constitutes 100 percent in the diet of *O. vigorsii*. It also contributes a significant percentage in the diet of *P. kolus* which forms a fishery of some magnitude in Nagarjunasagar. Macrovegetation occurs variously in the diet of *O. cotio* in Konar. It constitutes 100 percent in the diet of *P. dobsoni* in Nagarjunasagar. *T. khudree* and *P. pangasius* take to molluscs in Nagarjunasagar. Carp minnows and other trash fishes make forage fishes for *G. giuris* in Konar; for *Mystus seenghala*, *M. punctatus*, *Silonia childreni* and *Pseudoutropius taakree* in Nagarjunasagar. *L. bata*, *C. reba*, *P. sarana*, *P. stigma*, *A. mola* and *R. corsula* are chiefly detritophagic. Among major carps *C. mrigala* and *L. calbasu* also take detritus.

6. FACTORS AFFECTING PRODUCTIVITY OF ECONOMIC FISHES

6.1 Carp minnows and weed fishes

In the early years after impoundment a reservoir passes through a phase of peak productivity. During this phase the reservoirs hold vast food reserves and provide favourable conditions for the fast multiplication of trash fishes. They, thus, get an initial foothold which they maintain in subsequent years (Natarajan, 1972 1972a). Among weed fishes encountered in the reservoirs under study, mention may be made of *C. laubuca*, *O. bacaila*, *B. barna*, *P. ticto*, *P. stigma*, *E. danrica*, *A. mola*, *O. cotio*, *A. nama* and *A. ranga*. The gillnet fishing, being the dominant means of fish capture, helps further in the build-up of dense populations of carp minnows and other trash fishes as their small size enables them to escape the net. Studies carried out in Konar indicate the presence of dense stocks of *Ambassis nama* in this reservoir. They are seen to move shoreward during the monsoon season, and at this time the stocks could be reduced by seine netting. In Tilaiya, it was seen that they move shoreward in winter months as well as during the monsoon (Natarajan *et al.*, 1975). *Oxygaster* spp. are also seen in large concentration in Nagarjunasagar. In Tilaiya it was observed that as much as 70 percent of the food of *Ambassis nama* consisted of copepod plankters. *Osteobrama cotio* and *Oxygaster bacaila* were found to feed on copepods and cladocerans. These weed fishes thus directly compete for food with *C. catla*, a highly prized economic carp and reduce the latter's productivity and yield. *Esomus danrica*, *Amblypharyngodon mola* *P. stigma* and *P. ticto* were found to compete similarly with *C. mrigala* and *L. calbasu*. The control of these trash fishes is therefore necessary for the development of a major carp fishery in reservoirs.

6.2 Undesirable fishes

The abundance of weed fishes in reservoirs leads to the successful establishment of catfish populations. Since catfishes are on long food chains they necessarily reduce the overall productivity of reservoirs. Since most of them are predatory they affect the recruitment potential of major carps (Natarajan, 1975). Catfish populations have established a foothold in many of our reservoirs. *M. aor*, *M. seenghala*, *P. pangasius* and *S. childreni* together, contribute nearly 40 percent of the catch in Nagarjunasagar (Natarajan *et al.*, 1974). *M. aor* and *W. attu* contribute substantially to the fisheries in Bhavanisagar. In all these species there are indications of their breeding and successful recruitment. Not all catfishes, however, should be considered undesirable. Some of them like *P. pangasius* which take molluscs and *M. cavasius* which feeds on insects are desirable and have a role to play in the community metabolism (Natarajan, 1972a).

6.3 Parasites

Copepods, which are the dominant element in the zooplankton of Bhavanisagar, Nagarjunasagar, Rihand and Konar reservoirs, are the primary host of the cestode parasite *Ligula intestinalis*. Its final hosts are piscivorous birds in which it enters from the body cavity of the fish and parasitizes the intestine. The occurrence of *Ligula intestinalis* was noted in *C. catla*, *Amblypharyngodon mola* and *Puntius sarana* in Konar reservoir. It is necessary to control water birds to check the spread of this infection (Jhingran, 1974) and to increase the productivity of planktophagic fishes like *C. catla*.

6.4 Pollution

Insecticides used on agricultural crops adjoining the Konar reservoir are washed into the reservoir causing mortality to major carp fingerlings (*L. calbasu* and *C. mrigala*) in the littoral zone. Similar mortalities to fish populations were noted in Bhavanisagar from effluents of the South India Viscose Ltd., where the plant waste includes sulphite. In the Rihand the pollutants include free chlorine, calcium chloride and calcium hypochlorite. Fish mortality in this reservoir during the early years was reported heavy and according to the Fisheries Directorate of Uttar Pradesh it was largely due to free chlorine. Motwani, Banarjea and Karamchandani (1956) have shown that under low concentrations of dissolved oxygen even sub-lethal levels of free chlorine (up to 0.19 ppm) result in fish mortality. Pollution hazards pose serious problems to the productivity of fish stocks in reservoirs. Measures are indicated for safe disposal of these industrial wastes. Upstream stretches in reservoirs are very vital for fish migration, breeding and recruitment and those zones need to be kept free from industrial pollutants.

