GUIDELINES FOR SMALL RESERVOIR FISHERIES MANAGEMENT IN INDIA

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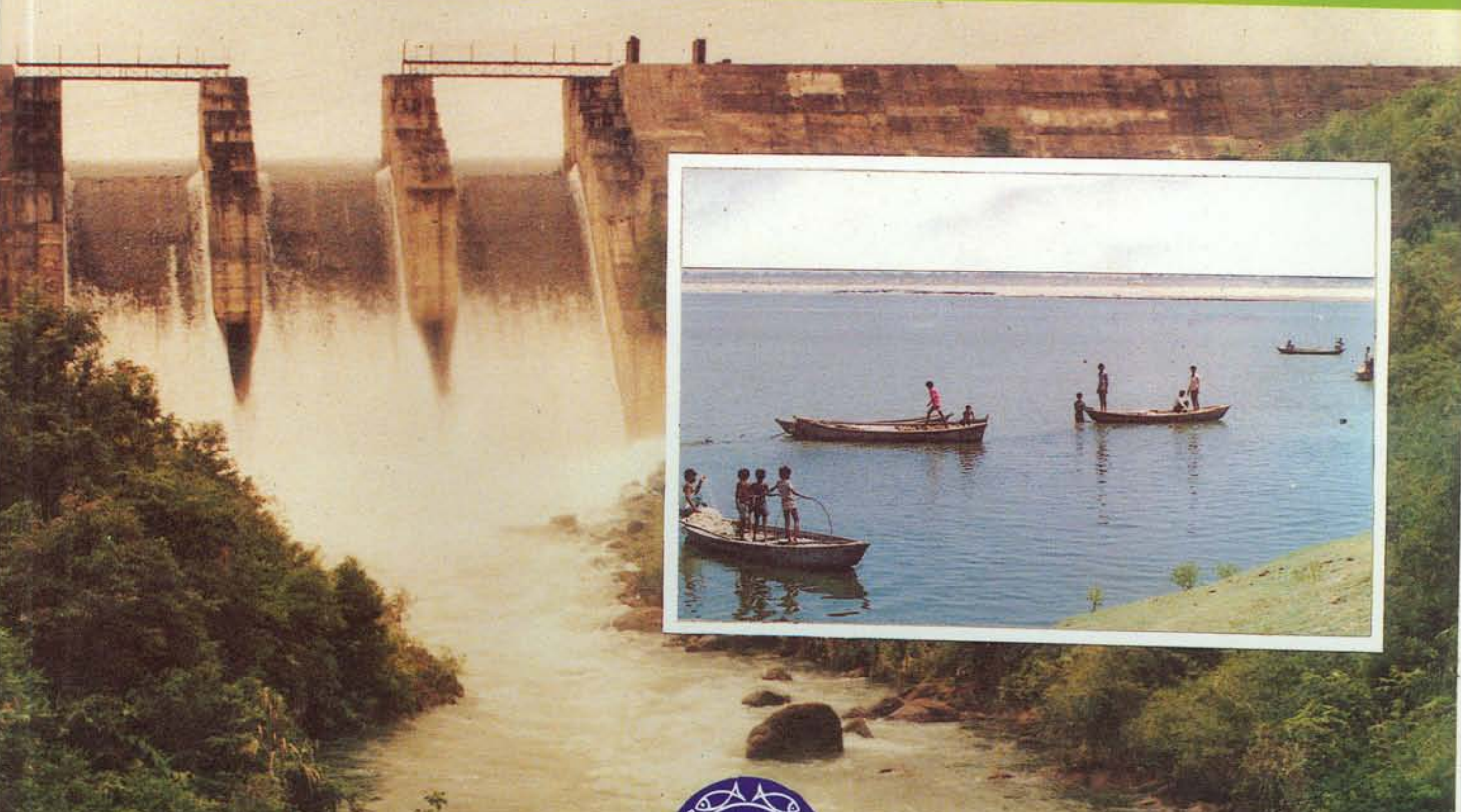

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Small Reservoir Fisheries Management

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Preface

Reservoirs constitute the prime inland fishery resource of India by virtue of their vast area and huge production potential. Apart from allowing quick yield enhancement at minimal capital investment and environmental cost, fisheries development of reservoirs directly benefits some of the weakest sections of our society. The benefits accrued due to increase in yield and income generation directly contribute to improve the quality of life of fishermen. Unlike the culture systems, where the profit is accrued to a single investor or a small group of investors, in reservoir fisheries, the cake of increased yield is more equitably distributed among a large number of people, albeit as smaller slices. This, being a community- based development process, has a direct bearing on our rural populace.

Reservoirs exhibit wide variations in their morphometric limno-chemical and biological characteristics making it difficult to develop a technology package that can be adopted uniformly in the country. Nevertheless, the researches conducted by CIFRI over the last few decades have resulted in many guidelines, based on which the reservoir fishery managers can develop location-specific management norms. Such guidelines are more effective in case of small reservoirs where the relation between management and yield improvement is known to be more precise compared to the large impoundments.

This Bulletin is an outcome of our endeavour to provide normative guidelines for management of aquatic resources of the country. Since the reservoirs in India are public water bodies, targeted users of these guidelines are mainly the fishery officers of state governments and office bearers of cooperative societies across the country.

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INTRODUCTION

The small reservoirs are a common feature of the rural landscape of India. Constructed on small intermittent watercourses, these impoundments serve to capture the surface run off for its abstraction during seasonal irrigation demands. Although built for the primary purposes of irrigation and soil conservation, they offer immense scope for various other kinds of enhancements leading to higher productivity and income generation for the local communities. They can undoubtedly contribute significantly to inland fish production, if managed on scientific lines. In India, the small reservoirs, which spread over nearly 1.5 million ha, form one of the most important inland fisheries resources on account of the large resource size and the huge untapped production potential. They have the advantage of enabling quick enhancement of yield due to their small size and easy maneuverability of fish stocks. The available technologies offer possibilities for achieving fish yields of 100-200 kg ha^{-1}, though the present national yield is about 50 kg ha^{-1}. By virtue of their unmistakable role in promoting fisheries development through mass participation of local communities, the small reservoirs assume special significance.

RESOURCE SIZE

The small irrigation impoundments are as nondescript as they are ubiquitous making the attempts to compile their inventory a very difficult task. The atomistic nature of the water bodies makes the task of assessing their fisheries potential more tedious than the resource assessment of other sectors where the units are situated at more identifiable locations. The problem is further compounded by ambiguities in the nomenclature adapted by some of the states. The word *tank* is often loosely defined and used in common parlance to describe some of the small irrigation reservoirs. Thus, a large number of small man-made lakes are designated as tanks, thereby precluding them from the estimates of reservoirs. There is no standard definition for a tank. In the eastern states of Orissa and West Bengal, *pond* and *tank* are interchangeable expressions, while in Andhra Pradesh, Karnataka and Tamil Nadu, tanks include a section of small irrigation reservoirs along with some large sized ponds.

