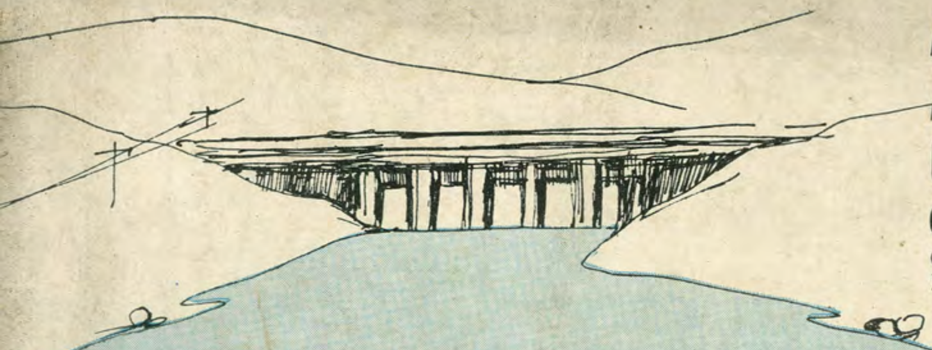

ARTIFICIAL RECRUITMENT AND FISHERIES MANAGEMENT OF INDIAN RESERVOIRS

CENTRAL INLAND FISHERIES RESEARCH INSTITUTE
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ARTIFICIAL RECRUITMENT AND FISHERIES MANAGEMENT OF INDIAN RESERVOIRS

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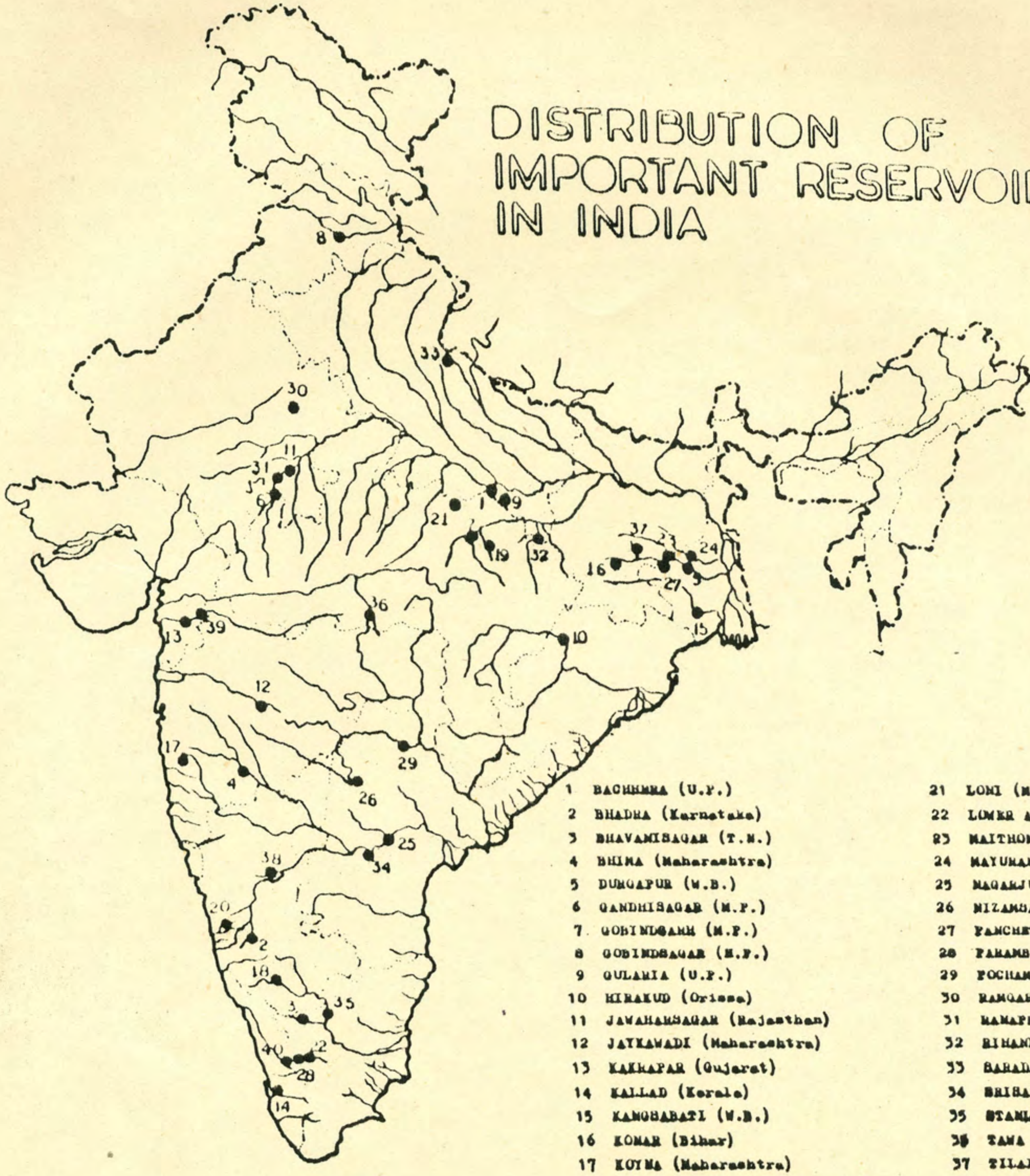
INTRODUCTION

The steadily rising demand for water in the country for industrial, agricultural and domestic purposes, power generation, flood control and other water-oriented activities has brought about an accelerated rate of dam construction. The total surface area of reservoirs in India has been estimated at 3 million ha and is expected to double by the turn of the century (Anon., 1976). According to Bhukaswan (1978), the area of reservoirs in India is 20,000 km^2. There are about 975 existing reservoirs in India, including medium and minor impoundments with an estimated storage capacity of 14.7 Mham (Srivastava et al.*, 1984). Average fish yield from Indian reservoirs is frustratingly low* i.e.*, less than 10 kg/ha/annum. These under-utilised fishery resources offer immense scope and potential for generating additional national income of the order of Rs. 100 crores per year and providing additional employment to lakhs of fishermen and others through fishing, handling, transport, marketing and ancillary industries (Srivastava and Reddy, 1983).*

Dams radically alter river hydrology both up and downstream creating a new artificial aquatic environment. The quality of impounded water varies from watershed to watershed and even within a watershed depending on soil, man's activities and climatic conditions. It also varies with the shape of the reservoir basin, exposure to light and wind action, and the amount of water exchange. Owing to these variables, although generalizations about the productivity of reservoirs can be made, evaluations of specifics of water

DISTRIBUTION OF IMPORTANT RESERVOIRS IN INDIA



1 BACHHMRA (U.P.)
2 BHADRA (Karnataka)
3 BHAVANISAGAR (T.N.)
4 BHIMA (Maharashtra)
5 DURGAPUR (W.B.)
6 GANDHISAGAR (M.P.)
7 GOBINDGARH (M.P.)
8 GOBINDSAGAR (H.P.)
9 GULARIA (U.P.)
10 HIRAKUD (Orissa)
11 JAWAHARSAGAR (Rajasthan)
12 JAYKAWADI (Maharashtra)
13 KAKRAPAR (Gujarat)
14 KALLAD (Kerala)
15 KANGSABATI (W.B.)
16 KONAR (Bihar)
17 KOYNA (Maharashtra)
18 KRISHNARAJSAGAR (Karnataka)
19 KULGARHI (M.P.)
20 LINGANAMAKKI (Karnataka)
21 LONI (M.P.)
22 LOWER ALIYAR (T.N.)
23 MAITHON (Bihar)
24 MAYURAKSHI (W.B.)
25 NAGARJUNSAGAR (A.P.)
26 NIZAMSAGAR (A.P.)
27 PANCHET (Bihar)
28 PARAMBIKULAMALIYAR (T.N.)
29 POCHAMPAD (A.P.)
30 RAMGARH (Rajasthan)
31 RANAPRATAPSAGAR (Rajasthan
32 RIHAND (U.P.)
33 SARADASAGAR (U.P.)
34 SRISAILAM (A.P.)
35 STANLEY (T.N.)
36 TAWA (M.P.)
37 TILAIYA (Bihar)
38 TUNGBHADRA (T.N.)
39 UKAI (Gujarat)
40 UPPER ALIYAR (T.N.)

quality have to be made separately for different sets or families of reservoirs sharing the same eco-climatic conditions.

Comprehensive research has been done under the All India Coordinated Research Project on Ecology and Fisheries of Freshwater Reservoirs and basic hypotheses regarding productive capacities of some large reservoirs have emerged. Although these studies have led to some increase in fish production from certain reservoirs, a standard technique has to be evaluated and management plans capable of manipulating fish populations have to be formulated since reservoirs are no more branded as 'biological deserts' and provide a remunerative fishing experience.

