Guidelines for Fisheries Management in Medium and Large Reservoirs in India

Department of Animal Husbandry, Dairying & Fisheries
Ministry of Agriculture
Government of India
Krishi Bhawan
New Delhi - 110 001

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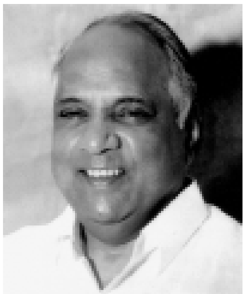

SHARAD PAWAR
MINISTER OF AGRICULTURE
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GOVERNMENT OF INDIA

30th July, 2008

MESSAGE

Sustainable development of the natural resources is the biggest challenge before mankind today. The increasing needs of the growing population have placed larger demands on the natural resources, necessitating a delicate balance between optimum exploitation of the resources and conservation of biodiversity. To achieve this, synergies have to be built between conservation and economic development. India's National Environmental Policy, adopted in 2006, adequately reflects this objective and has also been the guiding principle for integrating environmental concerns in the decision making processes in the country.

Impoundment of the river Narmada and its tributaries has provided the country with a large number of reservoirs, which can be harnessed for producing valuable fish protein for the masses. However, sustainable use of these impoundments for fish production would require sound management norms. The Guidelines for exploitation of fishery resources in the Small, Medium and Large Reservoirs would be valuable tools in the hands of planners and development agencies in achieving the objectives.

These Guidelines have been developed by key experts based on successful case studies not only from India but also from other parts of the world where reservoir fisheries have developed under similar settings. I would urge upon all concerned to adopt these Guidelines for optimum development of the fisheries resources of these water bodies. These Guidelines hold the key to our ability to develop and implement sound management plans for conservation and development of reservoir fisheries not only in the Narmada basin but also in other parts of the country. I am hopeful that sustainable development of the reservoirs can contribute immensely to the fish production of the country and provide livelihoods to the communities dependent on fisheries resources of the reservoirs.

(**SHARAD PAWAR**)

TARUN SHRIDHAR
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Foreword

The Narmada Control Authority (NCA) is a high-powered body constituted by the Central Government in 1980, to oversee implementation of the Narmada Water Dispute Tribunal Award. In 1987, under the initiatives and direction of the then Prime Minister Late Shri Rajeev Gandhi, the NCA was reconstituted to ensure preparation and timely implementation of the plans and programmes for safeguarding the environment.

Presently, the composition of the NCA includes five Union Ministries *viz.*, Environment & Forests, Power, Social Justice & Empowerment, Tribal Welfare and Water Resources, which are represented by their Secretaries. Besides, the States of Gujarat, Madhya Pradesh and Maharashtra are represented by their Chief Secretary and Secretary in-charge of the Department of Irrigation. In addition, there are four independent members, appointed by the Central Government. The Secretary, Ministry of Water Resources chairs the Authority.

While according clearance to the Sardar Sarovar and Indira Sagar Project from the environmental angle in June 1987, the Ministry of Environment & Forests recognized fish as an important indicator of aquatic ecosystem and, therefore, considered it as a key parameter for detailed Environment Impact Investigations. Subsequently, the Ministry of Agriculture was entrusted with supervision and guidance on the conservation and developmental aspects of fisheries in the Sardar Sarovar Project areas that included the reservoir, its down stream and the vast command area.

The order of clearance issued by the Central Government required preparation and implementation of the plan for conservation and development of fisheries in the impoundments. Subsequently, development plans were received from all the three project States but since they were found to be inadequate from conservational aspects, the States requested for expert advice. This led to the formation of a High Level Expert Group (HLEG) by the NCA. The HLEG observed that though several studies were available on the management of fisheries in the Indian reservoirs, a set of comprehensive guidelines on the conservation and management of the aquatic resources was lacking. The HLEG, therefore decided to frame a set of guidelines for small, medium and large reservoirs, which would be applicable not only for reservoirs under the Sardar Sarovar and Indira Sagar Projects, but also for reservoirs under similar settings in other parts of the country.

Prior to the formulation of the Guidelines, a team of experts led by Dr. Y. S. Yadava, the then Fisheries Development Commissioner in the Ministry of Agriculture, Dr. P. V. Dehadrai, Deputy Director General (Fisheries), Indian Council of Agricultural Research and Dr. Pawan Kumar, Director (Environment) of NCA conducted thorough reviews on the subject, made field visits and also carried out test fishing in selected areas of the Sardar Sarovar Reservoir to have a first hand assessment of the resources. The Guidelines were subsequently prepared by Dr. Yadava with valuable inputs from Dr. V. V. Sugunan, the then Director of the Central Inland Fisheries Research Institute and Dr. S. N. Chatterjee, former Director, Department of Fisheries, Government of Madhya Pradesh and Dr. Pawan Kumar. The Guidelines also drew upon the rich experiences of the Departments of Fisheries of the States of Gujarat, Madhya Pradesh and Maharashtra.

The Guidelines are in two volumes; the first volume deals with fisheries in large and medium reservoirs and the second with fisheries in small reservoirs, including the associated tanks and ponds in the command areas. It is expected that these Guidelines would be handy tools for the concerned agencies for conservation and optimum utilization of the productivity of reservoirs for production of valuable fish protein. This would not only benefit the communities subsisting on the fisheries in the reservoirs but also meet the growing requirements of fish in the country.

(**Tarun Shridhar)**

Preface

It is now widely accepted that reservoirs constitute one of the prime inland fisheries resources of India. Unlike the rivers, lakes, estuaries and other natural water bodies, which are under the increasing threat of environmental degradation and over-fishing, these man-made lakes offer ample scope for fish yield optimization through adoption of suitable management norms.

Considering the enormous resource size and the untapped production potential, the reservoirs have become the focus of future inland fisheries development in India. However, application of technologies and creation of an enabling governance environment would be needed to achieve the optimum production from the reservoirs.

The emerging Narmada Basin scenario portrays a large number of small, medium and large reservoirs, which along with their use for irrigation and electricity generation will also be ideal resources for production of fish and creation of employment opportunities.

This document gives guidelines for management of medium and large reservoirs, primarily to ensure that the impoundments created under the Narmada River Basin Project are optimally used for fish production. However, they would be equally applicable to similar reservoirs elsewhere in India.

Guidelines for the stock enhancement given in this document are essentially meant for medium and large reservoirs in the size range of >1000 ha in area. However, all medium and large reservoirs might not be suitable for practicing stock enhancement. The conditions suitable for practicing fisheries enhancement are discussed in detail in the document.

Guidelines generally carry limitations because of their general character and broad scope and the present guidelines are no exception. In view of the distribution of the reservoirs across the three States – Gujarat, Madhya Pradesh and Maharashtra – and in varying geo-morphological and ecological settings, it is likely that some of the suggestions made in the guidelines would need field-level alterations to meet the specific requirements of the impoundment and the user-groups. We hope that the managers responsible for fisheries development will take into account such requirements before initiating fisheries development in the reservoirs.

These guidelines are largely based on the research and development work carried out by the Central Inland Fisheries Research Institute (CIFRI), Barrackpore in optimizing fish yield from reservoirs in the country. The Institute's assistance in preparing these guidelines is gratefully acknowledged.

Y S Yadava **V V Sugunan**

Acknowledgements

These Guidelines have been prepared at the initiative of the High-Level Expert Group (HLEG) constituted by the Narmada Control Authority (NCA) for conservation and development of fisheries in reservoirs set up under the Sardar Sarovar and Indira Sagar projects. The NCA also provided funds for preparation of the Guidelines.

The activities of the HLEG were guided by the Department of Animal Husbandry, Dairying & Fisheries (DAHD&F), Ministry of Agriculture, Government of India, and coordinated by the Environment Wing of the NCA. We express our sincere gratitude to Shri Ajay Bhattacharya, former Joint Secretary (Fisheries), DAHD&F and to Shri Tarun Shridhar, Joint Secretary (Fisheries) who have provided valuable advice and leadership in the formulation of the Guidelines.

We are indebted to Dr. Pawan Kumar, Director (Environment) of the NCA, for organizing and coordinating the effort and providing assistance at every stage. We would also like to place on record our thanks to Dr. P. V. Dehadrai, former Deputy Director General (Fisheries), Indian Council of Agricultural Research, as well as Dr. S. N. Chatterjee and Dr. G. P. Dubey, both former Directors of the Department of Fisheries, Government of Madhya Pradesh, for their valuable assistance in accomplishing this professionally challenging task.

We also acknowledge the contributions of Shri M. K. R. Nair, Fisheries Development Commissioner, DAHD&F and Dr. Musharaf Ali, Assistant Commissioner (Fisheries), DAHD&F in finalization of the Guidelines.

Many agencies and professionals have shared their valuable experiences with us, which helped us in preparing this document. While it is not feasible to acknowledge all contributions personally, we place on record our sincere gratitude for their rich and varied experience and professional insight that enabled us to accomplish this task.

Finally, our special thanks to Shri M. K. Sinha, Member (Environment & Rehabilitation), NCA for his advice, unstinted support and constant encouragement in bringing out these Guidelines.

Y S Yadava

V V Sugunan

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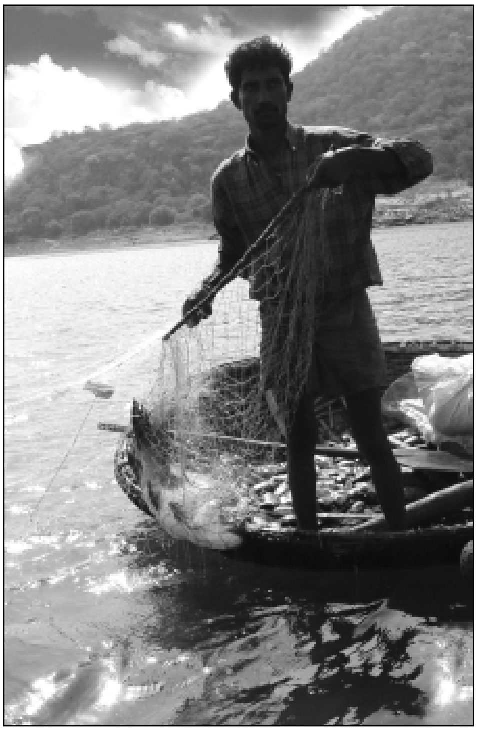


1. 0 Introduction

Reservoirs are defined as man-made impoundments created by constructing dams or other barricades across rivers or streams (Sugunan, 1995). India has more than 3.0 million ha of reservoirs distributed under divergent geo-climatic, morphometric and edaphic environments. These are classified generally as small (<1 000 ha), medium (1 000 to 5 000 ha) and large (>5 000 ha). Distribution of small, medium and large reservoirs in India, as per the Food and Agriculture Organization of the United Nations (FAO), is given in Table 1 below.

Table 1: Distribution of small, medium and large reservoirs in India

	Small	Medium	Large	Total
Number	19 134	180	56	19 370
Area (ha)	1 485 557	527 541	1 140 268	3 153 366

Source: Sugunan, 1995

India being a country of continental proportions, its reservoirs are spread over various types of terrains, and soil types exposed to diverse climatic conditions. They receive drainage from a variety of catchment areas. Fish yields from different categories of reservoirs - small, medium and large- have been estimated at about 50 kg/ha/yr, 12 kg/ha/yr and 11kg/ha/yr respectively, the average being about 20 kg/ha/yr. This yield is very low in comparison to countries such as China (>800 kg/ha/ yr) (De Silva, *et al.*, 1991), Sri Lanka (>300 kg/ha/ yr) and Cuba (>100 kg/ha/yr) (Sugunan, 1997). The present low level of production from the reservoirs is on account of many reasons: lack of fish seed for stocking, inappropriate gear and craft, poor landing and marketing channels, absence of closed season, poor governance, weak cooperatives, stranglehold of middle-men, etc.

There are various estimates about the total area under reservoirs in India. A detailed study made by FAO in 1995 has estimated the total number of reservoirs in India at 19 370 and the area at 3.15 million ha (Sugunan, 1995). However, the Handbook on Fisheries Statistics (2006) of the Ministry of Agriculture (Department of Animal Husbandry, Dairying & Fisheries), Government of India gives an estimate of 2.91 million ha under reservoir fisheries (Anon, 2006). Contrary to the common perception, reservoir fisheries is neither capture fisheries nor culture fisheries. Fisheries management of reservoirs is based on the principles of 'enhancement', which is defined as a range of management practices/processes by which qualitative and quantitative improvement is achieved from water bodies by exercising specific management options. This is something intermediate between culture and capture fisheries. Enhancement *inter alia* includes 'culture-based fisheries (stock and recapture)', 'stock enhancement (enhanced capture fisheries)', 'species enhancement (introduction of species)', 'environmental enhancement (fertilizing water bodies)', 'management enhancement (introducing new management options)' and 'enhancement through new culture systems (cage culture, pen culture, Fish Aggregating Devices, etc)'.