Tanks and reservoirs

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

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

In Tamil Nadu, the tanks are classified as *short seasonal* and *long seasonal*. The latter, also known as major irrigation tanks, have an average size of 34 ha and retain water for 9 to 12 months a year. Major irrigation tanks of Chengalpattu MGR and Salem districts are larger with average area of 222 and 156 ha respectively. A total of 8,837 major irrigation tanks of Tamil Nadu with water surface area of 300,278 ha can be included under small reservoirs. Similarly, 4,605 perennial large water bodies in Karnataka, listed as major irrigation tanks could easily be brought under the ambit of reservoirs. After removing the anomalies in nomenclature, especially with regard to the small reservoirs, by bringing the large (above 10 ha) irrigation tanks under the fold of reservoirs, India has over 19,134 small reservoirs with a total water surface area of 14,85,557 ha (Table 1, Fig. 1). The State of Tamil Nadu accounts for maximum number (8,895 units) and area (3,15,941 ha) of small reservoirs, followed by Karnataka (4,651 units and 2,28,657 ha) and Andhra Pradesh (2,898 units and 2,01,927 ha).

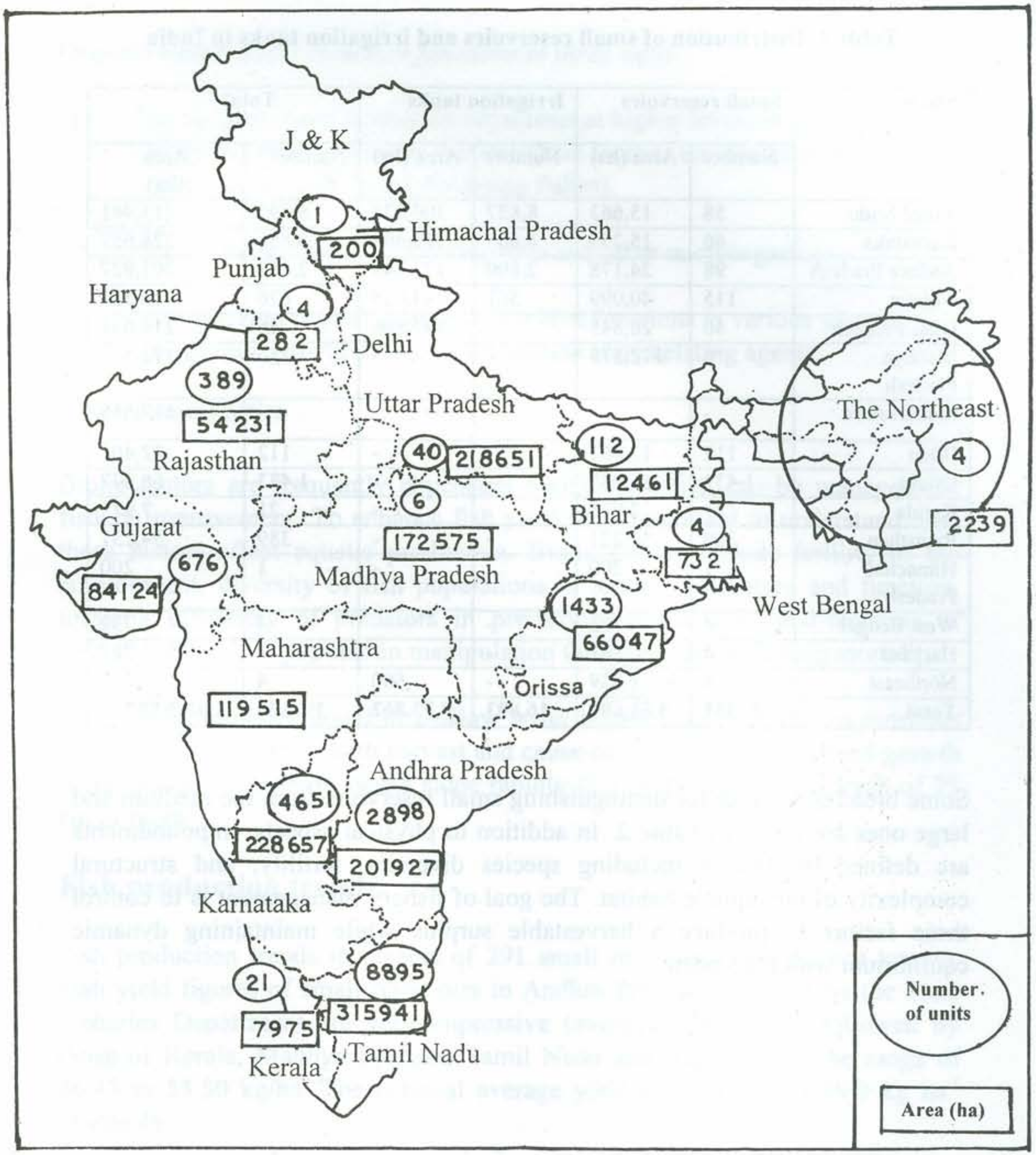

Fig. 1. Distribution of small reservoirs in India

Table 1. Distribution of small reservoirs and irrigation tanks in India

States	Small reservoirs		Irrigation tanks		Total	
	Number	Area (ha)	Number	Area (ha)	Number	Area (ha)
Tamil Nadu	58	15,663	8,837	300,278	8,895	315,941
Karnataka	46	15,253	4,605	213,404	4,651	228,657
Andhra Pradesh	98	24,178	2,800	177,749	2,898	201,927
Gujarat	115	40,099	561	44,025	676	84,124
Uttar Pradesh	40	20,845	-	197,806	40	218,651
Madhya Pradesh	*6	172,575	-	-	*6	172,575
Maharashtra	-	-	-	-	-	119,515
Bihar	112	12,461	-	-	112	12,461
Orissa	1 433	66,047	-	-	1,433	66,047
Kerala	21	7,975	-	-	21	7,975
Rajasthan	389	54,231	-	-	389	54,231
Himachal Pradesh	1	200	-	-	1	200
West Bengal	4	732	-	-	4	732
Haryana	4	282	-	-	4	282
Northeast	4	1,639	-	600	4	2,239
Total	**2 ,331**	**5,51,695**	**16,803**	**9,33,862**	**19, 134**	**1,48,5,557**

Some broad guidelines for distinguishing small reservoirs from the medium and large ones are given in Table 2. In addition to physical aspects, impoundments are defined by factors including species diversity, fertility, and structural complexity of the aquatic habitat. The goal of fishery management is to control these factors to produce a harvestable surplus while maintaining dynamic equilibrium with the system.