7. FISH YIELD

7.1 Species composition

Bhavanisagar is located on the Cauvery drainage. The species of commercial importance that occur in this river are: *Puntius dubius*, *P. carnaticus*, *P. micropogon*, *Cirrhinus cirrhosa*, *C. reba*, *C. fulungee*, *Labeo kontius* *L. potail*, *L. porcelus*, *L. calbasu*, *Garra* spp., *Lissocheileus hexagonolepis*, *Tor khudree*, *T. mussullah*, *Bagarius bagarius*, *Wallago attu*, *Mystus punctatus*, *Pangasius pangasius* and *Silonia childreni*. Both the lentic condition as well as the impact of stocking have changed the species composition and their abundance in Bhavanisagar. The fishery of the reservoir, at present, is largely made up by *L. calbasu*, *C. mrigala*, *P. dubius*, *M. aor* and *W. attu*.

Nagarjunasagar is located on the Krishna river in Peninsular India. The fishery of the reservoir is largely made up of *L. fimbriatus*, *L. calbasu*, *C. catla*, *T. khudree*, *M. aor*, *M. seenghala*, *P. pangasius* and *S. childreni*. These species are also endemic to the Krishna drainage.

Rihand and Konar reservoirs are located on the Ganga river system. The fishes of commercial importance belonging to this river system are: *Labeo rohita*, *C. mrigala*, *C. catla*, *L. calbasu*, *L. bata* and *C. reba* among carps; *M. aor*, *M. seenghala*, *Rita rita*, *S. silondia*, *P. pangasius*, *W. attu*, *B. bagarius*, *Clupisoma garua*, *Eutropiichthys vacha* and *Ompak bimaculatus* among catfishes. The fishery in Rihand and Konar is largely made up of endemic species. In Rihand the commercial fishery is more or less limited to one major carp, namely *C. catla*; and largely to Gangetic major carps in Konar. Details of species composition and carp-catfish ratio in the catches are presented in Tables 3 and 4.

7.2 Fishery and fishing gear

The fish yield varied in the range 94.5 to 205.0 tonnes (25.56 to 55.47 kg hm^{-2}) in Bhavanisagar; 32.3 to 157.7 t (1.75 to 8.56 kg hm^{-2}) in Nagarjunasagar; 147.3 to 328.8 t (4.89 to 10.91 kg hm^{-2}) in Rihand during the period 1971-72 (April-March) to 1974-75. In Konar the yield was in the range 1.7 to 5.7 t (1.12 kg to 3.69 kg hm^{-2}) during the period 1968-70. Details of fish yield in reservoirs under examination and yield hm^{-2} are presented in Table 5.

Gillnets are widely used in Bhavanisagar, Nagarjunasagar, Rihand and Konar and are the dominant gear in other reservoirs as well. They are of two categories: the surface net (known as "Rangoon" net) and the bottom set gillnet (also known as "Uduvalai"). The Rangoon nets have normally only floats but no sinkers. These nets, variously effective to capture both carps and catfishes, have different mesh (bar) range from reservoir to reservoir, thus: 40-180 mm in Bhavanisagar and Nagarjunasagar, 150-190 mm in Rihand and 35-150 mm in Konar. The Uduvalai, the use of which is restricted to shallow areas has, however, both floats and sinkers. Longlines are also used in Nagarjunasagar. These lines take mostly *Mystus* spp.

8. STOCKING

Reservoir management in India largely centres on the development of the carp fishery, especially those species belonging to Gangetic major carps. Details of stocking figures during the first five years immediately after impoundment, as well as stocking rate during recent years, are given in Table 6. The figures reflect the low stocking rate in the reservoirs under examination except, to some extent, Bhavanisagar in recent years. The full implications of stocking in relation to yield are examined in Section 9.

9. DISCUSSION

Studies carried out in the Konar reservoir in 1969 and 1970 revealed only stray breeding of *L. calbasu*, *L. rohita* and *C. mrigala* (Parameswaran *et al.*, 1969). The eggs appear to be washed into the reservoir depths with the result that there is hardly any recruitment. In the Rihand reservoir, successful recruitment has been observed only in respect of *C. catla* though breeding has been observed in major carps in 1974-75. Similarly successful recruitment has been observed only in respect of *L. calbasu* in Bhavanisagar though other major carps also breed in this reservoir. In Nagarjunasagar there is successful recruitment in respect of *L. fimbriatus*. The above observations go to show the need for stocking though the species and the extent of stocking may vary from reservoir to reservoir.