Reservoirs offer scope for one or more forms of enhancement. The most suitable management strategy for a particular reservoir is chosen, based on its morphometric, edaphic and biological characteristics.

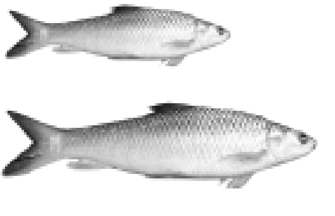
The two most common forms of enhancement followed in Indian reservoirs are culture-based fisheries and stock enhancement. Of these, stock enhancement is generally practiced in the medium and large reservoirs. However, it may be borne in mind that all reservoirs > 1 000 ha in area might not be suitable for stock enhancement. The conditions suitable for practicing stock enhancement are discussed in detail in this document.

Enhanced capture fisheries in medium and large reservoirs

While culture-based fisheries can be practiced in most of the small reservoirs, the medium and large reservoirs are not conducive for this kind of fisheries on account of the uncertainties in recapturing the stocked fish. In such water bodies, the main emphasis would be to build a breeding population that can support sustainable catch on a regular basis without having to stock annually. This process involves heavy initial stocking, followed by conservation of habitat to allow natural breeding and recruitment, regulated fishing and supportive/corrective stocking whenever necessary. This kind of management is called ‘stock enhancement’ or ‘enhanced capture fisheries’.

Medium and large reservoirs in India, which cover nearly 1.7 million ha, form a large resource size carrying a huge untapped production potential. Although the stock enhancement may result in a relatively low yield compared to culture-based fisheries in small reservoirs, they have the advantage of enabling yield optimization at a much lower cost. Presently, the medium and large reservoirs in the country are managed with little scientific inputs producing a paltry 11-12 kg/ha. Possibilities exist for achieving higher production levels by adopting sound management practices and improving the governance regime. By virtue of their important role in promoting fisheries development in a sustainable manner, stock enhancement is in better conformity with the norms of environmental sustainability. Further, it encourages community participation and social equity, especially for those residing on the reservoir margins.

The subsequent chapters of this document deal mainly with practices of stock enhancement in medium and large reservoirs. The methodologies for culture-based fisheries, as practiced in small reservoirs, are not discussed in this document. Description of management norms for such reservoirs is given in ‘Guidelines for Culture-based Fisheries Management in Small Reservoirs in India (Yadava and Sugunan, 2009).



2.0 Resource size

There are 180 medium and 56 large reservoirs in India, having an area of 527 541 and 1 140 268 ha respectively (Table 2). Considering that both medium and large reservoirs share most features that make them suitable for practicing stock enhancement, this document discusses the two groups together and hereinafter are collectively referred to as 'reservoirs'.

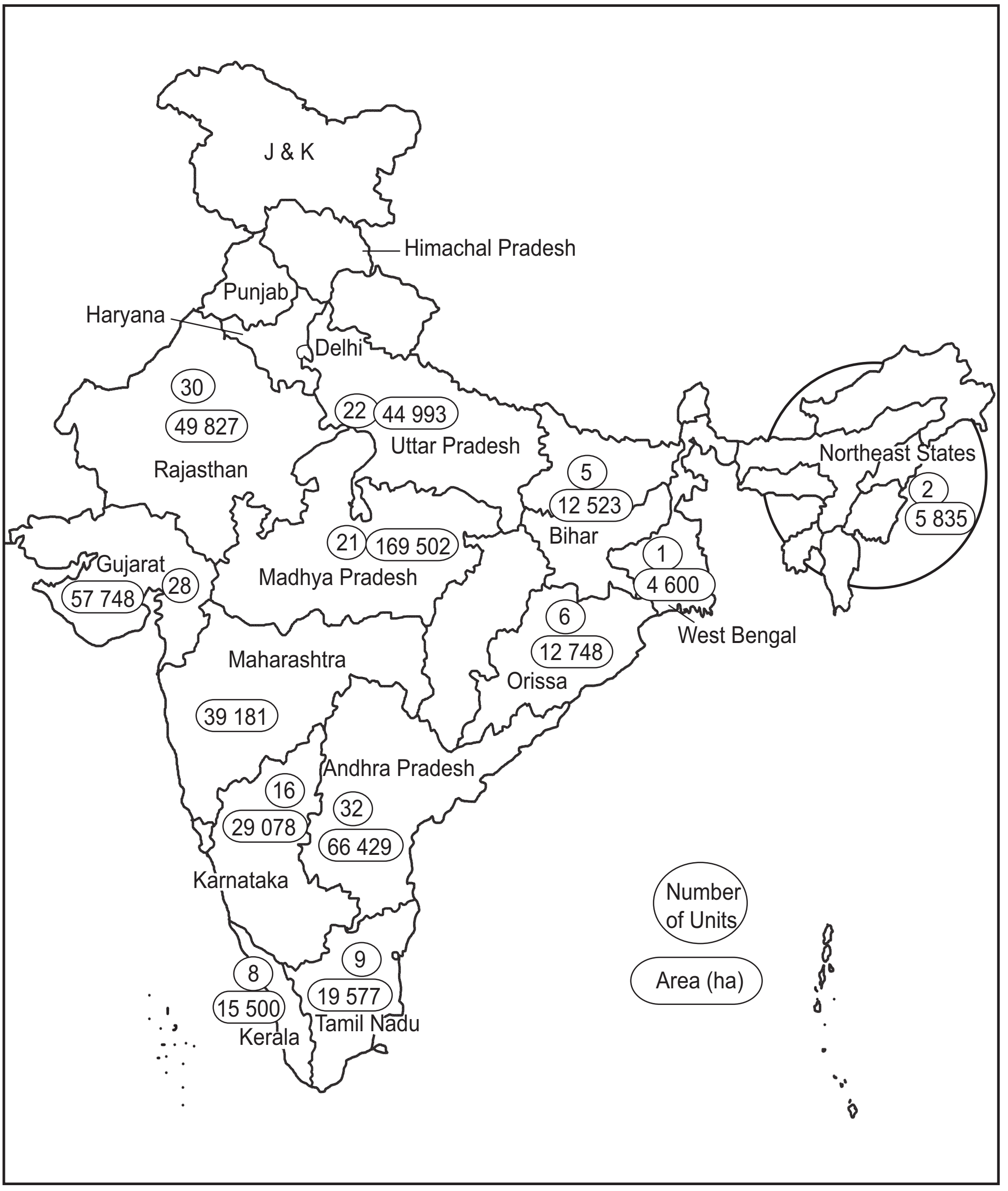
More than 57 percent of the reservoirs are situated in the four states of Andhra Pradesh, Gujarat, Karnataka and Madhya Pradesh. The two Narmada Basin States, Madhya Pradesh and Gujarat alone account for about 30 percent of the total area. Maharashtra, Orissa and Uttar Pradesh also have substantial area under reservoirs, each covering more than one lakh hectares.

Table 2: Distribution of medium and large reservoirs in India

States	Medium reservoirs		Large reservoirs		Total	
	Number	Area *(ha)*	Number	Area *(ha)*	Number	Area *(ha)*
Tamil Nadu	9	19 577	2	23 222	11	42 799
Karnataka	16	29 078	12	179 556	28	208 634
Andhra Pradesh	32	66 429	7	190 151	39	256 580
Gujarat	28	57 748	7	144 358	35	202 106
Uttar Pradesh	22	44 993	4	71 196	26	116 189
Madhya Pradesh	21	169 502	5	118 307	26	287 809
Maharashtra	NA	39 181	NA	115 054	NA	154 235
Bihar	5	12 523	8	71 711	13	84 234
Orissa	6	12 748	3	119 403	9	132 151
Kerala	8	15 500	1	6 160	9	21 660
Rajasthan	30	49 827	4	49 386	34	99 213
Himachal Pradesh	-	-	2	41 364	2	41 364
West Bengal	1	4 600	1	10 400	2	15 000
North East	2	5 835	-	-	2	5 835
Total	**180**	**527 541**	**56**	**1 140 268**	**236**	**1 667 809**

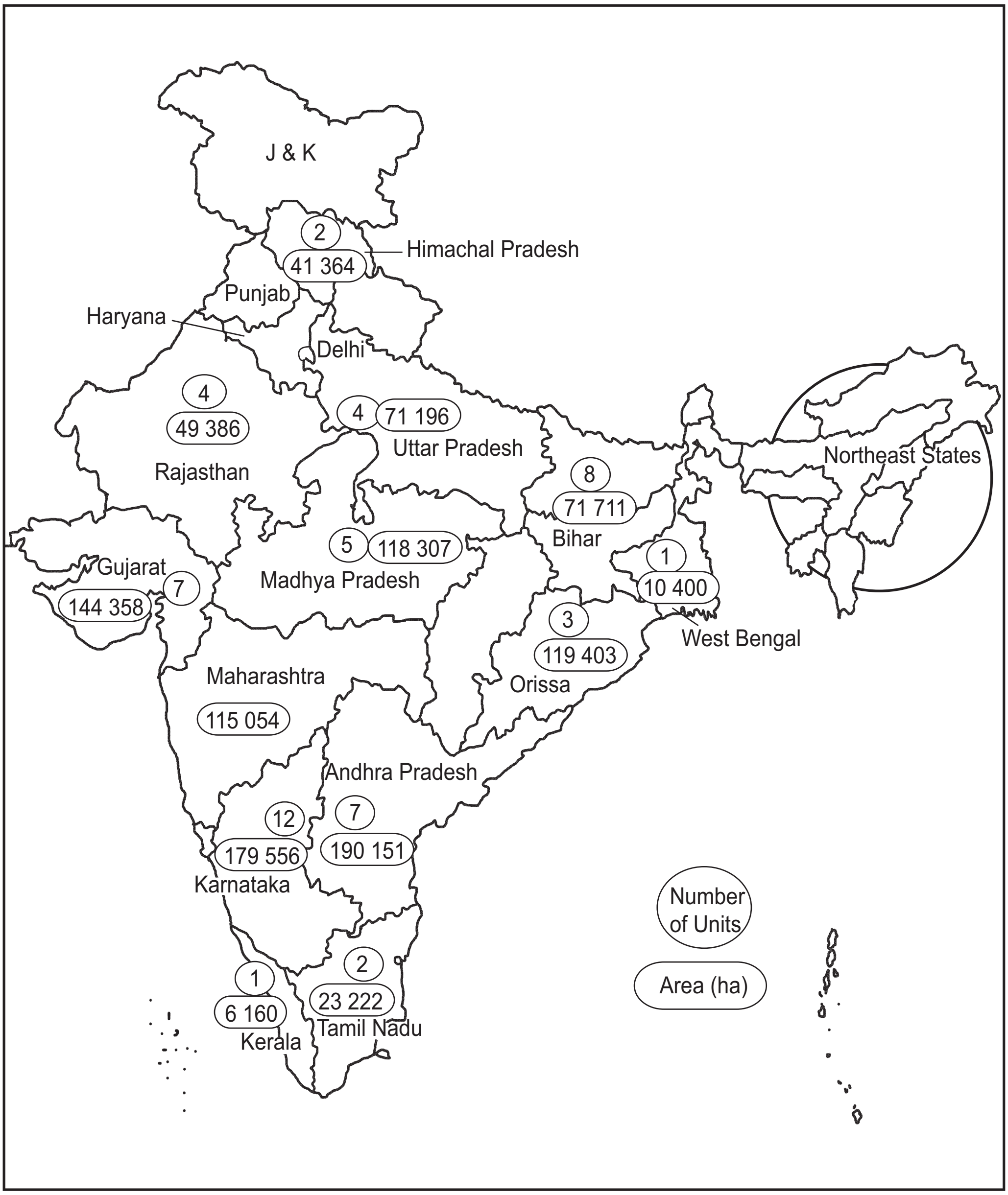
Source: Sugunan, 1995; NA: Information not available

Fig. 1: Distribution of medium reservoirs in India



Madhya Pradesh includes Chhattisgarh reservoirs.
Uttar Pradesh includes Uttarakhand reservoirs.
Bihar includes Jharkhand reservoirs.
Northeast States include Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura.