I LARGE MULTIPURPOSE RESERVOIRS

SEQUENCE OF ECO-MORPHOLOGICAL EVENTS FOLLOWING RESERVOIR FORMATION

Soon after impoundment, there occurs a phase of high initial fertility caused by nutrients leaching from the hitherto unflooded substrate, submerged forests and other organic matter. This accelerates the growth of bacteria, phytoplankton, zooplankton and benthos. In this new immense habitat, which has greatly reduced fish population per unit volume, zooplankton forms are under little predation pressure and build up large populations dependent on preponderance of planktonic algae. With the larger forms of zooplankton available for food, the general picture is one of good growth of fishes and good fishing success.

The maximum productivity in newly filled reservoirs is attained within the first few years of their existence. In Rihand and Gandhisagar reservoirs, fish yield reached its initial peak in the fourth year of impoundment (Jhingran, 1982, Dubey and Chatterjee, 1977).

However, this high production is not sustained for long and after a period, ranging from one to several years, it declines to a much lower level, partly owing to diminution of bottom leaching as volume of impounded water increases and partly as nutrients are used up by aquatic vegetation when it becomes established in greater quantity. The productivity ultimately gets stabilized somewhere near half the magnitude of initial phase (Bhukaswan, 1980) getting adjusted to the basic productivity levels of the basin and allochthonous nutrients from the inflows and watershed runoff.

DETERMINANTS OF RESERVOIR PRODUCTIVITY

Biological productivity of a biotope is influenced by climatic, edaphic and morphometric features. The geographic location affects the metabolism of a reservoir through nutrition supply, shape of basin and the efficiency with which the climatic factors are able to act in the dynamic exchange. They all have varying effects on final productivity.

The climatic factors have a profound effect on the utilization of nutrients in the particular lake basin. The temperature regimes of reservoirs in North India are lower than those of south Indian reservoirs. Whereas the average surface and bottom temperatures of the DVC reservoirs are $23.3^{o}C$ and $17.4^{o}C$ respectively, with similar pattern for Loni *and Kulgarhi reservoirs; the same for Pykara and Sandynulla reservoirs in the Nilgiris range from 18.8 - 22.4°C and 15.1 to 22.6°C although they are at an elevation of over 2,000 m.*

The edaphic factors affect the supply of dissolved nutrients in the reservoir water. The extent of drainage area, its rate of erosion and runoff are important in limiting the supply of nutrients to the lake. Soil basin quality influences the reservoir productivity to a great extent.

Area, mean depth and regularity of shore line are the most significant morphometric measurements having a significant bearing on the productivity of a reservoir. The notable abiotic and biotic factors that may influence the productivity at various trophic levels are listed in Table I as positive and negative factors.

PHYSICOCHEMICAL LIMNOLOGY

Density stratification

Density stratification in reservoirs is caused by non-homogeneous temperature distribution with depth resulting from water surface heat transfer, solar radiation, absorption, advection of heat by inflow, convective currents and other causes. The temperature gradient, being directly related to density gradient, can become the governing parameter in reservoir dynamics.

On account of unequal distribution of temperature with higher temperatures near the surface layers and decreasing temperatures with depth, the warm and less dense water accumulates at the surface (Epilimnion) and heavier and cooler water in the layers below. The temperature of the epilimnion is about the same from top to bottom varying a few degrees when surface is warming rapidly and high winds are not there. Below the epilimnion is a layer of water (Thermocline or Metalimnion) where the temperature decreases rapidly proceeding downwards @ $1^{o}C$ or more. The volume of water below thermocline (Hypolimnion) tends to show a fairly uniform temperature, the change in temperature being less than $1^{o}C/m$.

Thermal stratification results in a reduced heat budget for the reservoir since heat is concentrated at the surface causing more evaporation and heat loss. Due to separation of cold layer from the photosynthetic zone, algal and atmospheric aeration does not occur. As a result, oxygen gets depleted and chemical stratification sets in. Consequently, reductive products causing quality degradation effects result from the anaerobic organisms and formation of methane, hydrogen sulphide and ammonia nitrogen. Under reducing conditions, iron and manganese that settle down from the aerobic zone in an oxidized insoluble form go back into solution.

The sizable plankton population in the upper warm layer creates tons of organic matter which sinks to the bottom generating more oxygen demand and chemical reduction. The entire process continues until thermal and chemical stratifications are broken artificially or naturally to bring about circulation of water.

Reservoirs in North India have been reported to show thermal stratification during summer where wind action and influx of monsoon floods break the process. Konar and Govindsagar reservoirs have also shown thermal stratification with three district zones. Among peninsular reservoirs, thermal stratification has not been observed in Amaravathi, Tungabhadra and Nagarjunasagar. Variation of temperature from surface to bottom has been recorded only 3-4^{o}C for peninsular reservoirs (Nagarjunasagar) whereas the same for north India reservoirs has been registered as 10^{o}C (Konar). This has been ascribed to less-marked seasonal differences in temperature as one progresses towards lower latitudes. In most reservoirs, inflow plays a major role in the development of water quality patterns.

Chemical stratification

The oxygen curve is an important chemical parameter to indicate the biological productivity of a reservoir. Oxygen deficit at the bottom is a characteristic feature of productive reservoirs. Phytosynthesis at the surface and tropholytic activity at the bottom cause klinograde oxygen distribution as was recorded for Bhavanisagar, Amaravathi, Nagarjunasagar and Govindsagar reservoirs in India. In unproductive waters, the oxygen curve parallels the temperature curve since its solution is temperature-dependent (Sreenivasan, 1971). In Konar, Tilaya, Rihand and Tungabhadra reservoirs with low productivity such an orthograde oxygen distribution was observed.

In reservoirs with klinograde oxygen distribution, the carbon dioxide and carbonate concentration show a general inverse relationship to the oxygen i.e. concentration of carbon dioxide and bicarbonate increases slightly with depth. On the other hand, orthograde oxygen distribution is usually accompanied by only slight increase, if any, in carbon dioxide.

Reservoirs in regions of weakly soluble rocks contain little carbon dioxide in any form. The paucity of soluble minerals as nutrients in biological processes inhibits development of large biotic populations (Reid, 1961) which would contribute carbon dioxide through respiration, and the decomposition is also little. Reservoirs of this type are usually slightly acidic (pH near 6). In waters of low pH (4-6), the concentration of bound carbon dioxide as carbonate is low (less than 9-10 ppm). Such reservoirs are termed <u>softwater lakes</u>.

There are a large number of reservoirs having near neutral pH, these have been termed <u>mediumwater lakes</u> (carbonates : 30-35 ppm). In areas with substrate containing easily dissolved minerals, reservoirs are characterized by pH ranging from 8.5 upwards. Carbonates (35-40 ppm) often reach 200 ppm or more and negative values of free carbon dioxide are recorded. Such reservoirs are termed <u>hardwater lakes</u>.

The alkalinity or acid combining capacity of impounded waters is generally caused by carbonates and bicarbonates of calcium and magnesium. These with dissolved carbon dioxide in water form an equilibrium which plays an important role in the productivity of the system. Observations show that alkalinity values of more than 50 ppm are most productive and those of less than 10 ppm do not produce large crops. <u>Total alkalinity</u> values upto 20 ppm indicate poor production, *40-90 ppm show medium production and values above 90 ppm show high production.*

Nitrogen is a basic constituent of protein and occurs in water in free state (N), as ammonia (NH_3), nitrate (NO_3) and nitrite (NO_2). Observations reveal that a dissolved N concentration of 0.2 - 0.5 ppm is favourable for fish products.

Observations on lake productivity have indicated the optimal concentration of dissolved phosphorus as 0.1 - 0.2 ppm.

The wide variations in calcium content and the corresponding correlations and biological productivity have led to classification of lakes based on their calcium content. Waters with less than 10 ppm of calcium are designated as poor, those with a calcium content between 10-25 ppm medium and waters with more than 25 ppm as highly productive (Reid, 1961).

Rawson (1951) has described the usefulness of mineral content of a reservoir (Total Dissolved Solids) as a rough indicator of edaphic conditions which must in some measure affect the productivity of lakes. TDS represents an average edaphic condition for any watershed as chemically it proportions the effects of various soil and geological conditions as reflected by autochthonous and allochthonous dissolved minerals. Its seasonal variability seems to parallel, at least to a certain degree, seasonal variations in productivity (Ryder, 1974). TDS is also representative of climatic effects. Conductivity (Hutchinson, 1957) and total alkalinity (Ryder, 1964) are significant correlates of TDS.