The limited spawning habitat in Rihand reservoir has led to frequent inter-generic breeding as reflected by the frequent occurrence of catla x rohu hybrids (Natarajan *et al.*, 1976). The fishery in this reservoir is dominated by *C. catla* though experimental fishing has revealed the presence of *L. rohita*, *C. mrigala* and *L. calbasu* but the populations of these species are small. Bailey and Lagler (1958) were of the view that the construction of a dam causes ecomorphological changes in riverine habitat favouring hybridization. According to Hubbs (1955) hybridization is facilitated where there is scarcity of one species and dominance of an allied species. The occurrence of catla x rohu hybrids and the dominance of *C. catla* in Rihand bear out fully the views of these authors. The above observations also emphasize the need for balanced stocking in Rihand.

The average yield per hm^2 in Bhavanisagar during the 1971-75 period was of the order of 38.21 kg hm^{-2} out of which Gangetic major carps alone contributed 19.2 kg hm^{-2}. The higher yield in Bhavanisagar is thus attributable to the successful recruitment of major carps, especially of *L. calbasu* which formed between 38.9 and 47.2 percent in the total yield and 70.4 percent among Gangetic major carps.

In Nagarjunasagar the yield per hm^2 of Gangetic major carps was only of the order of 0.63 kg hm^{-2} during the above period. This was also reflected in the low total yield of 4.55 kg hm^{-2} in this reservoir for the above period. It is significant that there is a large harvest of catfish in this reservoir (Table 3). In Rihand the Gangetic major carps contributed 7.06 kg hm^{-2} and the total yield per hm^2 is also very nearly of the same order. This is because the entire yield is contributed by a single species, namely *C. catla* which breeds in the upstream stretches though the breeding fluctuates between years. This is reflected in the catch. While the average annual yield of *C. catla* during the period 1971-75 is of the order of 216 t, it was as high as 433 tonnes in 1968-69 with a yield per hm^2 of 17.79 kg (Jhingran, 1974). In the Konar reservoir Gangetic major carps contributed only 1.90 kg hm^{-2} as against the total yield of 2.07 kg hm^{-2} during 1968-70. The low yield of major carps in this reservoir has also resulted in the low total yield per hm^2. In the Konar reservoir, the breeding of major carps is poor and the recruitment poorer (Jhingran and Natarajan 1969). In Tungabhadra the major carps contributed only 0.03 percent in the total catch (David *et al.*, 1969). The yield per hm^2 of this reservoir was of the order of 5.7 kg hm^{-2}. The above survey emphasizes the importance of stocking major carps in order to obtain maximum yields from reservoirs.

The stocking rate of major carp fingerlings in recent years (Table 6) is of the order of 1 hm^{-2} in Nagarjunasagar, 25 hm^{-2} in Rihand, 25 hm^{-2} in Konar and 82 hm^{-2} in Bhavanisagar. Except in the case of Bhavanisagar the above stocking rates are totally inadequate as reflected by low yield per hm^2 in these reservoirs. The new impoundments are passing through the phase of peak productivity and hold a vast supply of fish food organisms. If they are stocked by fast-growing economic fishes at this phase there will be a better survival of economic fishes and their sustained fishery in the years to come (Lepitzky, 1968). Unfortunately this fundamental principle of reservoir fisheries management is scarcely, if at all, followed in India. The stocking rate during the first five years after impoundment was of the order of one fingerling per hm^2 each in Bhavanisagar and Nagarjunasagar and 24 fingerlings in Rihand. Major carps in general should receive priority consideration for large-scale stocking at this phase of a reservoir's history.

Trees, bushes and other physical obstructions in reservoir basins present serious difficulties to effective exploitation of the fish stocks, but as their removal involves a huge expenditure and capital investment they are left. Though they provide a base for the development of periphyton and thus enrich the food resources of the reservoir, efforts should be made to clear them to increase fishing efficiency. Investigations carried out at Konar reservoir on fish dispersal point to the denser fish concentrations toward the lotic zone of the reservoir. Timber clearance up to the drawdown limit in the lotic zone in Konar would enable better fishing and hence better harvest (Natarajan *et al.*, 1971). Similar studies need to be carried out for other reservoirs to locate areas for selective timber clearance. Such peripheral clearance of trees would enable operation of shore seines and dragnets which are known effective for harvest of catfish (David *et al.*, 1969) and trash fish populations (Natarajan *et al.*, 1971).

The reservoirs examined in this paper also suffer from varying degrees of underexploitation. In Bhavanisagar the annual fishing effort (in terms of 50 m calculated gillnet lengths) was of the order of 52 x 10^3 units in 1971-72. The fishing effort was increased to 85 x 10^3 in 1974-75, i.e., an increase in fishing effort by 63 percent. During the above period the catch rose from 94.4 t in 1971-72 to 205.0 t in 1974-75, i.e., an increase in yield by 117 percent. The catch per unit of effort per unit area was of the order of 0.065 in 1974-75 and was more or less similar to the previous years indicating thereby that the additional effort has not changed the overall stock densities in any manner.