Fig. 2: Large reservoirs in India



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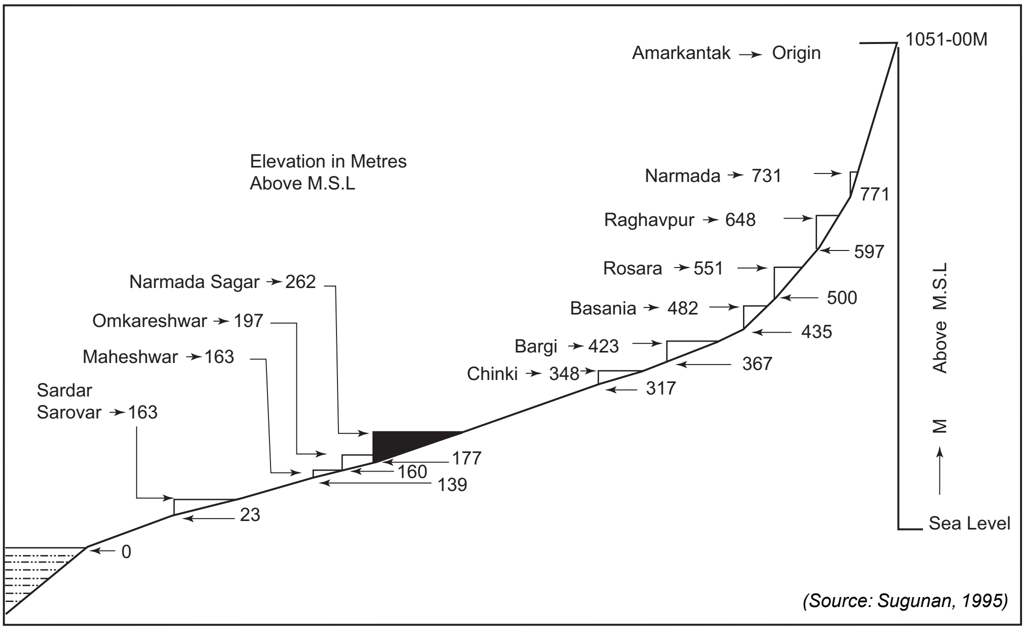
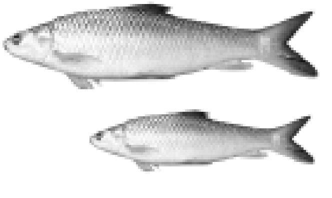


Fig.3: Cascade of reservoirs on the river Narmada

In terms of area, Madhya Pradesh with 169 502 ha tops the table in respect of medium reservoirs. Going by number, Andhra Pradesh, Rajasthan and Gujarat have more medium reservoirs than Madhya Pradesh, though the water area in these States is much less (Fig. 1). Karnataka has preponderance in number (12) of large reservoirs. Nevertheless, the 7 reservoirs in Andhra Pradesh in this category are much larger and have a water area of 190 151 ha (Fig. 2).

A large number of reservoirs have been created in the Narmada Basin and many more are in the making. On completion of all projects in the Basin, 3 979 reservoirs with a total water spread of 2 60 000 ha would be in place in Madhya Pradesh alone. Of this, the 91 300 ha Indirasagar Reservoir in Madhya Pradesh, which has already been commissioned, is the largest reservoir in the country today. The reservoirs of the Narmada Basin are situated on a wide range of altitudes, ranging from a slope of 1:1 000 at the origin at Omkareshwar to 1: 10 000 in the lower reaches. This cascade of reservoirs along the river course from origin to the coast is shown in Fig. 3 (Sugunan, 1995).



3.0 Production processes in reservoirs

Unlike the small reservoirs where fish production depends mainly on annual stocking and recapture, stock enhancement in the medium and large reservoirs is essentially an enhanced capture fishery where the emphasis is on establishing self sustaining populations to support a sustainable fishery. The human interventions here are limited to building up breeding populations initially through:

- stocking,
- keeping the habitats conducive for natural breeding and growth of fish stocks, and
- stock monitoring through regulating fishing effort.

Essentially, the limnology and inherent capacity of the water body to produce fish play a major role in fishery management.

3.1 Ecology and determinants of productivity

Reservoir is a man-made ecosystem without a parallel in nature. Although riverine and lacustrine characters coexist in reservoirs, they also have certain characteristic features of their own. For example, while the lotic sector of the reservoir harbours riverine communities, the lentic sector and the bays harbour communities adapted to still water conditions. Similarly, during the months of heavy inflow and outflow, the whole reservoir mimics a lotic environment whereas during the summer, when the inflow into and outflow from the reservoir dwindle, a more or less lentic condition prevails in most parts of the water body. Another unique feature of reservoirs that makes them distinct from their natural counterparts is the water renewal pattern, which is marked by swift changes in level, inflow and outflow.

The production capacity of a reservoir is determined by a set of key environmental parameters, especially the water and soil quality, which in turn, are a function of the geo-climatic conditions under which the lake exists. Thus, the geography, climate, topography and a number of physiographic parameters play a vital role in bestowing the reservoirs their inherent productive potential. Indian reservoirs are spread over various types of terrains and soil types. They are located in diverse climatic conditions and receive drainage from a variety of catchment areas. Therefore, they vary in their ecology and production potential.

The geo-climatic features

The Indian reservoirs are exposed to a wide range of geo-climatic situations from the temperate Himalayas in the north to the extreme tropical in the peninsula. Prevailing climatic factors including air temperature, wind velocity and rainfall play an important role in the biological productivity of a water body. Reservoirs in the higher latitudes receive relatively lesser amount of sunlight and are exposed to a lower temperature regime compared to their counterparts in the peninsula.

The wide seasonal variation in air temperature is the predisposing factor in the varying thermal features of the north Indian and peninsular reservoirs. In contrast to the reservoirs of the north, their southern counterparts are characterized by the narrow range of fluctuation in water and air temperature during different seasons, a phenomenon that prevents the formation of thermal stratification. Thermocline is limnologically important because in thermally stratified lakes, the top and bottom layers of water do not mix and thereby rich nutrients at the bottom layer get locked up. This is significant from a productivity point of view, as a warm bottom layer facilitates rapid decomposition of organic matter, thereby accelerating the process of nutrient release.

Variation in rainfall is also equally important. In India, most of the precipitation takes place during the monsoon months, which contributes substantially to the surface flow. During this period, due to a heavy inflow of water into the reservoir, all outlets of the dam are usually opened, resulting in total flushing. This process dislodges a considerable part of the standing crop of biotic communities at the lower trophic levels and disturbs the natural primary community succession. More often, rainfall in the catchment of the river situated hundreds of kilometers away from the reservoir affects the inflow rate.

The sudden water level fluctuations in a reservoir affect the benthos by exposing or submerging the substrata. Unlike their natural counterparts, the nutrient inputs in the man-made lakes are from allochthonous sources. This is because of the fact that the catchment of the rivers feeding the reservoirs is often situated far away, under totally different geo-climatic conditions. Deep draw down, wind-mediated turbulence and locking up of nutrients in the deep basins are also the characteristic features of many reservoirs.

Another important climatic factor with implications on thermal and chemical regimes of the reservoir is the wind. It helps in distribution and equalization of temperature and nutrients in the water column. Wind velocity is very high during monsoon and pre-monsoon months in most reservoirs in India.

Morphometric and hydro-edaphic factors

Mean depth: The varying purpose and design of the dams make the reservoirs different in their hydrographic and morpho-edaphic characteristics, with bearing on the fish production potential. Reservoir morphometry is a function of the height of the dam and the topography of the impounded areas. Apart from the nature of the basin and the characteristics of the terrain, it is the design of the dam and the water use pattern that govern the influence of morphometric and hydrographic features on the aquatic productivity. Most of the hydel reservoirs on the mountain slopes of Western Ghats, Himalayas and the other highlands are deep, with steeper basin walls than the irrigation impoundments.

One of the most important morphometric considerations that determines the productivity of reservoirs is the mean depth (Hayes, 1957; Rawson, 1952). This is based on the well-known fact that in shallow lakes the greater part of the water body is in the euphotic zone, facilitating higher productivity. Large portions of water in deep lakes serve as nutrient sinks at the bottom, where organic matter accumulates and thus the nutrients become unavailable at the photosynthetic zone.

Shoreline and volume development indices: A highly crinkled (irregular) shoreline, as indicated by the high values of shoreline development index, is believed to be indicative of productive nature of the water body. An irregular shoreline encompasses more littoral formations and areas of land and water interface. Ratio between the maximum depth and mean depth, often described as volume development index, denotes the depth of basin in relation to the nature of basin wall.

Hydrographic factors: Storage and release of water from dams are dictated by the requirements of irrigation, power generation and other primary uses of the dam, rather than any consideration for fisheries. The spillway discharge, apart from dislodging the standing crop of plankton, removes the oxygenated clear water at the top layer, leaving the oxygen-deficient, turbid bottom water. Similarly, the deep draw-down removes the decomposing material, including nutrients.

Edaphic factors: Water and the bottom soil being the media in which various biotic communities exist, the assessment of parameters determining their quality assumes importance. It is well known that the productivity of a reservoir is dependent on its biogenic capacity to transform solar energy into chemical energy. This energy fixation at primary producer level however is subject to a variety of factors, chiefly the availability of sunlight, conducive thermal regime, availability of carbon dioxide and the essential catalysing agents like nutrients. A high productivity regime throughout the year and plentiful sunlight by virtue of geographical advantage provide the ideal pre-requisites for photosynthesis in the Indian reservoirs.

Nutrient budget

Most of the Indian reservoirs are characterized by low levels of phosphate and nitrate in the available form. Phosphate very seldom exceeds 0.1 mg/1 in reservoirs free from pollution. Nitrate nitrogen in water in reservoirs is mostly in traces and seldom exceeds 0.5 mg/1. In many cases, despite their virtual absence, the production processes are not hampered. In the tropical reservoirs, phosphate level in water has limited scope as an indicator of productive traits. This phenomenon is attributed

to rapid turnover of nutrients (Ehrlich, 1960; Abbott, 1967) and their quick recycling, as seen from the high metabolic rates. Unlike nutrients like phosphate and nitrate, the measure of total dissolved solids in the form of total alkalinity and specific conductivity reflects the production propensities of reservoirs satisfactorily.

The ranges of notable abiotic factors indicating their productivity status in Indian reservoirs are given 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
Specific conductivity (μmhos)	76 – 474		Up to 200	> 200
Temperature (^{0}C)	12.0 – 31.0	18	18 – 22	> 22
				(with minimal stratification: i.e. > 5^0 C)
B. SOIL				
pH	6.0 – 8.8	< 6.5	6.5 – 7.5	> 7.5
Available P (mg/100g)	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

(Source: Jhingran, 1988)

A close examination of physico-chemical data pertaining to more than 100 reservoirs in the country leads to the conclusion that the vertical gradient of some of the chemical parameters, especially dissolved oxygen conveys the status with a higher level of accuracy (Sugunan, 1995).

3.2 Biotic communities

Plankton, periphyton, macrophytes and benthos are the major biotic communities of the freshwater ecosystems. But in reservoirs, the fluctuating water levels and heavy discharge of water during the monsoons result in high flushing rate, which do not favour growth of macrophytic communities. Similarly, inadequate availability of suitable substrata retards the growth of periphyton. Plankton, by virtue of their drifting habit and short turnover period, constitutes the major link in the trophic structure and events in the reservoir ecosystem. A rich plankton community with well-marked succession is the hallmark of Indian reservoirs.

Plankton

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

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

Macro-vegetation

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

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

Benthos

Benthic invertebrate fauna shows an erratic distribution in Indian reservoirs. The main factors that retard this community are the predominantly rocky bottom, frequent water level fluctuation and the rapid deposition of silt and other suspended particles. In spite of this, a number of reservoirs harbor rich communities of benthic invertebrates. The sequence of dominance of benthic communities closely follows the soil fertility pattern, the pre-impoundment debris often providing suitable habitats. The benthic community succession especially that of chironomids, is sometimes used to characterize habitat changes. High shoreline development, variable slopes and vegetation act as favourable factors for the development of a rich assemblage of benthic organisms. Chironomid larvae, being saprophobic, quickly fill the niches vacated by the saproxenes during the transformation of habitats. They form the most important constituent of benthos, reported from all soil types of different geographic locations and depths. Gastropods and annelids form the next important groups. The snail *Viviparus bengalensis* enjoys countrywide distribution.

Periphyton

Among the biotic communities of the reservoir ecosystem, periphyton is the least reported upon. It constitutes an important component of food for the browsing fishes, which contribute substantially to the total fish biomass of the tropical reservoirs. Apart from the limited littoral region in reservoirs, it is the frequent water level fluctuation that prevents the growth of periphyton on natural substrata. Significantly, rich periphyton, whenever reported, coincides with relatively stable reservoir levels. There are reports of rich periphyton deposits on anchored boats, rafts and experimentally suspended artificial substrata that move along with the receding water level (Sugunan and Pathak, 1986). The fixed substrata either get totally exposed when water level decreases or they are submerged too deep for the communities to survive when the level goes up.