Mean depth - a significant morphometric factor

Defined as the volume of the reservoir divided by area, mean depth is considered the most important morphometric parameter. It is indicative of the extent of 'euphotic - littoral' zone i.e. the depth zone which permits light penetration for growth of planktonic algae and also provides shallower shore areas for attachment of sessile algae and macrophytes. It is an inverse correlate of shore development, a direct correlate of area (Hayes, 1957) and an exact correlate of volume when area is held constant. Therefore, mean depth portrays many morphometric features of a reservoir rather than depth alone all of which contribute to the potential productivity.

Rawson (1955) has observed distinct inflection in the mean depth curves at 18 m (this has been recorded in some Indian reservoirs at 10 m). This suggests that water mass below this depth serves as a 'nutrient sink' and removes nutrients from trophogenic zone in the form of settling seston and phytoplankton when density stratification is in effect.

Basin soil

The chemical properties of water in reservoirs are a reflection of the properties of bottom soil. In mud layers not well-aerated, when oxygen supply falls short, the decomposition of organic matter is slow and products of decomposition are mainly reduced or partially oxidized compounds and short chain fatty acids which make the soil strongly acidic.

The bacterial action is reduced and productivity lowered. pH also influences transformation of soluble phosphates and controls the adsorption and release of essential nutrients at soil water interphase. A slightly alkaline soil (pH 7.5) has been considered optimal for fish production. Productive soils range mostly between slightly alkaline to slightly acidic (7.5 - 6.5) in reaction.

From a large number of observations, it has been found that soils with available phosphorus (mg/100 g of soil) less than 3 are poor, 3-6 average and above 6 are highly productive. Available N below 25 (mg N/100 g of soil) gives poor productions, the same in the range 25 - 75 indicates average to high production. Organic carbon less than 0.5% is considered too low, 0.5 - 1.5% average and 1.5 - 2.5 optimal. ([illegible] 197[illegible]).

Organic matter budget

Organic matter in reservoir ecosystem comes from two sources. Primary production by the photosynthetic phytoplankton is the major autochthonous source of organic production and the base of the food chain. The other source is allochthonous, significant qualitatively and quantitatively, coming along with runoff from the watershed and inflow. It varies from large visible particles to dissolved fractions such as low molecular weight organic acids and polypeptides.

Organic matter in the reservoir functions in three ways. (1) As an actual food source for higher levels in the food chain which are mostly detritus feeders. These include benthic invertebrates and certain filter-feeding and browsing fishes. (2) As a substrate for bacterial growth and growth of other micro-organisms. (3) As dissolved organic compounds which function in various ways as exogenous growth substances, vitamins and chelating agents.

Eutrophication

Eutrophication is a significant problem in both lakes and reservoirs. Whenever the rates of synthesis and input of organic matter exceed the rates of recycling and output, an accumulation of matter within the aquatic system occurs leading to its eventual extinction.

Although variable from season to season, such a considerable allochthonous energy accumulates in the reservoir system that this quantity is either deposited and accelerates eutrophication or else enters the food chain in significant quantities.

Energy transformation through primary production

Among the Indian reservoirs, the peninsular ones receive maximum incident solar radiation. However, reservoirs differ considerably not only with respect to incident light energy but also the efficiency with which this energy is converted to chemical energy by primary producers. Studies made in four reservoirs (Sugunan, unpublished) varying in location from $11^{\circ}25'N$ to $31^{\circ}25'N$ show that only 0.2 to 0.68% of the light energy, ranging from 17,20,000 cal/m^2/day ($31^{\circ}25'N$) to 21,30,000 cal/m^2/day ($11^{\circ}25'N$) is converted to chemical energy. The efficiency of energy flow from producers to different trophic levels of consumers differs considerably *from reservoir to reservoir depending upon the qualitative and quantitative variations in the organisms inhabiting the lake. In Indian reservoirs, only 0.034 (Rihand) to 0.28% (Bhavanisagar) of the energy fixed by producers is obtained as fish flesh.*

BIOTIC COMMUNITIES

Plankton

Well-developed plankton cycles become established immediately after the filling of the reservoir. A pattern of seasonal pulses occurs among the dominant species producing blooms. Extensive data on temporal and spatial variations of plankton population in Indian reservoirs have been gathered. Generally, two plankton pulses have been recorded one in February-June and the other in October-December. The dominance of various groups of phytoplankton, which always prevailed over zooplankton, seemed to vary from year to year. However, by and large, the predominant group was blue-greens, a group not noted for passing their high productive capability directly up the trophic web. Whereas Myxophyceae were observed to be mainly represented (Microcystis) in reservoirs of lower latitudes, the same were replaced by dinoflagellates (Ceratium) in reservoirs located in higher latitudes (Govindsagar). Bacillariophyceae were mainly constituted by Synedra Novicula, Fragilaria, Melosira and Gyrosigma; Chlorophyceae contained Oedogonium, Spirogyra, Pediastrum, Botryococcus Pandorina and Eudorina as dominant forms.

Copepods, the main constituents of zooplankton, were mainly represented by Diaptomus and Cyclops; rotifers by Keratella, Brachionus, Polyarthra and Filinia. The general trends of abundance were found to change due to rainfall and nutrients from runoff. Maximum numbers developed from April to June and minimum in July-August in most of the reservoirs. Seasonal cycles of rotifers have been found to follow that of phytoplankton closely (Benson, 1968).

Macrobenthic invertebrates

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 decomposition of these materials, combined with erosion-redeposition processes along newly formed shoreline produces rapid changes in bottom biotope. The sequence of benthos succession, particularly chironomidae, has been used to characterize these early habitat changes. Therefore, the type and quantity of littoral, benthic invertebrates found in association with selected preimpoundment vegetation, are indicative of benthic succession occurring soon after the flooding of new habitats.

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 changes in the bottom biotope. They abound soon after flooding and are well adapted to attach themselves or browse in soft decaying vegetation. With the siltation arising out of shoreline erosion, a shift in the abundance of various chironomid forms occurs (Patterson and Fernando, 1969). Besides siltation, benthic organisms are also limited by rheotactile deprivation, water level fluctuation, hypolimnetic oxygen deficiency, increased hydrostatic pressure, light and other impoundment-associated factors.

The maximum concentration of benthic animals in Indian reservoirs (Tungabhadra, Konar, Tilaiya and Loni) has been observed in the depth range of 4-10 m. Below the drawdown limit, redeposition of sediments reduced the number of bottom animals significantly. Krishnamurthy (1966) observed that gastropods (Viviparus, Melanoides, Gyrulus) were predominant in Tungabhadra reservoir from April to November, bivalves (Lamellidens, Corbicula, Parreysia) in May and October and oligochaetes (Tubifex) in October. Mayfly nymphs (Pentagenia) were abundant in summer months influenced by sandy and silty bed of the lotic zone where food was available in the form of bottom ooze containing disintegrated phyto and zooplankton. The diatoms and desmids present at the bottom provided the food. Chironomidae appeared to dominate in humic soils.

The importance of bottom biota as a fish food is well established. Many of the bottom feeding riverine species have adapted themselves to lacustrine conditions. They are Puntius dubius, P. hexagonolepis, P. kolus, Labeo calbasu, L. dero, Cirrhinus cirrhosa and Pangasius pangasius. Thus the benthos represents an important link in the production pattern.

<u>Aufwuchs</u>

Periphyton takes the form of a brown or green layer at the surface of submerged objects and forms the food source of browsing fishes. This group is represented mainly by diatoms, green algae and blue-greens. Periphyton develop best in littoral areas of the reservoir. In Konar reservoir, periphyton group was constituted of an algal complex comprising green algae (<u>Mougeotia</u>, <u>Hormidium</u>, <u>Oedogonium</u>), blue-green algae (<u>Anabaena</u>, <u>Phormidium</u>, <u>Lyngbya</u>) along with diatoms (<u>Navicula</u>, <u>Surirella</u>, <u>Synedra</u>, <u>Fragilaria</u>, <u>Gyrosigma</u>).

<u>Aquatic macrophytes</u>

In contrast of natural lakes, aquatic macrophytes generally do not take a foot-hold in the reservoirs due to severe drawdowns. Aquatic macrophytes are considered undesirable form of primary production. They often accumulate large quantities of inorganic nutrients early in the growing season and compete with the phytoplankton for nutrients. Floating macrophytes and submerged species (<u>Ceratophyllum</u>) absorb the nutrients primarily from water. Submerged ones with root systems are capable of absorbing nutrients from mud (McRoy and Barsdate, 1970). <u>Najas</u> absorbs minerals from mud and by foliar absorption of bicarbonate ions from water.

A high species diversity gives stability to ecosystem (Odum, 1969). The addition of macrophytes to a lake or reservoir creates habitat not available in a system with a flora consisting of phytoplankton. A high diversity of macrophytes ensures diverse habitats for invertebrate fish food organisms thereby increasing the diversity of these organisms as well. The macrophytes also serve as shelters for small fish. Therefore, when present in moderate quantities, macrophytes increase the stability of the ecosystem.