Table 2. The broad distinguishing features of small and large reservoirs

Small reservoirs	Large and medium reservoir
Single purpose reservoirs mostly for minor irrigation	Multi-purpose reservoirs for flood control, hydro-electric generation, large-scale irrigation, *etc.*
Dams neither elaborate nor very expensive. Built of earth, stone and masonry work on small seasonal streams.	Dams elaborate, built with precise engineering skill on perennial or long seasonal rivers. Built of cement, concrete or stone.
Shallow, biologically more productive per unit area. Aquatic plants common in perennial reservoirs, but scanty in seasonal ones.	Deep, biologically less productive per unit area. Usually free of aquatic plants. Subject to heavy drawdowns.
May dry up completely in summer. Notable changes in the water regime.	Do not dry up completely. Changes in water regime slow. Maintain a conservation-pool level (= dead storage).
Sheltered areas absent.	Sheltered areas by way of embayments., coves, *etc.* present.
Shoreline not very irregular. Littoral areas with a gentle slope	Shoreline more irregular. Littoral areas mostly steep.
Oxygen mostly derived from photosynthesis in the shallow, stratified reservoirs, lacking significant wave action.	Although photosynthesis is a source of dissolved oxygen, the process is non-confined to a certain region delimited by vertical range of transmission of light (euphotic zone) . Oxygen also derived from significant wave action.
Provided with concrete or stone spillway, the type and size of the structure depending on the size of the runoff.	Provided with more complex engineering devices.
Breeding of major carps not commonly observed.	Breeding mostly observed in the headwaters or in other suitable areas of the reservoir.
Can be subjected to experimental manipulations for testing various ecosystem responses to environmental modifications	Cannot be subjected to experimental manipulations.
Trophic depression phase can be avoided through chemical treatment and draining. Cycle of fish production can be repeated as often as the reservoir is drained.	Trophic depression phase sets in .

Table 2. Contd........	
Small reservoirs	**Large and medium reservoir**
The annual flooding during rainy season may be compared to overflowing of floodplains. Inundation of dry land results in release of nutrients into the reservoirs when it fills up, resulting in high production of fish food through decomposition of organic matter, predominantly of plant origin, leading to higher fish growth and survival.	Loss of nutrients occurs as they are locked up in bottom sediments. Rapid sedimentation will reduce benthos production.
No brood stock is left due to complete fishing or over-fishing of seasonal reservoirs. Fish stock has to be rebuilt through stocking. There is thus established a direct relationship between stocking rate and catch per unit of effort.	Prominent annual fluctuations in recruitment occur and balancing of stock number against natural mortality requires high density stocking of fingerlings. Fishing requires efficient capture methods.

ECOLOGY AND PRODUCTION PROCESSES

Determinants of Productivity

The objective of fishery management in small reservoirs is to regulate fish production to achieve sustained yields of fish of marketable size. The fish yield in small reservoirs is partly a function of abiotic and biotic factors influencing the productivity of the aquatic system. The degree of management that can be imposed upon these factors determines the intensity of operations.

Abiotic habitat variables

Abiotic factors are independent variables over which the fishery manager has little or no control. They relate to the geographical location and microclimate of the impoundment. Included are temperature as a function of elevation and latitude, precipitation, and water and soil chemistry.

Biological productivity of a biotope is influenced by climatic, edaphić and morphometric features. The geographic location affects the metabolism of a reservoir through nutrition supply, shape of the 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. 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 equally 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 shoreline are the most significant morphometric measurements having a significant bearing on the productivity of a reservoir.

Temperature is one of the most important factors affecting fish growth. Growth increases with increasing temperature to a maximum and then declines rapidly. Within limits, metabolism and food requirements increase with increasing temperature. For every 10° C increase in water temperature, metabolic rate doubles and oxygen demand increases. Concurrently, as temperature increases, the oxygen carrying capacity of water decreases, making less oxygen available for increased metabolic activity.

The chemical composition of water varies considerably among regions. Several indices are used as indicators of water chemistry. The complete array of ions in a water sample is measured as total dissolved solids. In impoundments, alkalinity and pH are linked through photosynthesis. These parameters affect the amount of carbon dioxide available for photosynthesis and subsequent fish production. Relative concentrations of dissolved carbon dioxide, carbonate, and bicarbonate depend on pH. The pH fluctuates during the day as photosynthesis increases with increasing sunlight. Another important water quality variable is dissolved oxygen. Oxygen dissolved in water is used for respiration by fish and other aquatic organisms. The quantity of oxygen that can dissolve in water is a function of temperature and elevation. Oxygen is more soluble at lower temperatures and elevations. Tolerance to low levels of dissolved oxygen is species dependent. However, many fish exhibit slow growth when oxygen levels fall below 5 mg l^{-1} for extended periods.

The chemical properties of water in reservoirs are a reflection of the properties of bottom soil. When oxygen supply falls short in mud layers that are not well aerated, the decomposition of organic matter becomes slow. This, along with the presence of partially oxidized compounds and short chain fatty acids, make the soil strongly acidic. The bacterial action is reduced and productivity lowered. pH also influences transformation of soluble phosphates and controls the absorption and release of essential nutrients at soil water interface. 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 value (mg 100 g^{-1} of soil) of less than 3 are poor, 3-6 average and above 6 are highly productive. Available N below 25 (mg N 100 g^{-1} of soil) gives poor production, the same in the range 25-60 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. Range of physico-chemical parameters and their significance in productivity are shown in Table 3.

Table 3. Physico-chemical features of Indian reservoirs (range of values)

Parameters	Overall range	Productivity		
		Low	Medium	High
A. Water				
pH	6.5-9.2	<6.0	6.0-8.5	>8.5
Alkalinity (mg/l)	40-240	<40.0	40-90	>90.0
Nitrates (mg/l)	tr.-0.93	Negligible	up to 0.2	0.2-0.5
Phosphates (mg/l)	Tr.-0.36	Negligible	up to 0.1	0.1-0.2
Conductivity (μ mhos)	76-474		up to 200	>200
Temperature (°C)	12.0-31.0	18	18.22	>22
B. Soil				
pH	6.0-8.8	<6.5	6.5-7.5	>7.5
Available P (mg/100 g)	0.47-6.2	<3.0	3.0-6.0	>6.0
Available N (mg/100 g)	13.0-65.0	<25.0	25-60	>60.0
Organic carbon (%)	0.6-3.2	<0.5	0.5-1.5	1.5-2.5

(After Jhingran and Sugunan, 1990)

Organic matter in reservoir ecosystem comes from both within (autochthonous) and outside (allochthonous) sources. Primary production by the photosynthetic phytoplankton, the base of food chain, is the major autochthonous source of organic production. The allochthonous nutrients that come along with runoff from the watershed and inflow are more significant both qualitatively and quantitatively.