Some of the biotic and abiotic factors affecting productivity of reservoirs at various trophic levels are given in Table 4.

3.3 Productivity

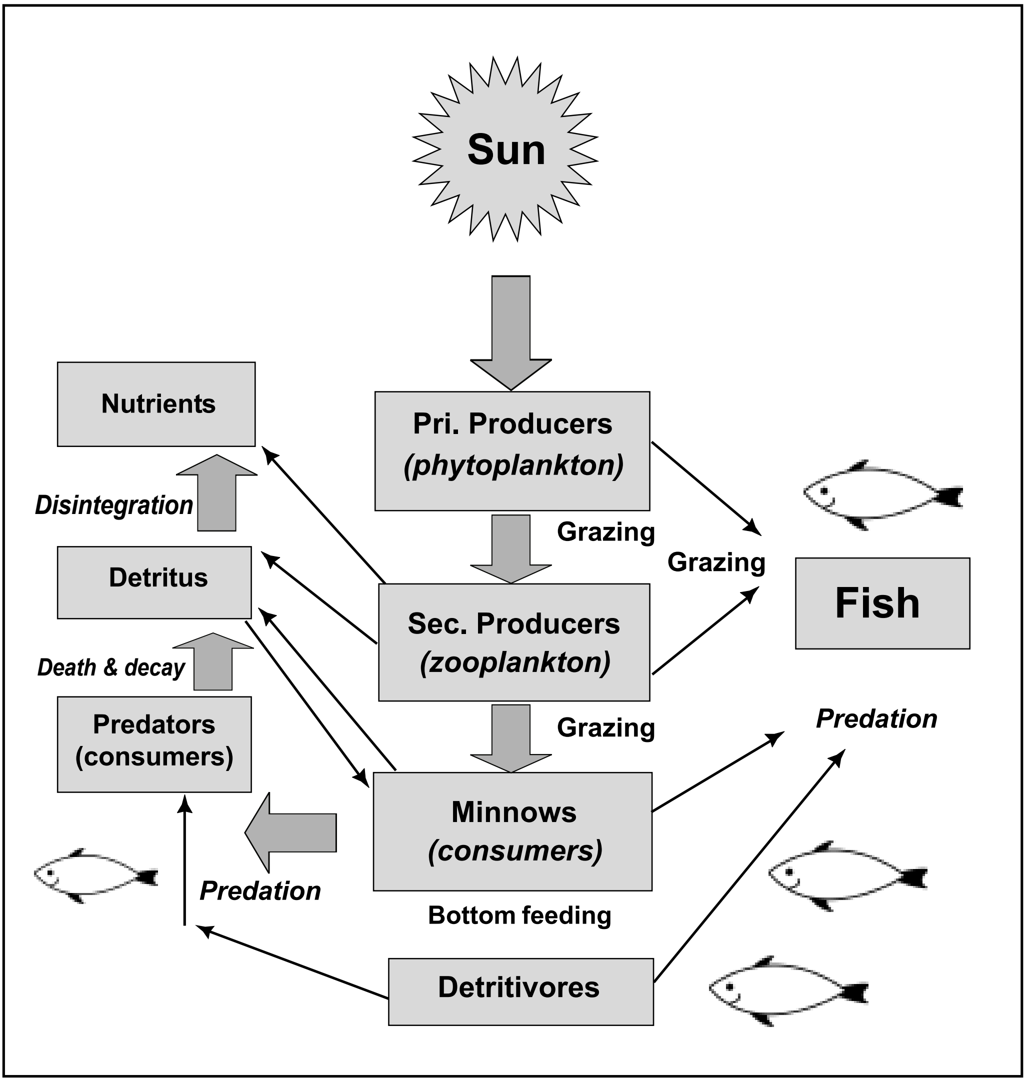
Phytoplankton forms the base of food pyramid in a reservoir ecosystem and their population determines its basic productivity (Fig. 4). One of the major criteria for determining fish yield potential of a reservoir is the rate at which solar energy is transformed into chemical energy by the photosynthetic organisms. Rate of primary productivity in the Indian reservoirs is very high due to the warm tropical conditions available in most part of the country.

Table 4: Biotic and abiotic factors affecting productivity of reservoirs at various trophic levels

Positive/augmentative factors	Major effects unknown	Negative/reductive factors
High shoreline development (coves, bays, etc).	Sedimentation of inorganic material	Low transparency in floods due to inorganic turbidity.
Low mean depth (less than 18 m).	High rate of evaporation.	High mean depth.
Existence and extent of marginal vegetation.	Contributions of autochthonous nutrients.	Erosion in the reservoir water shed area.
Optimum nutrient levels.	High surface temperature during summers (in northern India).	Reduction of quantity of water flowing into the reservoir.
Nutrient enrichment during floods.	Low water temperature during winters (in northern India).	Large water level fluctuations creating large aridal (barren littoral).
Moderate to long growing season.	Aquatic community inter-relationship.	Low level of dissolved oxygen in parts of hypolimnion.
Phytoplankton blooms at moderate scale.	-	Pollution in the reservoir watershed.
Moderately developed macrophyte community.	-	Blue-green algal blooms.
Periphyton abundant.	-	Relative low fish species diversity indicating low stability and a potentially low resilience to stresses.
Well established plankton and benthic communities.	-	Fish population dominated by predatory and trash fishes.
Trees and bushes cleared prior to impoundment.	-	Low abundance and diversity of terrestrial vegetation.
Conditions permitting migration of fish.	-	Relatively low environmental heterogeneity.
Stocking of fishes adapted to lenthic conditions.	-	Low diversity of plankton and benthos.
Deployment of suitable fishing gear and optimization of fishing effort.	-	Aquatic macrophytes obstructing operation of fishing gear.
Participatory approach and compliance of fishery regulations.	-	Top down approach and non-compliance of regulations.

(Source: Jhingran, 1988)

Fig. 4: Food chain in an aquatic ecosystem



Morpho-edaphic index

A first approximation of the fish yield potential of reservoir is essential before determining the management measures. One of the methods involves determination of Morpho-edaphic Index (MEI), which is calculated from two limnological variables *viz.* total dissolved solids (TDS) and mean depth (Z), each representing the edaphic and morphometric attributes of the lake in question. MEI can be calculated as MEI=TDS/Z and the fish yield potential is estimated from the linear equation:

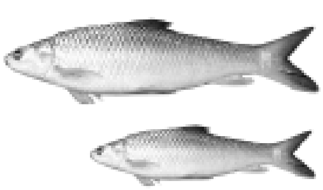
$$\mathbf{Y = KX^a}$$

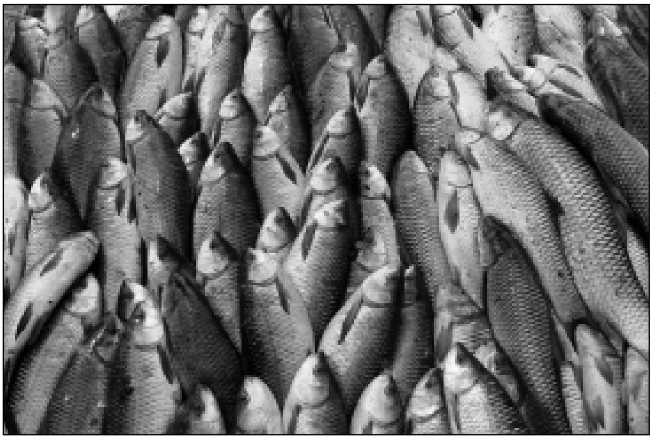
where Y is fish yield; X is MEI and K is a constant that represents a coefficient for climatic effects and a is an exponent derived empirically from the data.

This method, although provides a useful first approximation of potential yield from lakes and reservoirs, is more applicable to temperate and African lakes. Due to high variabilities in the factors leading to production in Indian reservoirs, this method may not always give accurate results. Some other models such as Jenkins model, Gulland model and Trophodynamic model might be needed to arrive at the potential yield (Jhingran, 1988 and Sugunan *et al*., 2002).

Presently, fishery managers in India might not have enough capacity to estimate the fish yield potential on the basis of MEI. A simpler method would be to estimate it on the basis of primary carbon productivity. Many still consider 1-10 percent of the total energy produced at the primary producer level as the fish production potential. For this purpose, the total carbon production of the reservoir needs to be estimated, based on the rate of carbon production in a unit area. If the major fishery consists of plankton feeders, up to 10 percent of the energy at primary producer (Phytoplankton) level can be harvested as fish flesh. This calculation involves:

- estimation of carbon as tonnes per unit area of water,
- conversion of this tonnage of carbon into energy (in calories),
- calculation of appropriate percentage (within 1 and 10 percent) in calories, and
- conversion of energy in calories into fish flesh in tonnes.





4.0 Fish and fisheries

4.1 Ichthyofauna

The ichthyofauna of a reservoir essentially represents the faunal diversity of the parent river system. Indian reservoirs on an average harbour about 60 species of fishes (Hora, 1949, Job *et al*., 1952, 1955), of which at least 40 contribute to the commercial fisheries. The fast-growing Indo-Gangetic carps, popularly known as the Indian major carps, occupy a prominent place among the commercially important fish species. In the last 2-3 decades, exotic species such as silver carp and common carp have also established in some reservoirs, contributing substantially to commercial fisheries. A broad categorization of the icthyofauna of reservoirs in the country is given in Table 5.

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

Riverine fish fauna is exposed to a series of habitat changes such as water current, turbidity levels, fishing pressure, loss of breeding grounds and the changes in fish food organisms due to lake formation. This results in loss of some fish fauna that are very sensitive to changes and the niche thus vacated is occupied by other hardy fish species. In many reservoirs, transplantation of fishes from other basins and introduction of exotic species has led to further changes in the species composition.

4.2 Fisheries

A realistic evaluation of fish production from reservoirs in India is elusive. Compared to the impressive volume of data generated by various institutions on limno-chemical variables and biotic communities, the estimates on fish catch and yield remain grossly inadequate. The lack of quality data on fish production also emerges as the weakest link when developmental programmes for reservoirs are planned in the country. This lacuna is imputable to a large number of factors, chiefly to the following factors:

- multiplicity of agencies owning fishing rights pose difficulties in some States to gather data,
- market channels are highly scattered and unorganized, mostly under the clutches of agents (middlemen) and money lenders, who are unwilling to provide reliable data,
- Ineffective cooperatives,

Table 5: Commercially important fish species of Indian reservoirs

Group	Species	Common Name
Indian major carps	*Labeo rohita*	Rohu
	L. calbasu	Calbasu
	L. fimbriatus	-
	Cirrhinus mrigala	Mrigal
	Catla catla	Catla
Mahseer	*Tor tor*	Golden mahseer
	T. putitora	Golden mahseer
	T. khudree	Deccan mahseer
	Acrossocheilus hexagonolepis	Chocolate mahseer
The minor carps, including peninsular carps	*Cirrhinus cirrhosa*	-
	C. reba	Reba
	Labeo kontius	-
	L. bata	Bata
	L. dero	-
	Puntius sarana	-
	P. dubius	-
	P. carnaticus	-
	P. kolus	-
	P. dobsoni	-
	P. chagunio	-
	Thynnichthys sandkhol	-
	Osteobrama vigorsii	-
Snow trout	*Schizothorax plagiostomus*	-
Large catfishes	*Aorichithys aor*	-
	A. seenghala	-
	Wallago attu	-
	Pangasius pangasius	Pangas
	Silonia silondia	-
	S. childrenii	-

	Species	Common Name
Featherbacks	*Notopterus notopterus*	-
	N. chitala	Chital
Air breathing catfishes	*Heteropneustes fossilis*	Singhi
	Clarias batrachus	Magur
Murrels	*Channa marulius*	-
	C. striatus	-
	C. punctatus	-
	C. gachua	-
Weed fishes	*Ambassis nama*	-
	Esomus danrica	-
	Aspidoparia morar	-
	Amblypharyngodon mola	Mola
	P. sophore	-
	P. ticto	-
	Oxygaster phulo	Chela
	Oxygaster bacaila	-
	Laubuca laubuca	-
	Barilius barila	-
	B. bola	-
	Osteobrama cotio	-
Exotic fishes	*Gadusia chapra* *Oreochromis mossambicus*	- Tilapia
	Hypophthalmichthys molitrix	Silver carp
	Cyprinus carpio specularis	Common carp (minor carp)
	C. carpio communis	Common carp (scale carp)
	C. carpio nudus	Common carp (leather carp)
	Gambusia affinis	-
	Ctenopharyngodon idella	Grass carp

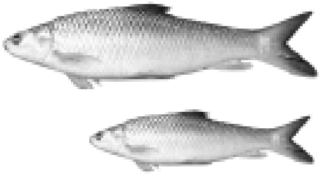
(Modified from Sugunan, 1995)

- diverse licensing/royalty/crop sharing systems practiced by different States, some of which have open access, providing little scope for recording catch statistics, and
- inadequate and poorly trained manpower in the Department of Fisheries and Cooperatives to follow statistically sound sampling procedures and collect reliable estimates of fish landings, etc.