Fish populations

The fisheries of Indian reservoirs is constituted of both indigenous and stocked fish populations. Among the former, the Gangetic major carps occupy a prominent place in North Indian reservoirs both as naturally occurring and stocked species. In addition to these, they also harbour Labeo bata, Puntius sarana, P. chagunio and Cirrhinus reba. However, in Govindsagar, the major carps constituted very low percentage of the total fisheries as the dominant fisheries comprised Tor putitora, Labeo dero and Schizothorax plagiostomus.

In peninsular reservoirs, the indigenous fishes forming the commercial fisheries are Cirrhinus cirrhosa, C. reba, Labeo kontius, L. fimbriatus, Puntius dubius, P. sarana, P. carnaticus, P. kolus, P. dobsoni, P. hexagonolepis, Tor tor, Thynnichthys sandkhol and Osteobrama vigorsii. In addition, Gangetic major carps are stocked.

Among large catfishes, the Indian reservoirs contain Wallago attu, Aorichthys seenghala, A. aor, Silonia silondia and Pangasius pangasius. Silonia childrenii and Pseudotropius takree have established in Tungabhadra reservoir (David, 1969) and Mystus vittatus in Poondi reservoir (Chacko, 1969).

Indian reservoirs also harbour a sizeable population of trash fishes like Ambassis nama, Esomus danrica, Aspidoparia morar, Amblypharyngodon mola, Puntius sophore, P. ticto, Oxygaster bacaila, Laubuca laubuca, Barilius barila, Osteobrama cotio and Gudusia chapra. Most of these trash fishes compete for food with Indian major carps tending to reduce the overall productivity of the reservoir.

The marked rise in biomass and growth rate and better feeding as well as high survival of young fish are characteristics of newly-filled reservoirs. The year class strength of fishes in the early stage of development of a reservoir is governed by fertility of water and inundated soils, food availability, water level fluctuation and the period of filling. Poddubny (1963) observed that the fish stocks will develop better in reservoirs where filling is accomplished in phases than in reservoirs filled in a single year.

In tropical reservoirs, strong year - classes of all species also coincide with the filling period taking one to several years. According to Petr (1975), the gradual flooding of new land over a number of years has the same impact on fish biological cycle and production as the annual formation of flood plains.

Bhukaswan (1980) has listed the reasons for change in riverine species composition consequent to the formation of reservoir resulting from different reactions of the species to alteration of living conditions. They are -

1 Reservoirs have fewer habitat types than the river with respect to current.

2 A reduction of turbidity in reservoirs due to sedimentation probably allows predators to reduce the population of small fishes more effectively than in turbid rivers.

3 An intensive fishing may remove rapidly growing valuable species which will thus be replaced by slow-growing undesirable species (Benson, 1968).

A cautious approach to fishery exploitation of newly created reservoirs has to be adopted. Any premature intensive fishery at this stage disrupts the formation of stocks of commercial fishes and leads to overpopulation of trash fishes.

Fish distribution

Fish are not distributed evenly throughout the reservoir. Studies in India indicate that the overall concentration of fish in Konar reservoir, as reflected by the index of catch/day, showed the average density to be greatest in lotic zone, followed by intermediate and lentic segments of the reservoir. The distribution also varied with the season. Catches were better in pre-monsoon and post-monsoon periods in the intermediate zone, in June and August in upper lotic zone and in October and December in the lentic zone. Variation in distribution of fishes is closely related to feeding habits and food availability. Fishes are generally limited to areas of shallower water close to shore and in bays and coves. A high drawdown also affects the distribution. The concentration of dissolved oxygen is one of the most important factors influencing fish distribution in reservoirs. Sreenivasan (1971) observed that in the absence of a thermocline in many South Indian reservoirs fish movement and their vertical distribution is governed by the DO content. Based on oxygen distribution it would be possible to operate suitable surface or bottom-set gill nets. He cited the case of Sholiar reservoir where Cyprinus carpio was caught in sizeable numbers in Rangoon nets when DO content decreased from 5 m and was depleted at 10 m depth.

For population estimation, fin-clipping and tagging by streamer tags and with internal anchor dart tags have been tried in Indian reservoirs (Jhingran et al., 1981). Catch and fishing effort monitoring has also been followed in many Indian reservoirs for measuring population density. However, more understanding and information is needed for multispecies tropical fisheries.

Fish yield from Indian reservoirs studied has varied from 94.5 t to 296.0 t (25.56 to 80.0 kg/ha) in Bhavanisagar; 32.3 - 190.0 t (1.75 - 10.0 kg/ha) in Nagarjunasagar; 147.3 to 328.8 t (4.89 - 10.91 kg/ha) in Rihand and 273.0 to 753.0 t (25 - 72 kg/ha) in Govindsagar during the period 1971-1979 (Natarajan, 1979). Of these reservoirs, Govindsagar, Bhavanisagar and Rihand have dominance of carps whereas Nagarjunasagar has catfishes dominating the total catches.

FISHING METHODS

Fishing gear in common use are gill nets of entangling type, the typical among them being Rangoon net. A typical Rangoon net has a length of 50 m and a hung depth of 3.9 m. The hanging coefficient is 0.5 and the mesh size 50 mm bar. The net has a head rope with floats. To increase the entangling capacity there is no foot rope. 8-10 units are operated at a time. Another indigenous gear used in reservoir fishing is 'Uduvalai' also of the entangling type but with reduced height, usually operated in shallow, marginal areas. The average size of net is 40 m length and 6 meshes of 35 m bar in depth. Both head rope with floats and foot rope with sinkers are present. Simple long lines, hand lines, traps and shore seines are other common gears. Stringed and stringless cast nets are also used in shallow areas of some reservoirs.

Nayar et al. (1969) determined 53 mm bar mesh-size suitable for fishing Labeo calbasu in Gandhisagar. 50 mm bar nets have been found to be effective for Labeo diplostomus in Govindsagar and 75 mm suitable for S. silondia and Catla catla in Hirakud reservoir (Sulochanan et al., 1968). Comparative studies with the three types of nets (Simple gill nets, vertical line nets and framed nets) in the Hirakud reservoir have shown the apparent superiority of framed nets (1.4 times to 4.76 times).

POTENTIAL YIELD

A first approximation of the fish yield potential of a reservoir is of paramount importance to have an idea of the expected harvest before large scale management measures are taken up. Several methods have been proposed based on theories postulated for estimating fish production from lakes and reservoirs (Ryder, 1965; Jenkins, 1967; Gulland, 1971; Sheldon et al., 1972; Mellack, 1976; Oglesby, 1977) with specific assumptions and variables.

Ryder model - the Morphoedaphic Index (MEI)

Ryder (1965) proposed the MEI and established it to be an effective tool for predication of yield from lakes and reservoirs. The index comprises two limnological variables viz., TDS, an edaphic factor correlative of nutrient levels *and mean depth ($\bar{z}$), a morphometric factor. The relationship is expressed as :*

$MEI = TDS/\bar{z}$ and the fish yield can be calculated from the equation :

$$Y = Kx^a$$

Where Y = fish yield; x = MEI; K = a constant that represents a coefficient for climatic effects; and 'a' an exponent approximating 0.5 or the square root. The MEI has provided a useful first approximation of potential yields from lakes and reservoirs of north - temperate and African lakes. A meaningful relationship between the two has indicated that the yield from tropical African lakes is approximately ten-fold higher than that from north - temperate waters due to differences in seasonality and mean temperature.

Studies on some Indian reservoirs (Gulariya) have shown that MEI approach is not truly valid for them on account of their shallow depth and high flushing rate.(Jhingran et al., 1981).

Jenkins model

Jenkins (1967) proposed a model, describing the relationship between standing crop and MEI. He developed the equation :

$$y = 2.07 + 0.164\ x$$

where y equals standing crop and x equals log MEI.

Regier, Cordone and Ryder (1971), with some modification of Jenkins model, found a significant relationship between total catch and the MEI.

In 1971, Jenkins and Morais reported on the influence of environmental variables on reservoir harvest, drawing the equation :

$$y = 0.2775 - 0.2401\ x_1 + 1.0201\ x_2 - 0.2756\ x_3$$

where y = total harvest in kg/ha, x_1 is log area; x_2 is log growing season; and x_3 is log age of reservoir.

Gulland model

Gulland (1971) developed a simple model of the relation of potential yield to virgin ichthyomass giving the equation :

$$y = kMB$$

where y = the total fish yield, k = a constant between 0.3 and 0.5; M = the natural mortality coefficient, and B is the biomass prior to fishing.

Regier, Cordone and Ryder (1971), applying the model to the unexploited multispecies standing stocks of Lake Victoria, used a community mortality coefficient based on individual species mortality coefficient weighted on the basis of their proportionately with the total experimental catch (Bhukaswan, 1980). Ryder and Henderson (1975) used this method in obtaining estimates of potential yield of Nasser lake.