Organic matter in the reservoir functions in three ways.

(1) As an actual food source for organisms at 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 growth of bacteria and other microorganisms.

(3) As dissolved organic compounds which functions in various ways as exogenous growth substances, vitamins and chelating agents.

Biotic communities

Biotic factors are frequently dependent variables, which can be managed for fishery improvement. To enhance fish yield, it is important to understand how these factors affect aquatic production. Biotic factors include fertility of the environment, diversity of fish populations in terms of structure and function, foraging efficiency of predators in predator/prey systems, modifications of aquatic habitat, and population manipulation through planned fishing mortality.

Aquatic macrophytes found in shallow water bodies also compete for nutrients with plankton, interfere with harvest and cause oxygen depletions. Weed growth is minimized if reservoir banks slope rapidly (2:1 or 3:1 ratio) to a depth of 75 cm or more.

Fish production trends

Fish production trends in respect of 291 small reservoirs in India are known. Fish yield figures of small reservoirs in Andhra Pradesh, as given by the State Fisheries Department are very impressive (average 188 kg/ha), followed by those of Kerala, Madhya Pradesh, Tamil Nadu and Rajasthan in the range of 46.43 to 53.50 kg/ha. The national average yield is estimated at 49.9 kg ha^{-1} (Table 4).

Table 4. **Fish production trends in small reservoirs in India**

State	Number	Production (t)	Average yield (kg/ha)
Tamil Nadu	52	760	48.50
Uttar Pradesh	31	168	14.60
Andhra Pradesh	37	2,224	188.00
Maharashtra	6	72	21.09
Rajasthan	78	970	46.43
Kerala	7	118	53.50
Bihar	25	22	3.91
Madhya Pradesh	2	24	47.26
Himachal Pradesh	-	-	-
Orissa	53	349	25.85
Average			***49.90***

FISHERIES MANAGEMENT

Management systems

There are marked variations in the fishery management practices followed in various reservoirs within the country. Even though the reservoirs are owned by the Government or corporate agencies in most of the states, their fishing right and exploitation system vary considerably. The fishing systems are distinguishable into the following broad categories :

a) Privately owned and managed reservoirs
b) Public water bodies
c) Community water bodies
d) Water bodies managed by the Government.

After a scrutiny of the various management practices followed in the country, it is difficult to miss a common underlying spirit of the common property norm. Majority of Indian reservoirs are public properties wherefrom a fixed number of licensed fishers make their living. The exceptions are the small reservoirs in some states like Karnataka and Uttar Pradesh, which are auctioned to private individuals on an annual basis.

Technological support in the form of management practices either received low priority or it has been overlooked altogether as far as small reservoir fisheries in India is concerned. This resulted in arbitrary stocking and non-adherence to sound stock management norms leading to low productivity. Fish yield of small reservoirs, where the management is on the basis of culture-based fisheries is dependent on a number of parameters, such as growth rate, natural mortality and fishing mortality. Therefore, stocking density, size at stocking, size at harvesting, rate of fishing mortality, and harvesting schedule hold the key for obtaining the optimum yield. A close scrutiny of the fishery management followed in the small water bodies indicates that these vital aspects of management have not received adequate attention.

Indian major carps are observed to congregate above the spillways for breeding, which result 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 been installed in some of the reservoirs paying rich dividends in enhancing the fish yield. However, caution is to be exercised to see that the screens erected across spillways do not get clogged during flood season to the detriment of dam. In some reservoirs, fishes have also been observed to ascend upstream through spillways, whereas in others the spillways provide an insurmountable barrier to fish moving up the dam. To minimize losses by way of escapement of fish through spillways and canals, 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.

Assessment of yield potential

Several methods are in vogue to assess the fishery potential of small reservoirs by deriving equations based on area, depth, catchment area and the chemical parameters of soil and water. Later, morpho-edaphic index (MEI) was evolved in an attempt to combine the morphometric as well as chemical parameters. Relationships between MEI and catch are based on the assumed characteristics for some sets of reservoirs possessing a certain number of limnological conditions, *i.e.* (i) that the ionic composition is dominated by the carbonate-bicarbonate system, (ii) that the water body is not dystrophic, (iii) that the volume does not fluctuate noticeably and (iii) that the temperature regime is similar. A morpho-edaphic index as :

$$MEI = \frac{\text{Specific conductivity } (\mu \text{ mhos/cm})}{\text{Mean depth (m)}}$$

has been set for African lakes (Henderson and Welcomme, 1974). Fish yield potential (C) is calculated from the MEI as :

$$C = 14.3136 \, MEI^{0.4681}$$

Asian reservoirs are known to have a lower yield potential than their African counterparts. However, till an Indian formula is derived, this formula can be applied to obtain a rough indication of the productivity of any reservoir within the limits of between one half and twice the estimate. Such equations are sufficiently precise to give an idea of the scale of investment, whether in research or developmental infrastructure, appropriate to any water body. More precision can be achieved after separate equations have been derived for different classes of reservoirs.

Enhancement

Majority of the small reservoirs and other community water bodies in India are essentially amenable to culture-based fisheries and there is a general consensus that any significant improvement in yield from them can be achieved only through some sort of enhancement activities. Fisheries enhancement can be achieved through human interventions in the aquatic ecosystems with a view to increasing their productivity. The nature and extent of the enhancement will determine the overall sustainability and environment-friendliness of the fishery.

The common modes of enhancement which are relevant to inland water bodies in India are *stock enhancement* (increasing the stock), *species enhancement* (inducting new species to broaden the catch structure), and *environmental enhancement* (enriching the water quality through artificial eutrophication).

Stock enhancement

Augmenting the stock of fish has been the most common management measure that is followed in the reservoirs in most countries of the world. Ever since the reservoirs were considered as a fishery resource, it had become apparent that the original fish stock of the parent river was insufficient to support a fishery. Augmentation of the stock is also necessary to prevent the unwanted fish to utilize the available food niches and flourish at the cost of economically important species. The policies and guidelines on the subject, wherever available, are often erratic and even arbitrary. Apart from the lack of any existing standards, it is a general lack of understanding on the production processes and the availability of facilities that come in the way of effective 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. This has proved to be a useful tool for developing fisheries potential of such small aquatic systems. However, stocking is not merely a simple matter of putting appropriate number of fish into an ecosystem but needs evaluation of an array of factors *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.

Fish seed production has made rapid advances in the country during the last few decades either through indigenous or imported technologies. Consequently, a number of hatcheries have come up for large-scale production of fish seed under the public and private sectors. But, despite a remarkable increase in carp seed production, the open water bodies of the country remain under-stocked, as all the seed produced in the private sector goes to the privately managed aquaculture industry. The Government hatcheries that have the responsibility to stock the public reservoirs could never produce fingerlings in the required number.