The estimated fish yield of 110 medium and 21 large reservoirs of the country is 12.30 and 11.43 kg ha^{-1} respectively. Applying this national average yield rates to the 527 541 ha of medium and 1 140 268 ha of large reservoirs in the country, their total production rate can be estimated as 6 488 and 13 033 tonnes respectively (Table 6).

Table 6: Present and potential production from reservoirs in India

Category	Yield *(kg ha^{-1})*	Area *(ha)*	Production
Medium	12.30	527 541	6 488
Large	11.43	1 140 268	13 033
Total		**1 667 809**	**13 521**



5.0 Fisheries management

Fisheries management in Indian reservoirs has been reported from 1940s onwards (Chacko and Kurien, 1948; Chacko and Dinamani, 1949; Dubey and Mehra, 1959). Fish production system in majority of medium and large reservoirs is based on the principle of enhanced capture fisheries, as the essence of management strategy lies in capture of self sustaining stocks. At the same time, there is scope for stock manipulation through adjustments in fishing effort, observance of conservation measures and gear selectivity. Periodic selective stocking is also resorted to for correcting imbalances in species spectrum and to fill the vacant ecological niches. Fish productivity of a reservoir is dependent on its capacity to transform the solar energy into chemical energy (photosynthetic efficiency) and the efficiency of the system to harvest a fraction of this energy in the form of fish flesh (Fig. 4). Thus, the organization of the biotic communities in the eco-system plays an important role in reservoir fisheries (Natarajan 1979a, b; Natarajan and Pathak, 1983).

Fish productivity depends on a number of factors such as:

- conducive environment for primary production,
- good food web (well balanced structure that ensures good conversion of primary energy into fish flesh),
- self sustaining fish stock(s) that contribute to high yield, and
- good post -harvest and marketing arrangements.

In other words, the three key requirements are (i) an enabling habitat, (ii) good fish stock(s) and (iii) good post-harvest arrangements.

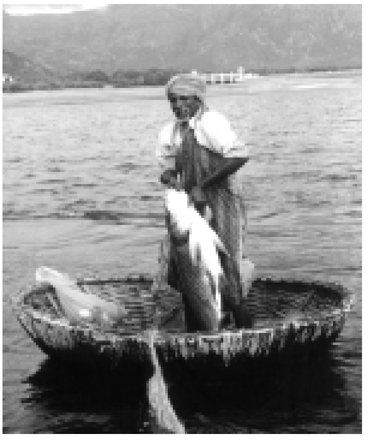
Various management processes involved in reservoir fisheries are:

- Environment management,
- Stock management,
    - fish stock monitoring
    - gear and effort management
    - exotic fish species
- Unconventional production systems,
- Other management measures, and
- Harvest and post-harvest management.

5.1 Environment management

The main focus of environment management centres around:

- a conducive habitat for primary producer organisms to flourish and produce carbon at a high rate, and
- maintenance of the habitat at optimal levels to suit the life cycles of all biotic communities including fishes.



In open waters, the harvestable organisms often belong to nekton, which, in turn, is dependent on plankton, macrophytes or benthos. Any change in sensitive environmental parameters that adversely affect any of the component communities in the trophic chain are bound to affect fish production. Therefore, capture fisheries management in reservoirs needs to be environment-friendly, aiming at conservation of the entire food chain.

Eco-degradation of reservoirs has been on the increase due to the rapid pace of industrialization, poor environment management in the catchment and a variety of other factors. Apart from the direct entry of industrial, municipal and thermal wastes, the pollution load carried by the upstream rivers and the tributaries joining the main river, is also accumulated in the reservoirs. The Indian reservoirs mainly receive pollutants from industrial, municipal and agricultural sources and the thermal power plants. High rate of siltation due to poor catchment management also affects the biological productivity.

In many cases, the water quality of reservoir is influenced by the catchment area situated hundreds of km away from the lake. For instance, soil erosion in the distant catchment leads to high sediment load and siltation in reservoirs, posing hazards to fish populations. The reservoir fisheries management therefore, entails protection of both terrestrial and aquatic ecosystems from environmental degradation.

As stated earlier, the major habitat constraints that come in the way of effective reservoir management are siltation and pollution from thermal, domestic, agricultural and industrial sources. Excessive siltation leading to drastic decrease in water holding capacity and even damage to concrete hydraulic structures is a common problem in reservoirs. Apart from diminishing the water holding capacity of the reservoir and shortening its life, siltation also affects the biota by blanketing the benthic and periphytic community. It further hampers recruitment by destroying the breeding grounds and retarding the overall productivity of the ecosystem. A number of reservoirs have been selected, of late, as sites for thermal power plants due to their dual utility as perennial source of water supply and disposal point for heated effluents and fly ash. The main ecological consequences of heated water discharged into the aquatic ecosystem are increase in water temperature, change in chemical composition and change in metabolism and life history of aquatic communities. Thick mat of fly ash deposited at the bottom bed over the years seal the nutrients away from the water phase and destroy breeding grounds of fish.

A number of reservoirs contiguous to towns and cities face threat from sewage pollution. Although from the fisheries point of view, organic loading within certain limits does not hamper productivity, but sewage load in excess can cause aseptic conditions, adversely affect the biotic communities, retard productivity and render the fish unfit for human consumption. Moreover, the problem needs to be addressed from public health and aesthetic points of view. Wastes emanating from industries such as chemical plants, textile mills, heavy engineering plants, paper mills and iron and steel factories are often dumped into the reservoirs causing hazards. Hazardous and toxic substances such as pesticides and heavy metals are also carried to the reservoirs through the effluents and rain washings from the catchments. These substances are highly persistent and thereby contaminate the entire bio-geochemical cycle of static systems like reservoirs.

5.2 Stock management

Management of fish stocks in reservoirs entail maintenance of enough quality stocks in adequate numbers in order to sustain a fishery. This involves several steps such as: stocking; conservation of fish habitat including breeding, dwelling and feeding grounds; fishing gear and effort regulation; mesh regulation; closed season; regulations on exotic fishes; etc.

Stocking

Stocking is *sine qua non* for the reservoir fisheries for building up stocks of fast growing species in the ecosystem to colonize the diverse niches. It is important to stock species that may breed and ultimately get naturalised in the system through autostocking. This is imperative to meet the long-term objective of obtaining a sustained yield. Management involving persistent stocking not only pushes up the input cost; such systems may also create many practical difficulties in raising the stocking material in adequate quantities.

It is well known that a reservoir passes through a period of 'trophic burst' during the first few years after its impoundment. During this period, there is a sudden surge in plankton and benthic communities due to high levels of nutrients derived from the submerged organic material in the reservoir bed. This is the right time to stock desirable species into the reservoir. Heavy stocking with fast growing fishes on a short food chain is essential during 'trophic burst' along with the protection of breeding grounds. This will facilitate establishment of desirable species which convert primary energy into fish flesh at a more economic rate in the reservoir. Any lapse in this important management measure might lead to proliferation of undesirable species like minnows, which in turn become forage to predators, thus establishing a longer food chain. There are many instances of establishment of such long food chains in India (Nagarjunasagar in Andhra Pradesh, Tungabhadra in Karnataka and Hirakud in Orissa), which is now difficult to reverse. These reservoirs harbour good standing crops of plankton and benthos, which are poorly converted into flesh of commercially important fish species.

Naturalization of inducted species is quite often beset with problems unless the species to be used for stock enhancement are identified with great care and abundant caution. It needs to be ensured that the species stocked should find the habitat conducive to its biological and physiological requirements, it has an edge in the competition for food and finally, the environmental conditions favour its requirements of feeding, spawning and larval development. Recruitment failure due to erratic hydrographic conditions that break the breeding rhythm have been found to be the single major factor responsible for the failure of stocked fishes to establish in reservoirs (Jhingran and Natarajan, 1969).

Selection of species for stocking

The principles to be followed in the selection of species for 'stock enhancement' can be summarized as:

- The species should have a fair chance of establishing itself as a naturalized population.
- The species should find the environment suitable for growth and reproduction.
- It should be quick growing, ensuring high efficiency in food utilization.
- Herbivores or fishes with a short food chain are preferable, as they have a better conversion of primary production to fish flesh.
- Existing laws and regulations should not be violated and necessary clearance should be sought for introducing species where applicable.
- Seed should be readily available or can be raised in large numbers near the reservoir.
- Cost of stocking and managing the species must be such that the operation becomes economically viable.

Fish populations in a newly impounded reservoir will be invariably too thin for the amount of fish food available in the system, leaving a void between carrying capacity and actual production of fishes. In order to fill this gap, there is a need to build a higher population density, which is achieved by addition of species to the original fish stock. In addition, information on differences, if any, in the growth rates of the endemic and stocked species, and the time taken by the stocked species in attaining harvestable size would provide insight into the production dynamics of the system. Both intra- and inter-species competitions for food and space are to be considered in the stocking programme. Situations where two or more species use a similar resource lead to overcrowding and poor growth rate.

Indian reservoirs, by and large, have a wide ranging representation of biotic communities. Phytoplankton comprising Cyanophyceae, Chlorophyceae, Dinophyceae and Bacillariophyceae dominate over zooplankton such as copepods, cladocerans, rotifers and protozoans. Benthos is represented by insect larvae and nymphs, oligochaetes, nematodes and molluscs. There is a rich growth of periphyton on the submerged objects, but the large magnitude of water level fluctuations does not favour establishment of aquatic macrophytic communities. Significantly, many of the above niches with the exception of insects, Cyanophyceae and molluscs are shared between Indo-Gangetic major carps, carp minnows and weed fishes focusing the need for controlling the latter two groups. The ecosystem-oriented management policy places due emphasis on trophic strata in terms of shared, unshared and vacant niches. Two main pathways through which primary energy finds its way to fish flesh are the grazing chain and the detritus chain. Based on this fact, either plankton feeding or detritus feeding fishes are considered suitable for stocking in Indian conditions. (Figures 5 & 6).

Fig. 5: Detritus Chain

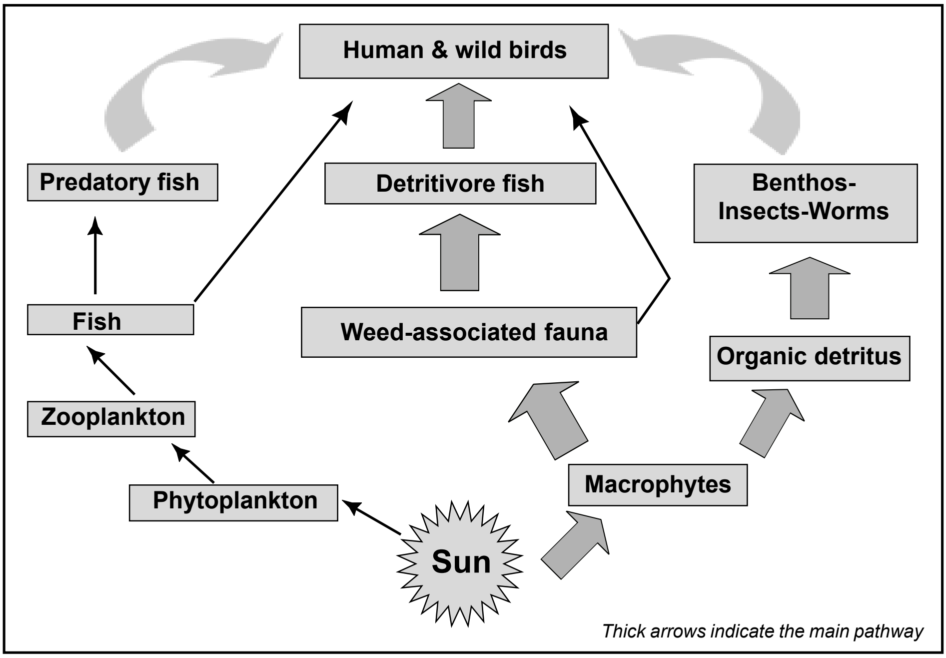
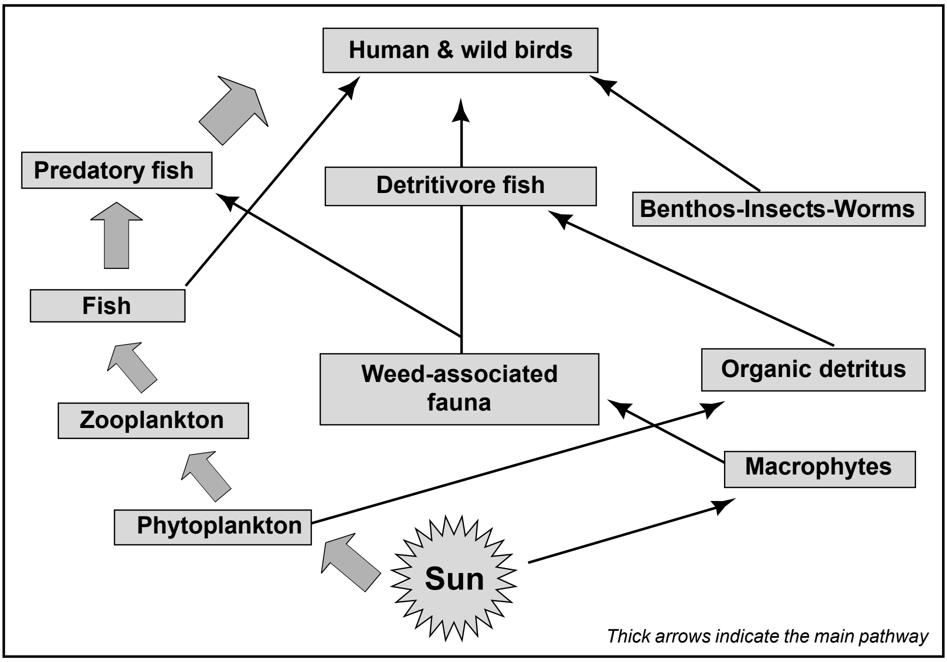