In Rihand the annual fishing effort (in terms of 50 m gillnet units) was of the order of 62 x 10^3 in 1971-72. The effort increased to 147 x 10^3 units in 1974-75, i.e., an increase in fishing effort by 137 percent. During the same period the fish yield (composed almost entirely of *C. catla*) increased by 116 percent, i.e. 152.4 t in 1971-72 to 329.0 t in 1974-75. The catch per unit effort per unit area of *C. catla* in 1974-75 was of the order of 0.007 which is more or less the same as that obtained in 1973-74. In order to increase the fish yield of this reservoir it is necessary to increase the variety of species. In theory a body of water with the greatest mix of species and sizes would possess a fish population utilising the available food resources to a maximum efficiency (Bennett, 1962). This principle is relevant to Rihand reservoir where the carp component needs to be enlarged by including in the stocking other species like *L. calbasu*, *C. mrigala* and *C. carpio*.

To improve the fish yield in Nagarjunasagar, intensive stocking with major carp fingerlings and an increase in the fishing effort are indicated. The fishing intensity in this reservoir is about a quarter of that in Bhavanisagar. The low yield is due to the fact that nearly the entire intermediate zone remains totally unexploited.

Size limitations are another important biological measure aimed at increasing the productivity of economic fish stocks. Studies carried out in Konar reservoir bring out the following mesh limits :

Name of fish	*Prescribed mesh (bar)*	*Size limit*
C. catla	91 mm	587 mm
C. mrigala	46 mm	460 mm
L. calbasu	52 mm	375 mm
L. rohita	*a:*	450 mm

a. Adequate data not available for *L. rohita* to derive length-mesh bar relationship

The above table indicates that there is a conflict of interest in terms of mesh size limits between *C. catla* and other major carps. This should be reconciled. In Bhavanisagar and Konar reservoirs mesh of 50 mm and above may be prescribed which would more or less fulfil the biological requirements of *C. mrigala*, *L. calbasu* and *L. rohita*. But in Rihand reservoir where *C. catla* is the only major carp and dominates the fishery, mesh sizes of 100 mm and above are indicated.

For effective exploitation, a knowledge of dispersal of stocks in time and space is necessary Detailed studies carried out in the Konar reservoir in 1970-71 using gillnets with mesh sizes in the range 30-150 mm have shown (effort comprising of 759 m length of gillnets and remaining constant between the months covered) that the fish catch was superior in the intermediate zone (6.7 kg day^{-1}) in May, intermediate and upper zones (4 kg day^{-1}) in June, upper (24 kg day^{-1}) in August, dam and intermediate zone (4 kg day^{-1}) in October, Dam (5.6 kg day^{-1}) and intermediate zones (5 kg day^{-1}) in November and Dam zone (9.8 kg day^{-1}) in December. The overall index of fish concentration in different zones of the reservoir, as reflected by the index of catch per day, shows that the average fish density is greatest in the upper zone followed by the intermediate and Dam zones (Natarajan *et al.*, 1973).

Studies carried out in Konar, Bhavanisagar, Nagarjunasagar and Rihand reservoirs reveal that *L. rohita* among major carps does not show the same adaptability to the reservoir ecosystem as other major carps. Catla x rohu hybrid, frequently encountered in the Rihand reservoir, appears to be an ideal replacement for *L. rohita* in reservoirs (Natarajan *et al.*, 1975). This hybrid is a detritus and phytoplankton feeder, grows faster than *L. rohita* and has a growth rate closer to *C. catla*. The proneness of the hybrid to take *Ceratium* has great application in Govindsagar reservoir where the species forms the dominant fraction in the plankton (Sarkar *et al.*, in press). The hybrid holds enormous promise for reservoir fishery development in India.

To obtain an optimum harvest in the reservoirs under study there is scope for stock manipulation. For general purposes *C. mrigala*, *L. rohita* (or catla x rohu hybrid), *L. calbasu* may be considered primary consumers while *C. catla*, a secondary consumer, and catfishes secondary/tertiary consumers. There is need to regulate stock structures so that primary consumers and other category consumers are in 4 : 1 ratio. For this ratio, fish production was estimated (calculation based on primary production) at 125 kg hm^{-2} year^{-1} in Bhavanisagar 113 kg hm^{-2} year^{-1} for Nagarjunasagar, 52 kg hm^{-2} year^{-1} in Konar and 48 kg hm^{-2} year^{-1} in Rihand. With the proper management measures discussed above, it should be possible to realize a much larger harvest from the above reservoirs than is the case at present.

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