During summer months, small reservoirs either dry up completely or else the water level in them gets so drastically reduced that through over-fishing 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 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 stock 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.

The primary aim of good management is to ensure utilization of the food reserves in the reservoir by large-scale stocking with suitable species to obtain higher productivity. Lack of such measures would lead to poor utilization of the biological productivity of such water bodies.

Selection of species for stocking

The basic principles that should be followed in selecting a species to be stocked are :

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 energy – effective.

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. Size of the stock should be chosen with the expectation of getting the desired results.

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 environment. This factor has a considerable bearing on stocking rates and depends on population density and hence the production. In multi-species systems, fish can occupy different niches, where competition is avoided or at least minimized. Species competition for space and food can occur if niches overlap for any life history stage.

Stocking rate

A large country like India, with too many water bodies to be stocked, has inadequate state machinery to meet the stocking requirements of all its reservoirs. This has resulted in under-stocking of the reservoirs. Stocking densities need to be fixed for individual water bodies or a group of them sharing common characteristics such as size, presence of natural fish populations, predation pressure, fishing effort, minimum marketable size, amenability to fertilizing and multiplicity of water use. The main considerations in determining the stocking rate are growth rate of individual species stocked, the mortality rate, size at stocking and the growing time. Recently, based on the National Consultation on Reservoir Fisheries (Sugunan, 1997), the Government of India has adapted the following formula (Welcomme, 1976) to calculate the stocking rate for small reservoirs:

$$S = \left[\frac{q.P}{W} \right] e^{-z(t_c - t_o)}$$

S Number of fish to be stocked (in number/ha)
P Natural annual potential yield of the water body
q The proportion of the yield that can come from the species in question
W Mean weight at capture
t_c Age at capture
t_o Age at stocking
z Total mortality rate

P can be estimated through MEI method (mentioned above) and the range of mortality rates can be found out from the estimated survival rate. Table 5 illustrates calculation of stocking rates using the formula given above, when P = 200 kg/ha, q = 1, W = 0.5 kg and t_c-t_0 is 1. The model assumes insignificant breeding by stocked population and therefore applies mainly to total cropping situations *i.e.,* those in which fish are caught below their minimum size for maturity, those whose natural reproduction does not take place and those where water body is not permanent. It shows that stocking density, which depends on the natural conditions of productivity, growth and mortality, are very sensitive to z. Because of the very large numbers of fry needed, this formula may have very limited utility in large reservoirs.

Table 5. Calculated stocking density at different levels of mortality
(adopted from Welcomme, 1976)

Approx. annual survival (%)	-z	Estimated number of fish to be stocked (number/ha)
50	0.7	805
37	1.0	1,087
22	1.5	1,792
13	2.0	2,955

Impact of stocking in small reservoirs

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

1. Selection of the right species, depending on the fish food resources available in the system.

2. Determination of a stocking density on the basis of production potential, growth and mortality rates.

3. Proper stocking and harvesting schedule including staggered stocking and harvesting, allowing maximum grow out period, taking into account the critical water levels.

4. In case of small irrigation reservoirs with open sluices, the season of overflow and the possibilities of water level falling too low or completely drying up, are also to be taken into consideration.

Effective recapture of the stocked fishes renders the stocking more remunerative in small reservoirs, compared to the medium and larger ones. Aliyar reservoir in Tamil Nadu (Anon., 1997) is a standing testimony to the efficacy of the management based on staggered stocking. The salient features of the management options adopted in Aliyar are :

- Stocking is limited to Indian major carps (earlier, all indigenous, slow-growing carps were stocked)
- Increasing the size at stocking to 100 mm and above.
- Reducing the stocking density to 235-300/ha (earlier rates were erratic ranging between 500-2,500/ha)
- Staggering the stocking, and
- Regulating mesh size strictly and banning the catch of Indian major carps <1 kg in size

A direct result of the above management practice was an increase in fish production from 1.67 kg ha^{-1} in 1964-65 to 194 kg ha^{-1} in 1990.

Successful stocking has also been reported from a number of small reservoirs in India. In Markonahalli, Karnataka (Anon., 1998), on account of stocking, the percentage of major carps has increased to 61% and the yield increased to 63 kg ha^{-1}. Yields in Meenkara and Chulliar reservoirs in Kerala have increased from 9.96 to 107.7 kg ha^{-1} and 32.3 to 316 kg ha^{-1} respectively through sustained stocking. In Uttar Pradesh, Bachhra, Baghla, and Gulariya reservoirs registered steep increase in yield through improved management with the main accent of stocking. An important consideration in Gulariya has been to allow maximum grow out period between the date of stocking and the final harvesting *i.e.,* before the levels go below the critical mark. The possible loss due to the low size at harvest was made good by the number. Bundh Beratha in Rajasthan, stocked with 100,000 fingerlings a year (164 ha^{-1}), gave a fish yield of 94 kg ha^{-1}, 80% of which was constituted by catla, rohu and mrigal (Table 6).

Table 6. High yields obtained in small reservoirs due to management based on stocking

Reservoir	State	Stocking rate (number /ha)	Yield (kg/ha)
Aliyar	Tamil Nadu	35	194
Tirumoorthly	-do-	435	182
Meenkara	Kerala	1226	107
Chulliar	-do-	937	316
Markonahalli	Karnataka	922	63
Gulariya	Uttar Pradesh	517	150
Bachhra	-do-	763	140
Baghla	-do-	-	102
Bundh Beratha	Rajasthan	164	94

Species enhancement

Decline of indigenous fish stocks due to habitat loss, especially caused by dam construction, is a universal phenomenon. The extent of such fish species loss is not assessed to any reliable degree in many countries. In India, all the major river basins have been affected. Planting of economically important, fast-growing fish from outside with a view to colonizing all the diverse niches of the biotope for harvesting maximum sustainable crop from them is *species enhancement*. It can be just stocking of a new species or *introduction*. Introduction means one time or repeated stocking of a species with the objective of establishing its naturalized populations. This widespread management practice has more relevance to larger water bodies were stocking and recapture on a sustainable basis is not feasible.

Introduction of exotics

In India, the fish transferred on trans-basin basis within the geographic boundaries of the country is not considered as exotic and so much so there are no restrictions on such species transfer. Thus, catla is not regarded as exotic to Cauvery or such other peninsular rivers. This is despite the fact that the peninsular rivers have habitats, distinctly different from that of Ganga and Brahmaputra. The small west-flowing drainages of the western Ghats, the two large west flowing drainages *viz.*, Narmada and Tapti, and a number of east flowing rivers of the peninsular India have ichthyofauna different from the Ganga and Brahmaputra. Catla, rohu and mrigal have been stocked in the peninsular reservoirs for many decades now, with varying results. In some of the south Indian reservoirs, they have even established breeding populations. The hallmark of the Indian policy on introductions is the heavy dependence on Indian major carps.