Fig. 6: Phytoplankton (Grazing) Chain



Today, reservoir fisheries in India largely centre on development of carp fisheries. Their unmistakable role has been demonstrated in the Gangetic as well as peninsular reservoirs. Major carps, by virtue of their feeding habits and fast growth rate are indispensable in reservoir fisheries. At the same time, the Indian major carps are ill suited to utilise phytoplankton, the most dominant constituent of plankton. The remarkable ability of silver carp in efficient conversion of phytoplankton into fish flesh has been demonstrated in Kulagarhi (in Madhya Pradesh) and Getalsud (in Jharkhand) reservoirs, despite the persisting doubts about the digestibility of *Microcystis aeruginosa*. However, introduction of exotic fish species in open waters is still a subject of debate due to their possible deleterious effects on indigenous populations.

Development of other indigenous/endemic species as stocking material for reservoirs has not made much headway in the country although some of them have a proven track record in ensuring an efficient energy transformation rate. *Pangasius pangasius,* subsisting on a molluscan diet is a species to be considered in the detritus-based, mollusc-rich reservoirs of the country. *Puntius pulchellus,* the peninsular species is a well-known macrophyte feeder and *Thynnichthys sandkhol is reported to* consume *Microcystis,* the common blue green alga in Indian waters. Diversification of stocking material is essential for establishment of a multi-species fish stock that utilizes all food niches of the ecosystem.

In reservoirs, where annual draw down is not pronounced and water level fluctuations are not steep, phytobenthos and macrovegetation develop in various degrees. The grass carp, *Ctenopharyngodon idella* can be considered for such water bodies. The common carp, stocked in many reservoirs, is a sluggish fish and does not survive normally in the warm, deep-basin reservoirs of the south, especially when infested with predators. However, this prolific feeder could carve out a place for itself in the reservoirs of the northeast, in Gobindsagar (Himachal Pradesh) and in some of the peninsular reservoir like Krishnarajasagar (Karnataka). The fish being a mud-stirrer is considered to be unsuitable for already turbid waters.

Stocking rates

One of the important considerations is to know the amount of food available in the new environment. This factor has a considerable bearing in determining stocking rates and hence production. Fish production from unit area is a product of individual growth rate and population density. From a study of growth rate of various species in a particular body of water, it is possible to assess their optimal stocking density.

The sizes of fingerlings that are stocked in Indian reservoirs come under the pre-recruit phase. Therefore, up to the size of entering the exploited phase they are prone only to natural mortality. Thus, a knowledge of the natural mortality rate is essential as due compensation can be provided for it while computing optimum stocking rates. During estimation of optimum stocking rates for such populations, about which no reliable estimates of natural mortality are available, it is felt that assumption of higher natural mortality rate would be desirable as a little overstocking would be less harmful than under stocking.

A number of methods are in vogue for calculating the stocking rate. Essentially, the number of fingerlings to be stocked is the total biomass to be harvested divided by the biomass of individual fish. However, as all fish stocked are not harvested, some addition will be needed to compensate for the possible stock loss due to mortality. Huet (1960) provided a general stocking formula, which can be applied universally irrespective of the size of the reservoir. This is the most popular formula among fishery managers, as it can be estimated without much difficulty. The fish yield rate can be estimated from the primary productivity studies. While estimating the percentage loss, chances of survival of the stocked fish in the light of predator pressure, escapement through the outlet(s) and overfishing are to be taken into consideration. The following formula can be used to calculate the stocking rate:

$$\text{Stocking rate (no/ha)} = \frac{\text{Expected yield (in kg/ha)}}{\text{Individual growth rate of fish in kg}} + \text{loss (percent)}$$

Stocking measures adopted in Indian reservoirs

The Indian experience of transplanting fish species from one river basin to another and introduction of exotic species has been very revealing. The performance of stocked and introduced fishes and their impact on the indigenous ichthyofauna have been examined (Jhingran, 1988; Sugunan, 1995). The Indian rivers are known for their rich faunistic diversity and many of the native species are considered to be superior to the introduced ones in their growth performance. While there are some instances of successful transplantations where the stocked species established good breeding populations in the reservoirs leading to increased yield rates, in many cases, stocking attempts were rarely governed by any ecosystem considerations. Such irrational stocking efforts were not only wasteful exercises, but they also proved to be detrimental to the native fish stocks from the conservation and yield optimization points of view.

The policies adopted in Indian reservoirs mainly consist of stocking fingerlings of a species or a combination of species without giving any consideration to the purpose of stocking. No criteria are followed in respect of stocking rates, species mix based on the biogenic capacity of the reservoir and without any follow up for achieving establishment of naturalized populations. On many occasions, the main consideration for deciding on the rate of stocking and species selection is the ready availability of fingerlings.

Fish stock monitoring

Experience from a number of reservoirs prompts us to conclude that stocking can be considered successful only if the stocked fish survive, grow, breed regularly and their natural breeding contributes to effective auto-stocking. In some cases, despite persistent stocking, the transplanted species have failed to show up in the catch, thereby rendering the expenditure incurred in stocking as waste. This is primarily either due to stocking wrong species or inadequate post-stocking measures such as stock monitoring/management measures. It is essential to ensure that the stocked fishes grow to maturity and breed naturally and the juveniles achieve desired levels of survival so that the natural recruitment takes place. A number of measures are required for this. A standard stock assessment method needs to be used to monitor fish population dynamics of the reservoir in order to monitor the stock. There should be restriction on fishing till the fish stocked in the first few years mature and breed in the reservoir. Other steps needed are:

- protection of brood stock,
- protection of breeding grounds,
- protection of feeding grounds of juveniles, and
- enforcement of mesh regulations to prevent catching of young ones.

There might be some reservoirs where stocked species will fail to establish despite the above measures, and in such case, new species need to be considered for stocking/introduction.

Initial stocking: It is very essential to continuously monitor fish stocks in the reservoir to make appropriate decisions. Standard population dynamics models are available for this purpose. During the initial 2-3 years, there should be heavy stocking and restricted fishing activity in order to allow the stocked fish to grow to adult size and breed. During this period, fishing gear that target stocked fishes should be banned altogether, but the gear for predators and other uneconomic species can be allowed.

Protection of breeding and feeding grounds: Different fish species have diverse breeding habits. The Indian major carps are known to migrate to the breeding grounds situated upstream. Tilapia makes nests in the littoral zone and common carp breeds on aquatic vegetation. The brooders of Indian major carps that migrate to the breeding grounds upstream through narrow shallow streams become easy prey for fishers. These brooders need to be protected while moving to and at the breeding grounds in order to allow them to complete the breeding functions. Similarly, the juveniles usually flock to shallow areas for feeding and fishing should be restricted in such places. In stock enhancement, the breeding population is established during the early phase of management. However, need for stocking might arise whenever there is a breeding failure or when stock is lost due to monsoon failure, flooding of spillways, breaching of earth dams, etc.

5.3 *Organization of fisher community*

A well motivated community is *sine qua non* for successful management of enhanced capture fisheries. This is due to the fact that stock management can be done only through participatory approach and not through enforcement under a ‘command and control’ regime as being practiced now. In an enhanced capture fishery, the management is best done by the community. For this, a sound governance framework should be in place. The community that manages the fishing should own the stock and they should organize themselves into a cooperative society, self help group or any other community group. It is most desirable, if the community organization fits into the framework of co-management. The members of the community should be empowered and motivated so that they can manage their affairs themselves without interference from middlemen or unscrupulous traders. Capacity needs to be built within the community to enable them for market intervention and value addition. The role of government agencies should be to facilitate the process of empowering the community for stocking, managing the stock, marketing and other post-harvest activities. The practice of government agencies stocking the reservoir needs to be discouraged and discontinued.

The following are the essential aspects of successful enhanced capture fisheries in a reservoir:

- right species should be selected for stocking,
- stocking should be done heavily for a few years during the early phase of reservoir formation (*i.e.* during trophic burst stage),
- fishing should be restricted during the first few years after stocking to allow the stocked fish to mature,
- breeding and feeding grounds should be protected,
- catching of broodstock and juveniles should be prevented through appropriate measures,
- stock assessment should be done through standard population dynamics modeling,
- supportive restocking should be done when breeding failure or stock loss occurs,
- the community should be organized into highly motivated and empowered groups so that they can manage the resource effectively,
- infrastructure facilities in terms of landing sites, electricity, ice plants/cold storage, transport vans, connecting roads, etc should be provided to reduce post-harvest losses, and
- marketing and financing channels should be provided in order to protect the fishers from unscrupulous money lenders and middlemen.

5.4 Role of exotic fishes

In spite of the already rich and diverse fish genetic resources in India, more than 300 exotic species have been introduced into the country so far. While a vast majority of them are ornamental fishes, which remain, more or less, confined to the aquaria, some others have been introduced in aquaculture and open water systems with varying degrees of success. *Oreochromis mossambicus, Hypophthalmichthys molitrix, Ctenopharyngodon idella, Cyprinus carpio communis, C. carpio specularis* and *C. carpio nudus* have gained entry into the reservoir ecosystem through accidental or deliberate introductions. Among them, the impacts of tilapia, silver carp and common carp introductions on the fisheries have been witnessed in various reservoirs in the country. Imapct of the recently introduced African catfish *Clarias gariepinnus* is yet to be assessed.

Tilapia

The tilapia *O. mossambicus* was first introduced into the pond ecosystem in 1952 and soon it was stocked in the reservoirs of south India. By the end of 1960s, most of the reservoirs in Tamil Nadu and those in Palakkad and Trissur districts of Kerala were regularly stocked with this fish. Performance of tilapia in ponds of south India has been discouraging mainly due to its early maturity, continuous breeding, over-population and dwarfing. It is reported to mature at 6 cm length at an age of 75 days and to breed at an interval of one month under tropical conditions. On the contrary, the south Indian reservoirs provided a conducive habitat for tilapia, where it established a secure position. In certain cases, tilapia virtually eliminated all other fishes including the stocked Gangetic carps. The average size of tilapia from Tamil Nadu reservoirs during the 1960s was reported to be 1.5 kg. Tilapia still continues to support a fishery in many peninsular reservoirs including Malampuzha reservoir in Kerala, although the size has declined.

Silver carp

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

- reported ability to utilise *Microcystis,*
- impressive growth rate, and
- propensities for affecting indigenous species, especially *Catla catla.*

The most spectacular performance of silver carp has been reported from Gobindsagar reservoir (Himachal Pradesh), where after an accidental introduction, the fish formed a breeding population and brought about a phenomenal increase in fish production from the reservoir from 160 tonnes in 1970-71 to 1 200 tonnes in the year 2000. Many workers have suggested the over-intensity of feeding in respect of silver carp, as reflected by the gorged and full conditions of gut all through the year. Jhingran and Natarajan (1978) pointed out that the silver carp, being a cold-water fish, when introduced into a warmer regime, consumed food much in excess and grew faster as expected of a true poikilotherm. A similar latitude-induced change worth noticing is the age at maturity. The fish matures when they are 5 to 6 years old in North China, 4 to 5 years in Central China and 2 to 3 years in south China. In India, it breeds just at the age of one year under optimum conditions.