Trophodynamic model

The relationship of fish yield to primary production has been described by Henderson et al. (1973) who found that most trophic transfer efficiencies tend to be low in waters of low primary productivity and high in waters of high primary productivity. Mellack (1976) drew a regression equation describing the relationship between fish yield (FY) and gross photosynthesis (PG). The relationship for 15 Indian lakes has been found to be :

$$\log FY = 0.122\ PG + 0.95$$

Oglesby (1977) studied relationships between fish yield and summer phytoplankton standing crop in temperate lakes oligotrophic to eutrophic, large to small in area and very shallow to very deep. He expressed the equation as :

$$\log Y_1 = 1.98 + 1.7 \log CHL_s$$

where Y_1 = annual yield of fish as dry weight per square metre of lake surface, and CHL_s is summer phyto-plankton standing crop.

Dubey and Chatterjee (1977) estimated fish production of Gandhisagar reservoir from frame survey and catch per unit of effort.

Such techniques for rapid assessment of potential yield of lakes and reservoirs are very important for the development and management of freshwater fisheries in developing countries to take up fisheries development in selected reservoirs in terms of productivity levels and socio-economic priorities.

MANAGEMENT OF HABITAT

The proper management of the reservoirs located in different regions of the country needs a thorough understanding of the fish populations and the ecological conditions. The management policies for stablizing fish population fluctuations and increasing yield generally fall into three categories (Bhukaswan, 1980):

1 The manipulation of habitats

2 The regulation of fish populations and their food supply

3 The regulation and control of fisheries

To achieve the above objectives it is required to know the changed patterns of fish populations consequent to the formation of reservoir, fish population dynamics, abundance of fish species and their biomass, and maximum yield that the reservoirs can sustain.

ARTIFICIAL RECRUITMENT OR STOCKING

Stocking of reservoirs with fingerlings of economically important fast-growing species to colonize all the diverse niches of the biotope is one of the necessary prerequisites in reservoir fishery management. The primary aim of good management is to ensure utilization of the enhanced food reserves in the initial phases of the reservoir formation by large-scale stocking of the reservoir with suitable species to obtain higher productivity. Lack of such measures would lead to trash fishes present in the riverine ichthyofauna to take advantage of the available vast food resources and gain a stronghold. This would also provide opportunity to catfishes to gain dominance in the reservoir fishery.

Because large reservoirs are to be developed on the principles of capture fisheries, it is imperative that the reservoirs should be stocked with such species which breed in the habitat to make them autostocked. However, prominent annual fluctuations in the recruitment have been observed in large, multipurpose Indian reservoirs and in such ecosystems balancing of stock number against natural mortality requires stocking of excessive number of fingerlings rendering the entire exercise uneconomical. Furthermore, in large reservoirs, the stocking policy cannot often be successfully implemented on account of dearth of stocking material.

The major carps breed only in the upper reaches of the reservoirs. In Konar reservoir, high currents washed the carp eggs into the reservoir depths resulting in negligible natural recruitment. In Rihand, successful recruitment was observed only in respect of C. catla and C. mrigala in early years. Since the breeding of Indian major carps is governed by time and magnitude of monsoon floods, there are bound to be annual variations in the breeding success. This necessitates artificial recruitment of desired species.

Selection of species

When stocking, priority should be given to those species which can establish themselves in the new environment. The basic principles that should be followed in selecting a species to be stocked are (Jhingran, 1971) :

1 The planted species should find the environment suitable for maintenance, growth and reproduction.

2 It should be a quick growing form from which highest efficiency of food utilization is obtained.

3 A fishery based on high production of herbivorous fishes with shorter food chain is more productive and hence results is more economic conversion to fish flesh.

4 The number of them to be planted should be such that the food resources of the ecosystem are fully utilized and densest population maintained consistent with normal growth.

5 The size of the stock should be chosen with the expectation of getting the desired results.

6 Stock should be readily available without major shift in the cost involved in its transportation.

7 Cost of stocking and managing the species must be less than the benefits derived from stocking and management.

One of the important phases of stocking policy is to know the amount of food available per individual in the new environment. This factor has a considerable bearing on stocking rates and depends on population density hence production.

POPULATION DENSITY AND INDIVIDUAL GROWTH RATE

Fish production from a unit area is a product of individual growth rate and population density. From a number of experiments it has been shown that below the *carrying capacity, the increase in population density results in decrease in individual growth rate. The relationship between these two parameters indicates that the decrease in individual growth rate with increase in stocking rate is constant and that the rate of decrease in individual growth rate is slower than the rate of increase in population density (Vaas Van Oven, 1957). By doubling the stocking rate, the individual growth rate decreased by 40% (Marek, 1952), 41% (Merla, 1962) and 41.5 - 43.2% (Vaas Van Oven, op. cit.).*

Thus from a study of growth rate of various species in a particular body of water, it is possible to assess roughly the quantity of fish that might be involved in it. Efficient utilization of prey population 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 biology of the system.

A small population of predators helps to crop down the trash fishes which pose as competitors for food with the economic varieties of carps in Indian reservoirs. Destruction of spawning grounds and young ones of predators along with trash fishes has been suggested by manipulation of reservoir water level which may not be possible in many large Indian reservoirs. Another way of checking the population of predators in the reservoirs may be through shore seining. David and Rajagopal (1969) reported that non-selectivity of shore seines helped in reducing catfish population in Tungabhadra reservoir by 75.8 to 80.8% in the total weight of fish landed during 1965-68. Seine operation also controlled the trash fish population, especially young catfishes thus bringing down the competition for food resulting in better growth of the desirable species in Tungabhadra reservoir.

Competition

Both inter-specific and intra-specific competitions are to be considered in any stocking programme. If two or more species use similar resources e.g., food or space, overcrowding results in change of growth rate.

With high stocking rate, production may be high but the individual growth rate will be so small that to attain a marketable size a long growing period will be needed. However, if bigger fishes are needed, the rate of stocking should be lowered and a low productions will have to be accepted. 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 between 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 accordingly.

Methods of computing stocking rate

Based on studies of different waters, quite a number of stocking formulae have been proposed (Embody, 1927; Davis, 1938; Swingle and Swingle, 1967). For estimating the number of fishes to be stocked in small reservoirs, Hey (1952) proposed the following formula based on the acreage of the reservoir and its productivity :

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

Percent loss was taken by him to be 33.5% if stocking was done with fingerlings and 66.6% if with advanced fry.

For large reservoirs he estimated the natural increase (productivity) and weight of fish removed each year. He advocated that for such reservoirs the rate of stocking should be much lower and sufficient fingerlings should be added to build up an efficient breeding stock. 100 fingerlings or 200 fry were recommended by him.

Huet (1960) provided a general stocking formula :

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

For estimating the total production, he introduced the Factor B, representing the biogenic capacity or the nutritive value of the water body which may be calculated by the formula :

$K = \frac{Na}{10} \times B \times K$; where. K = annual output in kg,

Na = acreage of water body, B = biogenic capacity and k, a coefficient varying from species to species and depending upon age of fish and physico-chemical characteristics of water. The value of B, according to him, varies from 1 to 10 and those of k from 1 (in temperate zone) to 13.5 (in tropical zone).

A similar formula for computing the number of fishes/ ha to be stocked in reservoirs has been proposed by Jhingran *et al. (1959) which reads :*

$$N = \frac{S_1 - S_0}{G} + M;$$ *where N = number of fish/unit area/unit time,* S_1 = *the fish biomass/unit area at the end of the 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 = *anticipated mortality.*

Evaluation of natural mortality rate vis-a-vis stocking rate

The sizes of fingerlings that are stocked in Indian reservoirs come under the pre-recruit phase and so upto the size they enter 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 optimum stocking rates of D.V.C. 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 a higher natural mortality rate would be desirable as a little overstocking would be less harmful than understocking.

Stocking measures adopted in selected Indian reservoirs

The stocking policies hitherto adopted in Indian reservoirs mainly consisted of supplementing the natural stock of fish with some raised fingerlings of a species or a *combination of species and their release in the water body without any definite density levels or ratios founded on the biogenic capacity of the reservoir. Rate of stocking adopted in the states of Uttar Pradesh and Madhya Pradesh are 371-495 fingerlings/ha (150-200 fingerlings/acre). Fish Seed Committee recommended the stocking rate for reservoirs at 495 fingerlings/ha (200 fingerlings/acre) of the size range 40-150 mm. In other states no records of any fixed stocking rates are available. In those states too, where definite rates of stocking are prescribed, they do not appear to have been strictly followed and the stocking programmes have depended mainly on the availability of stock. Elsewhere, definite rates of stocking, if adopted, have been arrived at on the basis of such ratios recommended for ponds.*

Despite the arbitrary stocking rates followed by different states, a few Indian reservoirs have been reported to have shown higher production with repeated, regular stockings (Ramgarh lake, Rajasthan). Alikunhi (1960) has given a list of the production figures from four reservoirs in the States of Andhra Pradesh and Tamil Nadu wherein the main feature of the development of fisheries in them has been the regular, repeated stocking with quick-growing indigenous and exotic varieties.