There is evidence that the Gangetic major carps have affected the species diversity of peninsular cyprinids. The Indian policy on stocking reservoirs, though not very explicit, disallows the introduction of exotic species into the reservoirs. However, common carp is very popular in reservoirs of the northeast where it enjoys a favourable microclimate and a good market. Silver carp and grass carp are not normally encouraged to be stocked in Indian reservoirs, though they are stocked regularly in a few small reservoirs of Tamil Nadu and the northeast. The three exotic species brought in clandestinely by the fish farmers *viz.*, bighead carp, *Aristichthys nobilis*, *Oreochromis niloticus* and African catfish *Clarias gariepinus* have not gained entry into the reservoir ecosystems so far and they remain restricted to the culture systems.

There is a case for examining the virtue of selective introduction of some exotic fish species in small reservoirs, which have no connections with the rivers, or those, which dry up completely in summer. However, such introduction should be made only after proper policy decisions are taken at the national level.

Environmental enhancement

Improvement of the nutrient status of water by the selective input of fertilizers is a very common management option adopted in intensive aquaculture. However, a careful consideration of the possible impact on the environment is needed before this option is resorted to in reservoirs. It is generally believed that most of the lakes and reservoirs may have sufficient nutrient inputs and any excessive nutrient loading can lead to pollution problems. However, scientific knowledge to guide the safe application of this type of enhancement and the methods to reverse the environmental degradation, if any, is still inadequate. On account of all these, this is not a very common management tool. China is known to have used this instrument in a big way to augment production from small reservoirs. Cuba, taking a cue from China, has tried manuring of small reservoirs using both organic and inorganic fertilizers. This is also practiced selectively in the community water bodies of northeastern Thailand.

Fertility typically refers to the quantity of nutrients available and higher fertility is usually equated with higher productivity. Primary productivity is the rate at which new organic matter is added through photosynthesis. In some small impoundments photosynthesis is commonly limited by nutrients, so the greater the fertility, the higher the primary productivity. There is also a positive correlation between primary productivity and fish production.

To a large extent, impoundment fertility is determined by the fertility of the locale, as nutrient-rich sites have more fertile waters. The least available nutrients limit productivity. When increased quantities of these nutrients are present, primary production is increased until another less abundant nutrient becomes limiting. Phosphorus is frequently the first limiting factor in fresh water impoundments. Fertility may also be limited by nitrogen, carbon, sulfur, or other nutrients.

Fertilizers are less effective in soft water with total alkalinity less than 20 mgl^{-1}. Soft waters have inadequate carbon (usually in the form of carbon dioxide and bicarbonate) for good phytoplankton production. Fertilizer response, and hence productivity, can often be enhanced by applying lime to low alkalinity impounded waters. The application of lime equivalent to 2,000 to 6,000 kg ha^{-1} calcium carbonates is generally sufficient to maintain total alkalinity above 20 mgl^{-1}.

Fertilization of reservoirs as a means to increase water productivity through abetting plankton growth has not received much attention in India. Multiple use of the water body and the resultant conflict of interest among the various water users are the main factors that prevent the use of this management option. Surprisingly, fertilization has not been resorted to even in reservoirs, which are not used for drinking water and other purposes. Documentation on fertilization of reservoirs in India is scarce. Sreenivasan and Pillai (1979) attempted to improve the plankton productivity of Vidur reservoir by the application of super phosphate with highly encouraging results. As soon as the canal sluice was closed, 500 kg super phosphate with $P_2 O_5$ content of 16 to 20% was applied in the reservoir when the water spread was 50 ha with a mean depth of 1.67 m. As an immediate result of fertilization, phosphate content of water increased from nil to 1.8 mg/l and that of soil from 0.242 to 0.328%. Similar improvement in organic carbon and Kjeldal nitrogen have been reported from the soil and water phases on account of fertilization. Experiment were also conducted with urea in the same reservoir.

Eutrophication is a significant problem in both lakes and reservoirs. Whenever the rate of synthesis and input of organic matter exceed the rate 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 considerable allochthonous energy accumulate in the reservoir system that this quantity is either deposited, thereby accelerating eutrophication, or else enters the food chain in significant quantities.

Application of lime was tried in some upland natural lakes for amelioration of excessive CO_2 and acidity at the bottom (Sreenivasan, 1971). This measure, together with the application of super phosphate in Yercaud lake, raised the pH of water from 6.2 to 7.3 and decreased the CO_2 in bottom water from 6.5 to 3.8 mgl^{-1}. There was a corresponding increase in species number and biomass of plankton. Fertilization in Vidur reservoir resulted in a marked increase in benthic and plankton communities and doubling of the primary production rate. After two successive application of fertilizer, significant limnological changes took place including the presence of free CO_2 and decrease in pH and dissolved oxygen at the bottom layer of water. The methyl orange alkalinity increased from 44 to 108 mgl^{-1} from the surface to bottom, indicating a high organic productivity. Phosphate fertilization triggered the tropholytic activities mineralizing the organic matter and producing carbon dioxide. As a direct benefit from the fertilization, a 50% increase in fish production, along with three-fold increase in size (average weight) of catla, rohu, mrigal, *L.fimbriatus* and *L.calbasu* were achieved.

Artificial eutrophication as a decisive management option was opted for the first time in Kyrdemkulai (80 ha) and Nongmahir (70 ha) reservoir of the Northeast (Sugunan and Yadava, 1991a,b) by applying poultry manure (10 t ha^{-1}), urea (40 kg ha^{-1}) and single super phosphate (20 kg ha^{-1}) .

Fertilization can play a key role in many small reservoirs of India, which require correction of oligotrophic tendencies. A number of reservoirs in Madhya Pradesh, Northeast and the Western Ghats, receiving drainage from poor catchments show low productivity, necessitating artificial fertilization. Chinese experience in fertilizing the small reservoirs for increasing productivity has been reassuring (Yang *et al.*, 1990). In Shishantou reservoir, a management strategy comprising fertilization by organic and inorganic manures and feeding resulted in a phenomenal production hike from 1,500 kg ha^{-1} to 6,000-7,000 kg ha^{-1} during 1985 to 1989. Plankton biomass of Shishantou was 1.5 mgl^{-1}, which was raised to 7.5 mgl^{-1} through application of organic fertilizers at the rate of 6.375 t ha^{-1}. The plankton biomass, after dropping during the peak precipitation period, picked up to 20.51 mgl^{-1} during the post rainy season months, with corresponding increase in fish production.