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

Common carp

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

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

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

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

5.5 Craft and gear

Crafts

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

Unlike Gobindsagar, where all the fishers posses boats, reservoir fishers, in general, are too poor to own boats. In many reservoirs like Vallabhsagar (in Gujarat) and Hirakud, the fishermen could procure boats with the help of subsidy and other financial assistance from funding agencies. In Vallabhsagar, boats are distributed by the State among the fishers at a subsidy of 50 percent, while in Hirakud they get it from various schemes operated by the National Agriculture Bank for Rural Development (NABARD) and the National Cooperative Development Corporation (NCDC). Wooden boats are used for fishing in a number of reservoirs, especially in northern India. Flat bottomed, locally fabricated boats ranging in length from 3 to 7 meter are used in Kyrdemkulai (in Meghalaya), Hirakud, Malampuzha, Gobindsagar, Gandhisagar and Rihand (in Uttar Pradesh). A plank-built, flat-bottomed canoe, 2 to 3 m in length is the most popular fishing craft of Gandhisagar. In the same reservoir, the repatriates from the erstwhile East Pakistan used the Bengal type dinghy, which is 5 to 7 m in length and has the additional facility of setting sails for propulsion.

Mechanized boats are not used in reservoir fishing to any appreciable extent. A 9.1 m long wooden, mechanized boat was introduced by the Central Institute for Fisheries Technology (CIFT), Kochi in Hirakud reservoir, but it proved to be too expensive for the fishers. It is significant to note that large water bodies like Nagarjunasagar, Tungabhadra and Krishnarajasagar have no motorised craft either for fishing or for fish transport.

Dugout canoes, carved out of palm trees are used in Yerrakalava reservoir. In most of the reservoirs in the country, fishers rely on improvised materials and show

considerable ingenuity in fabricating makeshift rafts out of discarded old tyres, logs, used cans, thermocole, etc. In a vast majority of Indian reservoirs, where the catch is not very remunerative, fishers depend entirely on these improvised devices.

Gear

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

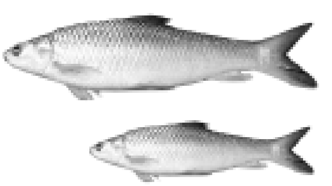
Unlike marine fisheries, very little attention has been paid over the years towards improvement of gear in the inland sector, barring an attempt to upgrade the reservoir fishing gear by two experts under the aegis of FAO/ UNDP programme during the 1960s (Gulbadamov, 1962 and Znamensky, 1967). A number of improvements were suggested by the experts in the fishing techniques followed by the reservoir fishers. Apart from the introduction of frame net, they also suggested improvements in the design of gill nets, beach seines and long lines. Unconventional methods such as electrical fishing, use of light as fish lure, the use of echo sounder for fish detection and survey of bottom topography were the other important suggestions.

The main emphasis of gear improvement was the modification of gill nets. The Russian experts designed two nets *viz.* Sebgul I and Sebgul II, which were gill nets with modified rigging pattern. While ensuring a proper fixing of webbing on head and foot ropes, a uniform hanging coefficient was ensured. Similarly, the sideways movement of the webbing was checked to maintain effective area of the net. Ranganathan and Venkataswamy (1966) conducted experiments in Bhavanisagar reservoir in

Tamil Nadu to check the efficacy of the new design and found no appreciable superiority of Sebgul nets over the *Rangoon* nets.

The CIFT has experimented with gill nets of various colours and found yellow and orange coloured nets yielding better catch than the white coloured ones. It has been observed that 77 percent of the carps were caught by entangling and the rest by gilling. The usual method of increasing the entangling capacity of gill net is by decreasing the slackness of webbing, which can be achieved by suitable modifications in the hanging of the net. Gill net continues to be the main fishing gear employed for fishing in reservoirs. However, being a highly selective gear, its unregulated use can lead to serious distortions in fish populations. For instance, selective removal of carps by gill nets can result in situations leading to domination of carp minnows, predators and other undesirable fish.

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



6.0 Other management measures

6.1 Pre-impoundment surveys

In India, pre-impoundment surveys conducted during dam construction invariably lack fisheries perspective. However, in case of River Narmada, the Narmada Control Authority has conducted a socio-economic survey of the Narmada basin with the objective of addressing fisheries development in the reservoirs created by the impoundment of the river and its tributaries.

The pre-impoundment surveys help providing a framework for future fisheries and other development activities in the reservoir, which *inter alia* encompass the following aspects:

- inventory of the native ichthyofauna in the river stretch above and below the dam, and their likely chances of survival,
- breeding habits of fishes and the possible impact of impoundment on their recruitment,
- survey of breeding grounds in relation to submergence, both above and below the dam,
- hydro-biological characteristics of water and soil with special emphasis on the nutrient and thermal regime,
- need for creating infrastructure such as, hatcheries, nurseries, ice plants, etc,
- site selection for pen nurseries, cages, etc,
- possibilities of removing submerged trees and other obstructions, and
- inventory of fishing villages, together with demographic details on fisher population and craft and gear.

The following account deals with some of the important pre-impoundment activities:

6.2 Timber clearance

Opinion is divided on the wisdom of removing timber from the reservoir bed. While it is mostly appreciated that a reservoir bed free from obstructions facilitates the use of active fishing gear and leaves room for other management options, many workers feel the necessity to leave at least the non-commercial timber intact for a variety of purposes such as, reducing wave action, flocculating the colloidal clay turbidity, providing habitat for fishes and substrata for periphyton deposition (Bhukaswan, 1980). Timber clearance has been tried in a number of reservoirs in India, both before and after the impoundment. In Chillar and Benisagar reservoirs of Madhya Pradesh, trees were cut from the lake bed and auctioned before the reservoirs were filled. Harsi, Jamoia and Ghatera reservoirs, also in Madhya Pradesh, are examples of complete clearance of date palm trees from the marginal areas during the summer months. A forest area of about 61.4 km^2 was cleared in Hirakud, when the bed was exposed during draw down. Clearance of forest has also been undertaken in many impoundments created under the Narmada River Basin Project.

The need for timber clearance is largely dictated by the cost of such clearance and also the requirements of the major users of the impoundment. In the post-impoundment stage when fisheries development is normally planned, fishery managers should make a careful assessment of the status of timber clearance from the reservoir and take appropriate decisions with regard to the deployment of the gear. Since gill nets are the predominant gear in Indian reservoirs, timbers, if even left uncleared would not impede the fishing activities. The only obstructions that the gear would encounter would be during shore seining, if at all practiced for removal of minnows and weed fishes.

6.3 Removal of predators and weed fishes

Presence of predatory and weed fishes poses impediments in survival and growth of economic species in many Indian reservoirs. Keeping these unwanted populations under check is a challenging management problem, especially in large reservoirs. A small population of predators helps to crop trash fishes, which compete for food with the economic species. However, no scientifically sound methods are available to keep a limited population of predatory species. Repeated use of gill nets of appropriate mesh sizes, use of long lines, traps, etc are suggested for control of the uneconomic and undesirable populations.

Manipulation of reservoir level with a view to checking the breeding and destruction of young ones of predators and minnows has been tried in several countries. However, this is not practicable in many Indian reservoirs since the water release pattern is dictated by priority sectors like irrigation and power generation. Poisoning of selected sheltered areas, arms and coves as practiced in some other countries has also limited use in India due to the multiple uses of water and objections from the other water users. *Alivi,* the giant shore seine of Tungabhadra has been successfully used to remove trash fish in large numbers. Judicious use of this gear, with a condition that the juveniles of economic species are released back, can go a long way in containing the trash fish population.

Recent findings with regard to the efficacy of trawling in checking predators and trash fishes are of interest. Bottom trawling in Gandhisagar was found to catch 64 to 91 percent of the unwanted fishes and this has been recommended as a method to crop the predators and carp minnows. Nevertheless, applicability of this method is limited to places where the bottom is free from obstructions.

6.4 Cage and pen culture

Production systems, such as cage and pen culture are becoming increasingly popular in India. It is now widely accepted that pen enclosures erected in the reservoir margins can be used as nurseries to raise stocking material to obviate the necessity of constructing land-based nursery farms, which are cost-intensive. Similarly, rearing of fish in pens up to marketable size enables easier stock manipulation and total harvesting. In case of some hardy species such as common carp and tilapia, cages can also be used for raising stocking material. However, non-standardization of farm practices and materials to be used in cage and pen culture still acts as a major retardant for large-scale adoption of these culture systems in the Indian reservoirs.

Species selection for cage and pen culture

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

- fast growth rate,
- adaptability to the stresses in enclosures due to crowded conditions,
- ready acceptance of artificial feeds consisting mainly of cheap agricultural by-products,
- high feed conversion rates,
- resistance to diseases, and
- good market demand.

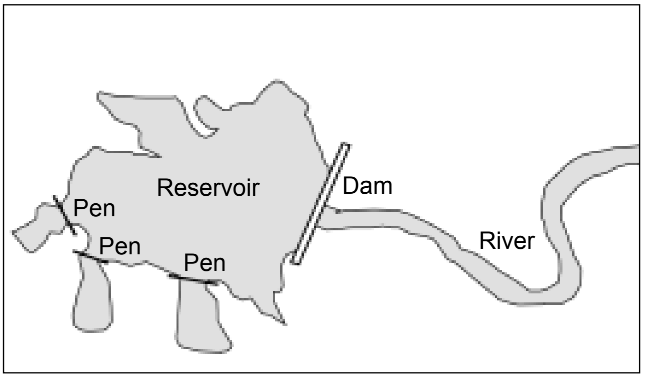
Under the Indian conditions, the Gangetic major carps (*C. catla, L. rohita, C. mrigala)*, murrels, the Chinese carps (*H. molitrix, C. idella*) and common carp *(C. carpio)* satisfy these requirements to a great extent. Selection of species, however, is mainly dictated by the local demand and availability of quality seed and other inputs in adequate quantities.

Site selection

Appropriate site selection is important for installation of pens and cages. Sheltered, weed-free, shallow bays are the ideal locations for installing pens and cages. The sites should have adequate circulation of water, with wind and wave action within moderate limits. Water level fluctuation is the most important consideration in site selection for pen culture. A scrutiny of the contour map and the monthly fluctuation pattern of reservoir levels will enable location of suitable sites, which retain sufficient water for the required period of time. Sites which dry out during summer will be ideal, as it is easier to erect pens on dry land, to be inundated later as the water level rises (Fig. 7).

Fig. 7: Erection of pen in a dry area (to be inundated as water level rises)

Fig. 8: Installation of pens in a reservoir



Ideal locations of pen in a reservoir.

Erection of pen in a reservoir.

Drag netting in the pen to remove unwanted fishes and other organisms.

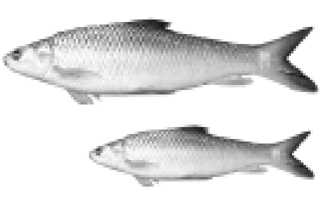
Similarly, some bays of the reservoir retaining water for sufficient period can be identified and cordoned off by erecting barricades (Fig. 8). While selecting the site, it is also important to see the accessibility of the site, as transportation of the juvenile stages (spawn/fry) of the stocking material will be difficult in remote and inaccessible corners of the reservoir.

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

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

- steep water level fluctuations,
- wind and wave action,
- lack of suitable pen materials, and
- weed infestation.

The water retention time in the reservoir is important, since rearing has to be completed before the water level in the pen goes down to critical limit. In reservoirs with high draw down, water retention time is very limited. Sometimes filling takes place so late that no spawn of desirable carps will be available when the water level attains the desirable limit. Recent advances made by research institutions in the country to breed fish for protracted time give hope for solving this problem. The other problems encountered are pen walls limiting water circulation, accumulated feed and fertilizers causing eutrophication leading to weed infestation and fouling of water and fish kills.



7.0 Exploitation systems

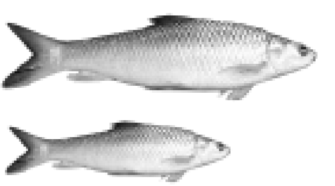
Fisheries being a State subject, management of reservoir fisheries vests with the State Governments. There is a great deal of divergence in the management practices followed by individual States, which vary from outright auctioning to almost free-fishing. Cooperative societies (primary and apex) and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

Commercial exploitation systems followed in different States can be broadly classified under four headings *viz.*

- departmental fishing,
- lease by auctioning,
- licensing to cooperative societies or individuals, and
- fishing on royalty basis (crop sharing).