The 259 ha Keetham reservoir in Uttar Pradesh was stocked with 10,65,616 fingerlings on an average every year. The exploitation started in 1953-54 and till 1963 the average fish production from the reservoir was estimated to be 276 kg/ha. Highest production was obtained from the reservoir in 1959-60 when production amounted to 530 kg/ha (Khare, 1954). One of the best managed Indian reservoir, the Stanley reservoir in Tamil Nadu, having an area of about 15,600 ha and a reported yield of 600 tonnes/year or 40 kg/ha (Jhingran, 1965) has been under regular repeated stocking with indigenous as well as other species which were not native to the reservoir. Most of these fishes, as a result of repeated stockings, have now established themselves (Alikunhi, 1960; Ranganathan and Natarajan, 1969).

Recommendations regarding rational stocking programmes that should be taken up in D.V.C. and Tungabhadra reservoirs in relation to their productivity have been given by Jhingran and Natarajan (1969) and David et al. (1969) respectively. While discussing the drawbacks in the stocking measures now being adopted in Tungabhadra reservoir, David et al. (op. cit.) have stated that if adequate number of late fingerlings are introduced into the reservoir in September to December months within inundated bays and inlets, they would grow quicker and probably remain within the reservoir. Stocking as being done in March-April has been advised by them to be abandoned.

GENERAL CONSIDERATIONS

Although some valuable work has been done on some of the Indian reservoirs (Sreenivasan, 1964, 1969; Jhingran and Natarajan, 1969; David et al., 1969 and Ranganathan and Natarajan, 1969) much remains to be achieved on the assessment of their fisheries in relation to stocking. Recruitment, whether it be due to successful spawning of endemic stock or due to species planted, is one of the most important parameters entering the yield equation. Work on breeding and recruitment of the stocked economic species is conspicuous by its absence on many Indian reservoirs. Biological productivity of the water depends upon the physico-chemical and biological characteristics of the ecosystem. Hence, a rational stocking programme to increase the production from Indian reservoirs from its present low level demands an understanding of the entire organism - environment complex to make it successful.

PRE-IMPOUNDMENT SURVEYS

Pre-impoundment studies have only been carried out in case of DVC reservoirs and Hirakud Dam. Data from the pre-impoundment surveys alone will form the basis of development of fisheries in reservoirs and their management. For want of such basic information on an elaborate scale, no standard techniques have so far been developed to manage the fisheries of these resources with the result that development measures in them are taken up long after impoundment. Consequently, the advantage of early enhanced productivity of the water in such man-made lakes is lost for ever. Pre-impoundment studies provide the framework for future development policies aimed at collecting information on (i) species of fish present in the river stretch above the dam site and future stocking policies, (ii) breeding of fish within the area of submergence and upstream to evaluate auto-stocking, (iii) changes in hydrobiological conditions of water in the area impounded and below, (iv) setting up of a hatchery for producing stocking material and (v) cleaning the proposed area of submergence of forest trees and other obstructions.

POST-IMPOUNDMENT MEASURES

Tripathi (1971) has listed the post-impoundment measures to be adopted for management of reservoir fisheries. They are :

1 *Stocking of mature brood fishes to build up the population of desired species, taking advantage of the initial fertility phase.*

2 Stocking of large fingerlings or yearlings (20-26 cm long) so that their survival is higher and they contribute to fishery. In many reservoirs, small fingerlings or fry are stocked which serve more as food for predators than contributing to fishery.

3 During the first five years only experimental fishing be done to assess the stock and the success of planted fish in terms of growth and survival.

4 The efficiency of gear and catch composition in different gears should be estimated.

5 Estimation of food resources of the reservoir.

TIMBER CLEARANCE

Opinion on removal of timber from reservoir basins vary. Some favour complete removal for reducing deoxygenation during initial filling and for facilitating fishing operations in the reservoir. Many suggest removal of commercial timber only and leaving the rest; while still others advocate for leaving large areas uncleared due to benefits summed up by Bhukaswan (1980) as under :

1 A substantial saving in the cost.

2 The timbered areas reduce wave action and protect dam and shoreline.

3 Dead timber and litter retards erosion when the areas are exposed during drawdowns.

4 The organic material produces carbon dioxide from decomposition which may help flocculate the colloidal clay turbidity.

5 *The timbered areas provide a different type of fish habitat than the open water areas.*

6 *The standing timber, litter and debris considerably increase the surface area for attachment of periphyton and other organisms thereby increasing the reservoir productivity.*

Selective clearance of trees upto drawdown limit has been favoured in India to facilitate operation of shore seines.

FISH PASSES

Provision of fish passes in the dams is less recognized in the tropical countries and many fishways built in the dams have failed to be effective. The fisheries of Hilsa ilisha, an anadromous fish of high economic value, has been adversely affected in many rivers on account of construction of dams, weirs, barrages. In the Godavari, hilsa could ascend up to 280 km but after the construction of Dowleiswaram anicut it is confined to the lower reaches of the river. In the Krishna and the Cauvary, hilsa could ascend up to 175 km and 160 km respectively prior to construction of anicuts at Bezwada and Lower Anicut. Hilsa known to migrate upriver in the Ganga to a distance of about 1,300-1,600 km from the sea and contribute about 300 t (30-60% of the total catch) annually at Allahabad has almost completely disappeared from the river above Farakka Barrage in the lower Ganga.

Since fish passages are expensive to build and operate, it requires close coordination between engineers, *fishery biologists and environmental scientists to design and construct effective fishways.*

PARASITES AND DISEASES

One of the factors contributing to decline in fisheries of reservoirs is parasites and diseases. These may cause fish kills directly or bring down the productivity by adversely affecting the growth rate and reproductive capacity of the individuals. The major carps are infested with Ligula sp. The infestation comes from the birds. Major carps and catfishes have been found to be with metacercaria of Isoparorchis in their muscles. A part of life cycle of this parasite is passed in a mollusc. Introduction of fish like Pangasius pangasius in such reservoirs which feed on molluscs may help in the biological control of this infection. Little is known about the parasitofauna of fish in reservoirs and about their control in large bodies of water. A checking of fish fingerlings before they are introduced in the reservoir may be one step towards the control of parasites in reservoirs.

POLLUTION

A number of industries come up where hydel power generation is done and discharge their effluents in the reservoir causing heavy fish mortality. In Rihand reservoir, the effluents of Kanoria chemicals, chiefly manufacturing caustic soda, cause heavy fish mortality and impairment of biotic communities. The effluents contain high content of chlorine, chlorides and heavy metal. Mercury pollution has been noticed due to its use in the electrolysis of caustic soda. Acid wastes containing zinc from

South India Viscose Ltd. on Bhavani river above the reservoir have adversely affected the primary productivity. Confluence of Sindri nulla in Panchet reservoir (Bihar) is polluted by the effluents from the Sindri Fertilizer factory affecting fish spawn. Dal lake in Kashmir is severely polluted by sewage.

Reservoir waters, in general, are low to moderately hard because of low buffering capacity and are more susceptible to pollution from heavy metals, pesticides and other pollutants.

Treatment of wastes should form part of industrial planning. Very little is known about mercury pollution status in India. Such studies are needed.

FISHING EFFORT

Increase in fishing effort has improved fish yield from many Indian reservoirs.

Though the methods of fishing have undergone considerable changes in recent years, they need effective improvement if the potential resources are to be fully exploited. The possibility of introducing active gears in the ideal locations of the reservoir needs active consideration.

The knowledge required to develop reservoir fishery resources to their maximum potential can be broadly categorised into the following :

1 Actual and potential yield of commercial fishes.

2 Influences of water level fluctuations on fish production.

3 Effects of environmental changes by age of reservoir.

4 Influence of various degrees and types of exploitation on the fish population, and

5 Socio-economic aspects.

FISH POPULATION DYNAMICS

Total catch and effort must be followed to evaluate the effects of exploitation. Growth, density, mortality and recruitment of most abundant species must be known.

Most of the reservoirs in India have been observed to suffer from varying degrees of under-exploitation and remunerative experience on yield improvement has been gathered by increasing the effort. In Govindsagar reservoir, increase in effort along with increase in mesh size during 1975-1979 brought a spectacular change when the catch improved from 273 t in 1975 to 753 t in 1978.