Modeling approach in culture-based fisheries of small reservoirs

Recent studies based on modeling approach have opened up new avenues for the culture-based fisheries of small reservoirs. Notwithstanding the fact that studies on the population dynamics based on modeling approach demand higher levels of inputs in the form of money and trained manpower, an insight into the modeling approach will help the manager in understanding the ecosystem approach. Many of the small water bodies seem to be overstocked. In a culture-based fishery, an undue increase in stocking density can lead to severe loss of production (Fig 2). It is well known that at higher stocking densities, the fish grow at a slower rate with attendant higher rate of natural mortality. A moderate overstocking results in sub-optimal production due to slow growth and high mortality, but fishery can still operate. On further increase in stocking density, the asymptotic length of the population falls below the gear selection length (if the mesh is selective) and the fishery fails to remove biomass from the population. If stocking continues, the water body is literally choked with stunted populations without any production.

Available models have clearly confirmed that production is a function of fishing mortality and stocking density. If some standard variables on population parameters, such as the *density-dependent growth, size dependent mortality* and *weight-length relationship* are known, the optimum stocking density and the fishing mortality can be arrived at. The optimum stocking density in a hypothetical situation with a gear selection length of 30 cm and mean seed size of 5 cm is given in Fig. 3 (Lorenzen, 1995). In the current example, reflecting

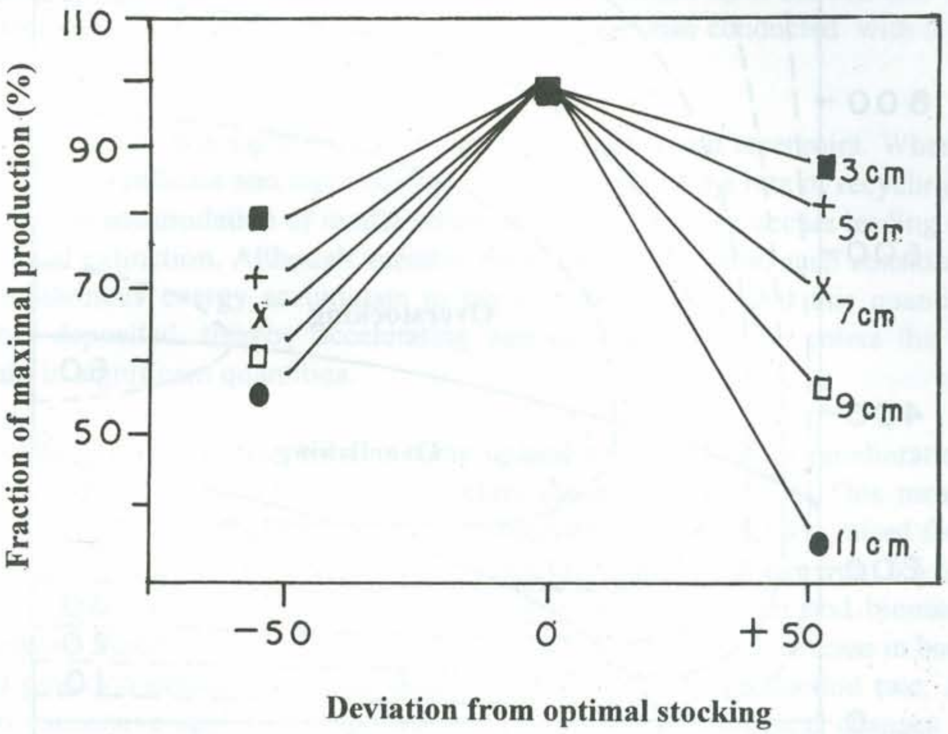

Fig. 2. Sensitivity of production to over- and understocking

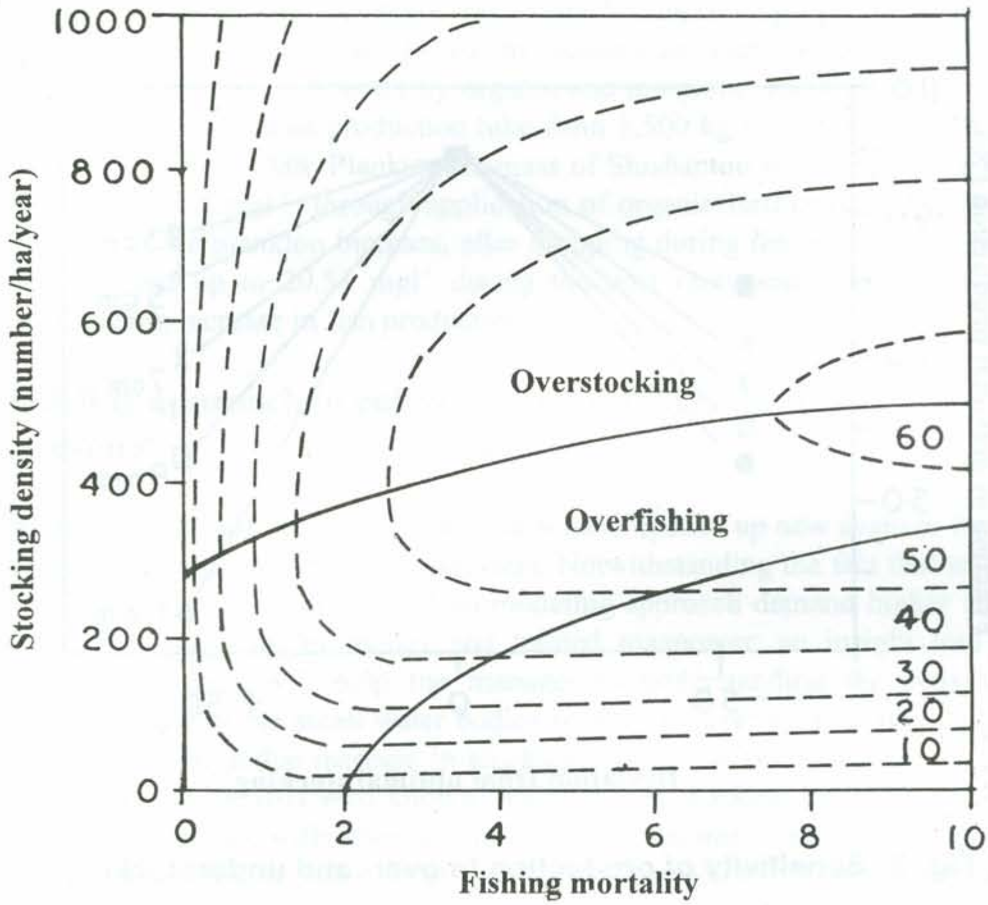

Fig. 3. Production as a function of fishing mortality and stocking density (after Lorezsen, 1995)

the density-dependent reduction in individual growth and the consequent increase in natural mortality, the maximum biomass harvested is estimated at 67.6 kg/ha at a stocking density of 560/ha/yr. Since the maximum yield is attained at a stocking rate of 560/ha, any increase in this parameter will amount to overstocking and loss of production. Similarly, any increase in fishing effort above certain limits will be counter productive.