CONSERVATION MEASURES

Since large multi-purpose reservoirs are to be managed on capture fishery principles, the fishery regulations and controls are to be exercised to ensure sustainable yields from them. According to Nikolskii (1969), fishing is liable to change the growth rate, population structure and reproductive capacity of the population. Some measures are, therefore, to be taken to control the fishing activity for optimum utilization of the resources and for economic returns to the fishermen. The well-known conservation measures are :

1 Closed areas and closed seasons prescribing time of the year when fish exploitation should be suspended.

2 Regulation of minimum size limit of fish caught, based on biological studies, through regulation of mesh size of the gear.

3 Fixation of annual catch quota of economic varieties based on information on population abundance, growth, recruitment and mortality rates.

4 Prohibition of all destructive fishing practices like dynamiting, poisoning, etc.

5 Diversion of release of pollutants in and above the reservoir or rendering the toxicants inoccuous before their release.

II SMALL RESERVOIRS

INTRODUCTION

The dependence of Indian agriculture on the south-west monsoon and its consequent vulnerability have necessitated maximum utilization of country's surface and ground water resources estimated at 66.5 and 27.5 million ha respectively. A large number of tanks and small reservoirs have been constructed; besides the large multipurpose dams, wells, inundation and diversion canals, to raise the gross irrigated area. In contrast to large multipurpose reservoirs, the small irrigation reservoirs, constructed on small intermittent water courses, serve to capture the surface runoff for its abstraction during seasonal irrigation demands. Experience has revealed that these water bodies offer immense potential for fish husbandry through extensive aquaculture technique. It seems indubitable that they would contribute significantly to country's inland fish production, if managed scientifically.

SMALL RESERVOIRS vis-a-vis LARGE RESERVOIRS

The broad distinguishing features of small and large reservoirs may be summarised as under :

	Small reservoirs	Large reservoirs
1	Single-purpose reservoirs mostly for minor irrigation.	Multipurpose reservoirs for flood-control, hydro-electric generation, large-scale irrigation, etc.
2	Dams neither elaborate nor very expensive. Built of earth, stone, masonary work on small seasonal streams.	Dams elaborate, built with precise engineering skill on perennial or long seasonal rivers. Built of cement, concrete or stone.
3	Shallower, biologically more productive per unit area. Water-weeds commonly observed in perennial reservoirs but absent or scanty in seasonal ones.	Deep, biologically less productive per unit area. Usually free of aquatic weeds. Subjected to heavy drawdowns.

4	*May dry up completely in summer. Notable changes in the water regimen.*	*Do not dry up completely. Changes in water regimen not so pronounced. Maintaining a conservation-pool level.*
5	*Sheltered areas absent.*	*Sheltered areas by way of embayments, coves, etc. present.*
6	*Shore line not very irregular. Littoral areas mostly gradually sloping.*	*Shore line more irregular. Littoral areas mostly steep.*
7	*Oxygen mostly derived from photosynthesis in these shallow, non-stratified reservoirs lacking significant wave action.*	*Although photosynthesis is a source of D.O. the process is confined to a certain region delimited by vertical range of transmission of light (euphotic zone). O_2 also derived from significant wave action.*
8	*Provided with concrete or stone spillway, the type and size of its structure depending on the runoff water handled.*	*Provided with much more complex engineering devices.*
9	*Breeding of major carps invariably observed in the reservoir above the spillway.*	*Breeding mostly observed in the head waters or in other suitable areas of the reservoir.*

10	Can be subjected to experimental manipulations for testing various ecosystem responses to environmental modifications.	Cannot be subjected to experimental manipulations.
11	Trophic depression phase can be avoided through chemical treatment and draining and cycle of fish production can be repeated as often as the reservoir is drained.	Trophic depression phase sets in.
12	The annual flooding of such reservoirs during rainy season may be compared to overflowing flood-plains. Inundation of dry land results in a release of more 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 growth and survival.	Loss of nutrients occurs which get locked up in bottom sediment. Reduction in benthos also occurs due to rapid sedimentation.

13 Through complete fishing or overfishing in such seasonal reservoirs, no brood stock is left over to contribute to succeeding year's fishery through natural recruitment. The fish population has to be built up solely through regular stocking. There is thus established a direct relationship between stocking rate and catch per unit of effort.

In contrast, prominent annual fluctuations in recruitment occur and balancing of stock number against natural mortality requires excessive number of fingerlings in such large reservoirs. Their capture requires effective exploitation techniques.

AQUACULTURE TECHNIQUE

Aquaculture practices employed in small reservoirs may be defined as 'extensive' where cultured fingerlings are raised in water bodies with few or no modification of the environment. This is in contrast to the 'intensive' culture practised in ponds, raceways, etc. where complete control of aquatic and biotic components is exercised. The capture and culture fishery principles grade into each other in such ecosystems where the capture of fishes depends on such stocked cultured fingerlings which have been caught as fry from the wild environment.

Past and present approach

Fish culture in the existing small reservoirs, hitherto being practised by the State Governments, consists of supplementing the natural stocks of economic fishes with some raised fingerlings and their release into the water body on an arbitrary basis without any definite levels or ratios founded on the biogenic capacity of the ecosystem. In those cases too, where definite stocking rates are prescribed, they do not appear to have been followed strictly, depend as they do on the availability of stocking material. Despite the arbitrary stocking rates followed, a few Indian reservoirs have been reported to have shown high yield rates with repeated regular stocking. A case in point is the Keetham Reservoir in Uttar Pradesh (259 ha) which gave a yield of 530 kg/ha in 1959-60. However, the same reservoir is on record to have turned into a stronghold of weed fishes (mainly Gudusia chapra) for non-adoption of a rational stocking policy and lack of understanding of the environmental organism complex of the ecosystem. This emphasises the need to direct the present approach towards fish culture in such ecosystems based on an understanding of the environmental and biological parameters, basic productivity levels and ecological relationships.

Stocking policy

Stocking of fish into small reservoirs and lakes has proved to be a useful tool for developing fisheries potential of such small aquatic systems. Planting of economically important, fast-growing fish from outside is aimed at colonizing all the diverse niches of the biotope for harvesting *maximum sustainable crop from them. This widespread management practice has been shown to be highly remunerative in such small water bodies where almost complete annual harvesting is possible. However, stocking is not merely a simple matter of introduction of appropriate species into an ecosystem but needs evaluation of an array of faction viz., the biogenic capacity of the environment, the growth rate of the desired species and the population density as regulated by predatory and competitive pressures.*

During summer months, small reservoirs either dry up completely or else the water level in them gets so drastically reduced that through overfishing no brood stock is left over to contribute to the succeeding years' fishery through natural recruitment. Consequently, the entire catch from these water bodies depends on the fishes planted from outside to compensate for this loss. There is thus established a direct correlation between the stocking rate and catch per unit of effort in such heavily fished waters. Stocking is, therefore, a useful tool for the management of small reservoirs where stocks can even be maintained at levels higher than the natural carrying capacity of the environment through supplemental fertilization. The number of fish to be stocked per unit area has to be based on the natural productivity of the system, growth rate of fishes, natural mortality rate and escapement through the irrigation canal and spillway.

Formulation of stocking policy

A number of methods are in vogue for assessing the potential yield from lakes and reservoirs and the same have *been described earlier. One approach towards formulation of stocking policy is to assess the potential of the reservoir by any of the described methods, most suitable to the system, and adjustment of stocking rate accordingly to approach the potential yield.*

According to Ryder et al. (1974), MEI value of 50 represented a standing crop of 200 kg/ha for a temperate reservoir which could yield 55 kg/ha when exposed to an intensive fishery (assuming a yield of 0.4 X mortality X biomass). The Keetham reservoir has given a MEI value of 57 and a yield of 90 kg/ha. The highly productive tropical lakes of Africa (Lake George and Lake Kyoga), having MEI values ranging from 40-100, have given yields of over 100 kg/ha.

However, the MEI approach was not found to be truly valid for Gulariya, being shallow and having relatively lower volume and high flushing rate. On account of this and based on Ryder's concept, this reservoir would be placed in the 'Lotic' category where production at the primary level is dependent on the allochthonus detritus and sessile algae and contribution of indigenous primary production is small (Hynes, 1970). Therefore, the efficiency of MEI in such systems is proportionately reduced to the increase of the ratio of lotic to lentic characteristic of the reservoir. Furthermore, the decrease in MEI efficiency is created by the depth parameter which becomes unimportant in such cases as an expression of 'nutrient sink effect' (Ryder et al., 1974) in such ecosystems with lesser volume and high flushing rate.

Considering the above, the performance of Keetham and other Indian reservoirs, and using the thermodynamic and energy-flow approach, a production of 234 kg/ha should come from the reservoir. However, in the first year of investigations, ichthyomass of 200 kg/ha was presumed and considering that 80% of it (160 kg/ha) would be harvestable in view of the drastically diminished water level, the stocking rate was computed from the following formula (Huet, 1960) :

$$\text{Stocking rate} = \frac{\text{Gross or total production in kg}}{\text{Individual growth rate in kg}} + \text{Loss}$$

Thus, expecting a yield of 160 kg/ha and an average annual growth of 500 g for the species to be stocked as revealed by tagging experiments (Jhingran et al., 1981), the stocking rate was computed as under giving an allowance of 50% for natural mortality and escapement of fingerlings through irrigation canal.

$$\text{Stocking rate} = \frac{160}{0.5} + 50\%$$

$$= 320 + 160 = 480 \text{ or } 500 \text{ fingerlings/ha}$$

Total fingerlings required = 75,000

RESULTS

During 1976-77, the total fish yield from the reservoir amounted to 5 t. In 1977-78, 45,199 major carp fingerlings were stocked in the reservoir and a fish-yield of only 0.59 t was obtained. One of the reasons for this frustratingly low yield was that the reservoir was transferred by the Uttar Pradesh Government to Central Inland Fisheries Research

Institute (CIFRI) in April and on account of sudden heavy downpour, the reservoir attained full level leading to suspension of fishing which could be carried out only for 17 days. The catch/unit of effort during the season was estimated at 0.06 kg. In 1977-78, 75,801 fingerlings were stocked and in 1978-79, a record fish yield of 15.15 t was obtained, the catch/unit of effort being 12.5 kg. Observations on previous yield records with the State Government indicated that the total yield from 1971-72 to 1976-77 ranged from 0.076 to 8 t (53 kg/ha). It was, therefore, considered a significant achievement for the yield to increase three-fold from 5 t to 15 t (100 kg/ha) as compared to the preceding year (1976-77) and two-folds as compared to 1973-74. This has indubitably projected the remunerative impact of stocking appropriate species in such aquatic systems. During commercial fishing of 1978-79, it was observed that the reservoir could yield about 7 t of fish more in addition to 15 t already harvested. This showed the possibility of taking the total yield to 22 tonnes (150 kg/ha) in that year. However, on account of the drastically reduced water level owing to sudden release of water through the irrigation canal, the fishing operation increased the turbidity immensely due to constant agitation in the water body and the undersized, stocked fishes began to show distress due to choking of their gills. The fishing, therefore, had to be suspended for the season.

Based on the Gulariya experience and the past experience from another small impoundment, the Loni reservoir, it has been established that stocking is one of the most significant developmental measure for maximizing fish production from such aquatic systems. Future approach towards the fisheries development in such ecosystems should be directed towards assessment of their fisheries potential and formulation of stocking policy based on the framework of ecological parameters obtaining in the environment.

The values of some important physico-chemical parameters and the numerical abundance of planktonic, macrobenthic and macrovegetation communities in some small reservoirs are given in Table II.

PLANNING CRITERIA

A systematic and integrated approach towards scientific studies and planning criteria for undertaking fish culture in small reservoirs should be so directed as to have an understanding of the following factors :

1. The reservoir morphometry and water residence time.
2. The physico-chemical characteristics of water and soil.
3. The animal and plant inhabitants.
4. The relation between the inhabitants and the physico-chemical aspects of the environment in terms of population and community dynamics.

Depth, mean depth, length, breadth, area, volume, extent and development of shore line, water level and elevation above M.S.L. are basic to limnological studies. Values of certain important chemical parameters of reservoir water (Ca $>$ 25 ppm; total alkalinity $>$ 40 ppm; total hardness $>$ 25 ppm and specific conductivity $>$ 200 micromhos suggest high biological productivity) also indicate whether the reservoir productivity is poor, medium or high.

It is felt that under the prevailing socio-economic conditions, such short-range studies undertaken for small reservoirs would provide rapid assessment of their fisheries potential to take up fish culture in them.

In keeping with the need for rapid assessment of the country's small reservoir resources, the following planning criteria are suggested for the resource assessment:

1 Preparation of an inventory of such small ecosystems along with the estimates of their potential yields. This can be further divided into :

a) Reservoirs which are best developed as capture fisheries.

b) Reservoirs mostly of local interest having significant potential for fish culture.

c) Reservoirs intermediate in size and potential yield.

The reservoirs may then be substratified in terms of priority, based on their basic productivity levels, geographical location, market vicinity and demand, etc.

GENERAL CONSIDERATIONS

Since the breeding of major carps has been repeatedly observed to take place above the spillway, resulting in heavy escapement of the brood, this poses a serious problem for building up stocks of desirable fishes in such reservoirs. The situation is further worsened by heavy escapement of *fingerlings and adults through irrigation canals. Development of fisheries in such water bodies, therefore, requires suitable screening of the spillway and the canal mouth. Such protective measures have already been installed in the Loni reservoir based on the recommendations of the Central Inland Fisheries Research Institute and have paid dividends in enhancing the fish yield from the reservoir. However, caution is to be exercised to see that the screens across spillway do not get clogged during flood season which may threaten to washout the dam. In some of the reservoirs (Loni) fishes have also been observed to move up the spillway into the reservoir whereas in others the spillway provides an insurmountable barrier to fish moving up the dam. To minimize losses by way of escapement of fish through spillway and canal, it would be an economic proposition to have an annual cropping policy so that the reservoir is stocked in September-October and harvested by June-end. However, this depends on the growth of fish and general productivity of the water body.*

Vegetation must never be planted in the reservoir since the wrong kinds can choke up the reservoir and the canal completely. Methods of predator control and check of weed fishes are already available in literature and can be easily applied to perennial small reservoirs.

Aquaculture in small reservoirs can also play an important role in integrated rural development since it can be profitably combined with poultry, duckery and piggery. The exposed areas of the reservoir can be auctioned to be utilized for agricultural farming of leguminous crops which would also add to the productivity of the soil. Such schemes promise to increase fish production and rural earning making a significant contribution to the nutritional requirements of the rural community.

Summing up, it may be added that small reservoirs occupy a unique position in limnology analogous to field plots used in agricultural science i.e., a means of assessing effects of environmental modifications on the ecosystem on a reduced scale.

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Table I : Abiotic and biotic factors affecting productivity of reservoir at various trophic levels

(Modified from Ryder, 1975, Bhukeswan, 1980, Jhingran, 1981)

	Positive/augmentative factors	Major effects unknown	Negative/Reductive factors
	1	2	3
1.	High shoreline development (coves, bays etc.)	Sedimentation of inorganic materials.	Low transparency in floods due to inorganic turbidity.
2.	Low mean depth (less than 18 m)	High rate of evaporation.	High mean depth.
3.	Existence and extent of marginal vegetation.	Contributions of autochthonous nutrients.	Erosion in the reservoir water shed area.
4.	Optimum nutrient levels	High surface temperature during summers (In North India)	Reduction of quantity of water flowing into reservoir.
5.	Nutrient enrichment during floods.	Low water temperature during winter (In North India)	Large water level fluctuations creating large aridal (barren littoral).
6.	Moderate to long growing season.	Community interrelationship.	Low level of dissolved oxygen in parts of hypolimnion.
7.	High frequency of phytoplankton blooms.		Pollutions in the reservoir water shed areas.
8.	Moderate macrophytes		Phytoplankton biomass mainly blue greens.
9.	Periphyton density increasing markedly.		Relative low fish species diversely indicating low stability and a potentially low resilience to stresses.

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1	2	3
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, Aorichthys seenghala due to severe drawdowns.

Table II : Values of some important physico-chemical parameters and the numerical abundance of planktonic, macrobenthic and macro-vegetation communities in some small reservoirs

Parameters	Loni	Govindgarh	Kulgarhi	Gulariya
Transparency (cm)	58.0-69.8	55.8-102.1	9.4-116.9	11.0-80.0
pH	7.5-8.1	8.0-8.2	8.0-8.2	7.2-8.4
D.O. (ppm)	6.7-7.5	6.2-12.1	6.2-11.5	4.9-9.0
Free CO (ppm)	nil -1.69	1.48-3.65	2.14-5.25	nil-4.0
Total alkalinity (ppm)	85-162	26-54	38-130	38-80
Hardness (ppm)	27-101	15-39	30-73	13-34
Phosphates (ppm)	0.11-0.165	Trace-0.058	Trace-0.082	0.05-0.13
Nitrates (ppm)	0.13-0.24	Trace-0.130	Trace-0.047	0.08-0.20
Silicates (ppm)	8-15	Trace-13	2.5-13.2	5.0-14.0
Plankton (u/1)	490-1034	93-1908	32-860	245-4060
Macrobenthos (u/m^2)	6054 (average)	387-1610	29-457	95-4769
Macrovegetation (g/m^2)	44 (average)	Absent	Absent	Absent