Thus, a desired balance among stocking rate, population density and growth is to be maintained with enough flexibility so as to swing it to suit the changes in environmental factors. Such a plan must determine tentative stocking rates and population thinning accordingly.

It has also been pointed out that the highest production is achieved if fish are produced at the minimum marketable size. Thus, it becomes very important to determine the minimum size at which the fish are preferred for domestic consumption or can be marketed. The mesh size regulations and the gear selection have to be guided by this parameter. The fishing pressure assessed on the basis of size groups in the population is a useful guide in determining the quantum of fishing effort. This tool has been effectively used in many countries to make necessary adjustments in fishing effort. In reservoirs, the populations of some species consist of more than one age group and the older individuals dominate the populations in terms of biomass, clearly indicating low fishing pressure. This situation calls for an increase in fishing effort.

Similar models to suit Indian conditions need to be derived from field data. Adoption of such rational stocking rates, guided by models will go a long way in improving the fish yield from the small reservoirs.

Fishing gear

A variety of fishing gear are used in small reservoirs, but by and large, the fisheries of small reservoirs are based on gill nets. The other types, especially the artisanal ones are used by the subsistence and casual fishers. Artisanal fishing implements like dip nets, cast nets and hooks and line are known to affect the fishery adversely due to removal of small sized fishes. At the same time, they are also known to keep the number of predators under check. Thus, a careful monitoring of gear can go a long way in effective stock management. Gill nets are amenable for mesh size regulations and monitoring of the total fishing effort.

Fish health management

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. Some of the largest and most harmful parasites that infest reservoirs are the larval forms of cestodes, which have copepods and fish as their intermediate hosts and birds as the final host. These parasites are particularly important in lakes and reservoirs as the environmental conditions in these water bodies favour the abundance of copepods and birds. A very common cestode that infest major carps is *Ligula sp.* 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. *Ergasilus*, a parasitic copepod, is also found commonly in reservoirs. Very 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 is a good practice that can help control of parasites in reservoirs.

PLANNING CRITERIA

Keeping in view the need for rapid assessment of the country's small reservoir resources, there is a need to develop planning criteria based on the resource assessment of small reservoirs at the state level. As a first step, an inventory of the following types of small reservoirs, along with the estimates of their potential yields needs to be prepared:

Reservoirs which are best developed as capture fisheries

i. Reservoirs mostly of local interest having significant potential for extensive fish culture; and

ii. Reservoirs intermediate in size and potential yield.

These under-utilized fishery resources offer immense scope and potential for generating additional national income of the order of Rs.100 crore per year and providing additional employment to lakhs of fishermen and others through fishing, handling, transport, marketing and ancillary industries. A systematic and integrated approach towards scientific studies and planning criteria for undertaking extensive 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 & soil.
3. The animal and plant communities,
4. Growth rate of commercially important fish species, and
5. The relation between the biotic communities and the physico-chemical aspects of the environment in terms of population and community dynamics.

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.

Integrated approach

Very small reservoirs are amenable for integrated aquaculture since the culture-based fishery can be effectively combined with piggery, duckery and poultry rearing. Many of the waste products from these animal husbandry practices act as fish food or fertilizer leading to higher fish yield. Such systems have special relevance to the small reservoirs of the north east. However, this approach has limitations from aesthetic and hygienic point of view, especially when the reservoir is a source of drinking water supply. The exposed areas of the reservoir can be auctioned for agricultural farming of leguminous crops, which would also add to the productivity of the soil. Such increase in fish production and earnings can make a significant contribution to the nutritional requirements of the rural community.

A common feature of reservoir fisheries all over the world is their basic common property character, which is also the cause of all the dilemmas faced by the reservoir fishery managers. Fishery regulations in reservoirs are essential though they are difficult to enforce. The cost involved in policing the regulations exceeding the monetary value of the resource itself, many governments find it difficult to allocate money for the purpose. At the same time, the real value of the resource is much more than their monetary value. The environmental, cultural, moral and aesthetic considerations prevent the community from taking a purely commercial view on the subject. Therefore, social-cost benefit analysis can be an effective tool for project evaluation. The emerging trends of a *community management concept* is worth a trial. Africa and Latin America have already taken a lead and it must be tried in Asia as well where there is a tradition of community management of reservoirs.

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DOs and DON'Ts in small reservoir fishery management

DOs	DON'Ts
Get scientific advice in determining the production potential, stocking density and fishing effort.	Do not stock without a plan
In the absence of other criteria, use the recommended formula to determine stocking density.	Do not overstock the reservoir. (Remember, production loss due to over-stocking is higher than that of under-stocking)
Follow staggered stocking and harvesting schedules, whenever feasible	Do not fish immediately after stocking
Stock fish in shallow areas away from the spillways and other outlets.	Do not stock in deep areas and near to spillways and other outlets.
Approximately estimate the possible production loss through inlet and outlet channels and account for this while putting the value of mortality in the formula for stocking density.	Do not plan transporting fingerlings from far away places for stocking (Raise them near the reservoirs).
Get engineering help to explore possibilities for providing wire mesh to guard the inlet and outlet channels in order to prevent escape of fish.	Do not try to provide wire mesh structures without consulting the dam authorities (It may cause undue increase in water pressure leading to collapse of the hydraulic structure).
Fix the minimum size at capture and restrict the use of mesh size accordingly (Remember that theoretically, stocking fish at smaller size in large numbers and catching them at the smallest marketable size will give more yield, compared to larger size. However, survival is size-dependent).	Do not catch fish at too small or too large size. Do not grow fish to higher size than marketable/acceptable size.

DOs and DON'Ts ......Continued

DOs	DON'Ts
Fix the size at stocking high where the predator population is very high. Work out an optimum fishing effort and limit the number of fishing units	Do not stock higher sized fingerlings if there is no predator pressure
Explore possibilities of stocking locally available indigenous species	Do not stock exotic species without obtaining clearance from the authorities
Select fish species for stocking carefully, taking into account the available fish food resources and the catchability.	Do not stock/overstock fish species only because their seed are available
Explore possibilities of integrating animal husbandry practices to make the fisheries more profitable.	Do not practice animal husbandry in reservoirs used for drinking water purposes
Participatory management often works better than punitive measures and deterrents to motivate the community to follow mesh size and fishing effort regulations. Therefore, ensure community participation in management	Do not fertilize the reservoirs with organic and inorganic manures, unless it is very essential and does not conflict with other water uses.