Direct departmental fishing not being an economic proposition, is followed only in a very few reservoirs. In most of the cases, the department exerts its control over the exploitation by acting as a marketing link and controlling the fishing effort. In Rajasthan, Madhya Pradesh and Uttar Pradesh, small reservoirs are mostly auctioned on a yearly basis. In a number of large reservoirs, free licenses are issued to fishers without any limit. This virtual open access has been found to be detrimental to the interests of both the ecosystem and the fishers. Crop sharing is a very popular mode of exploitation in Tamil Nadu and can be used in other parts of the country with similar settings.

Privatization of the reservoir fisheries is also discussed from time to time. While privatization *per se* may not be a bad idea, but before any attempt to privatize reservoirs for fisheries exploitation is considered, even on a trial basis, the required policies and guidelines for stocking and harvesting should be in place. Similarly, a sound monitoring mechanism should also be instituted to ensure that the private operators adhere to the agreed norms. This would ensure sustainable exploitation of the resources.



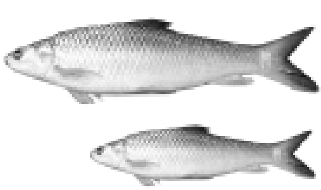
8.0 Economic indicators in reservoir fisheries

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

- rehabilitating the displaced (during dam construction) population,
- improving the living conditions of fishermen, and
- providing employment/livelihoods opportunities.

Although capture fisheries in the reservoirs is akin to extractive industries where the yield depends on the state of technology involved and the quantum of labour and capital deployed, the renewable nature of the resource and the intricate biological principles involved in the ecosystem processes impart a heavy element of management challenge. While human interventions are less intense in reservoirs, compared to aquaculture operations, the production-function relationship is more intricate and less precise. Further, a certain measure of stability needs to be imparted in production by affecting sustained improvements in yield along with remunerative returns to fishers by narrowing the price spread between the producer and the consumer.

In aquaculture, it is estimated that 77.23 percent of the price paid by the consumer is received by the producer. As opposed to this, a major chunk of the price is siphoned away by the wholesalers and other market intermediaries in reservoir fisheries. A factor that can bring serious distortions in the income level of fishers is the over concentration of fisher in the wake of low fish productivity. For instance, in Ukai reservoir in Gujarat, with an area of 36 525 ha, 306 boats with 3 400 gill nets (50 m each) operated during 1985-86 to 1992-93. In a fishing year comprising 260 days, 1 836 fishermen netted out 174 tonnes of fishes. In sharp contrast to this, 520 fishermen of Nagarjunasagar shared a catch of 170 tonnes in a year. In lower Aliyar (Tamil Nadu), 17 tonnes of fishes were harvested by 14 fishermen and each of them after meeting the royalty obligations could take home only Rs. 1 000 to 1 400 a year. A better picture, however, emerged in Bhavanisagar, where 80 fishermen after sharing 150 to 300 tonnes of fishes, earned an annual individual income of Rs. 8 175 (Paul and Sugunan, 1990).

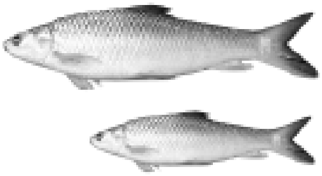


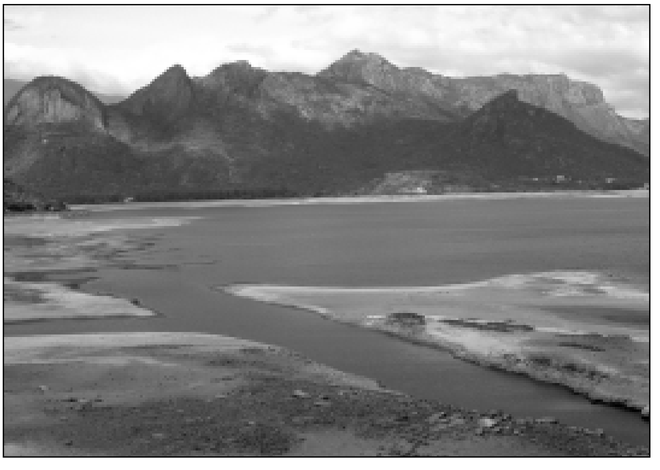
9.0 Conservation of habitat and biodiversity

There is a need to achieve tradeoff and synergy between the twin objectives of conservation and yield optimization in reservoir fisheries. While the fishers and fish merchants strive to increase production for economic considerations, it is the responsibility of the State to ensure that economic expediency of development does not mar the ecological reasoning. Virtual free fishing, as followed in many reservoirs is counter-productive to the norms of conservation and yield optimization. Although there are fair possibilities of linking reservoir fisheries development with poverty alleviation programmes, the progress made so far in this direction is not very encouraging. Chances of creating additional employment are not much in majority of Indian reservoirs. On the contrary, many reservoirs have surplus manpower, which can be diverted to other reservoirs having the capacity to absorb more, without eroding the income level of the existing fishers.

Ecosystem approach to reservoir fisheries management

Reservoir ecosystems are set in complex and dynamic environment and these water bodies produce multiple public goods and services, including fisheries. Fisheries management in reservoirs is as unique as the ecosystem itself. Depending on a variety of extraneous factors that govern the sustainability of fish stocks in the reservoirs, and balancing the multi-purpose needs for which such impoundments are created, fisheries management in the reservoirs needs a holistic approach. For this purpose, an ecosystem approach to fisheries management (EAFM) is the right answer, as this approach allows putting into place sustainable development concepts into fisheries by addressing both human and ecological well-being. The EAFM also allows implementation of an integrated socio-ecological system and fully recognizes the principles of equity and sustainability.





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11.0 Glossary

Alkalinity

A measure of the capacity of water to neutralize a strong acid. In natural waters this capacity is attributable to basic ions such as bicarbonate, carbonate and hydroxyl ions as well as other ions often present in small concentrations such as silicates and borates.

Aquaculture

The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.

Aquatic Organisms

A complex of living organisms and their non-living environment, which are inseparably interrelated and interact upon each other.

Bathymetry

The measurements defining the size, depth and shape of a lake.

Benthos

Animals attached to, crawling on or burrowing into the bottom substrata in a water body with no or limited mobility.

Biological Diversity

The variety and variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Biological Indicator

Organism, species or community whose characteristics show the presence of specific environmental conditions. Other terms used are indicator organism, indicator plant and indicator species.

Biological Interaction

An interaction between species or stock elements resulting from direct predation or competition for food (predator-prey relationships) or space (or both). Because of their importance, the impact of fishing on associated species or dependent species needs to be assessed.

Biomass

Also referred to as the standing stock. The total weight of a group (or stock) of living organisms (*e.g.* fish, plankton) or of some defined fraction of it (*e.g.* spawners), in an area, at a particular time.

Biotic

Live and living organisms.

Bloom

When related to phytoplankton, a sudden and rapid increase in biomass of the plankton population. Seasonal blooms are essential for the aquatic system productivity. Sporadic plankton blooms can be toxic.

Brood Stock

Specimen or species, either as eggs, juveniles, or adults, from which a first or subsequent generation may be produced in captivity, whether for growing as aquaculture or for release to the wild for stock enhancement.

Capture-based Aquaculture

Aquaculture system where seed is sourced from natural (wild) collections.

Carrying Capacity

The maximum population of a species that a specific ecosystem can support on a sustainable basis.

Catchment Area

The area drained by a river or body of water.

Co-management

A governance system in which representatives from the community and government participate in decision-making processes.

Common Property Resource

A resource held collectively and managed by a community or a particular group (two or more persons) within a community for the common benefit. Excludes individual rights.

Conservation

Actions, which are directed towards sustaining otherwise decreasing rates of use, towards sustained yield management, or towards increasing a sustained use.

Culture-based Fisheries

Fisheries that depend solely or mostly on stocking (stock and recapture).

Drawdown

The lowering of a reservoir or lake by controlled withdrawal.

Detritus

Tiny particles of material found in sediments or suspended in water. Organic detritus is derived from the decomposition of organisms: inorganic detritus is derived from the erosion of rocks and other mineral materials.

Ecological Impact

Effect of human activities and natural events on living organisms and their non-living environment.

Ecosystem

Systems of plants, animals and microorganisms together with the non-living components of their environment.

Ecosystem-based Management

An approach that takes major ecosystem components and services- both structural and functional- into account in managing fisheries. It values habitat, embraces a multi-species perspective, and is committed to understanding ecosystem processes. Its goal is to rebuild and sustain populations, species, biological communities and ecosystems at high levels of productivity and biological diversity so as not to jeopardise a wide range of goods and services from ecosystems while providing food, revenues and recreation for humans.

Edaphic factors

Water and soil quality parameters that has a bearing on fish productivity.

Enhancement

Qualitative and quantitative improvement in productivity of water bodies through specific management options.

Enhancement through new Culture Systems

Cage culture, pen culture, Fish Aggregating Devices (FADs), etc.

Environment

The combined external conditions affecting the life, development and survival of an organism or an ecosystem.

Environmental Enhancement

Input of nutrients through fertilization to increase plankton for enhanced fish production in reservoirs.

Environmental Impact

Direct effect of human activities and natural events on the components of the environment.

Environmental Impact Assessment

A sequential set of activities designed to identify and predict the impacts of a proposed action on the bio-geophysical environment and on man's health and well being, and to interpret and communicate information about the impacts, including mitigation measures that are likely to eliminate the risks.

Epilimnion

Water column below the thermocline.

Eutrophication

Natural or man-induced process by which a body of water becomes enriched in dissolved mineral nutrients (particularly phosphorus and nitrogen) that stimulate the growth of aquatic plants and enhances organic production of the water body.

Exotic Species

Species not native to a particular area.

Fish Aggregating Devices (FADs)

Artificial substrata provided in natural water bodies allowing fish to take shelter for their easy capture.

Fish Production

Total quantity of fish produced from a water body.

Fish yield

Quantity of fish produced from a unit area and time.

Food Chain

Organisation of plant and animal communities into groups, which are dependent on one another for food. These communities form a trophic chain that transforms energy from one level to the other.

Forage Species

Species used as prey by a predator for its food.

Habitat

The environment in which the fish live, including everything that surrounds and affects its life: *e.g.*, water quality, bottom, vegetation, associated species (including food supplies).

HDPP

High Density Polyproylene.

Hypolimnion

Water column above the thermocline

Indigenous species

A species living in its natural range of distribution.

Integrated Production System

Combining fish production with crop and animal husbandry practices to enhance benefits.

Isotherms

Lower animals (lower than birds and mammals) that do not maintain their own body temperature. It is determined by the ambient temperature of the surroundings.

Limnology

Study of the ecology of freshwater ecosystems.

Lentic Ecosystem

Ecosystem of a lake, pond or swamp.

Littoral vegetation

Plants, mostly terrestrial adapted to living in submerged conditions at the interface between land and water.

Lotic Ecosystem

Ecosystem of a river, stream or spring.

Macrovegetation/Macrophytes

Submerged, floating, rooted, emergent or rooted & emergent aquatic plants.

Management Enhancement

Introducing new management options like recreational fishery, etc.

Mortality

Depletion of stock from a population. Depletion due to natural causes is natural mortality and depletion due to fishing is fishing mortality.

Niche

The role and position of a species in an ecosystem.

Oligotrophic

Water bodies deficient in nutrients.

Open Access

A condition of a fishery in which anyone who wishes to fish may do so.

Periphyton

Organisms (mostly microscopic), both plants and animals attached to submerged substrata like stones, pebbles, plant trunks, leaves, etc.

Photosynthesis

The conversion of water and carbon-dioxide by plants into glucose and oxygen. Light is used as an energy source.

Plankton (Phyto and Zoo)

Floating organisms whose movements are more or less dependent on currents. Plant component is called phytoplankton and the animal component- zooplankton.

Poikilotherms

Higher animals (mainly birds and mammals) that maintain their body temperature irrespective of the ambient temperature of the surroundings.

Pollutant

Extraneous substances present in concentrations that may harm organisms (humans, plants and animals) or exceed an environmental quality standard. The term is frequently used synonymously with contaminant.

Population

A group of fish of one species which shares common ecological and genetic features. The stocks defined for the purposes of stock assessment and management do not necessarily coincide with self-contained populations.

Precautionary Approach

Set of measures taken to implement the Precautionary Principle. A set of agreed cost-effective measures and actions, including future courses of action, which ensures prudent foresight, reduces or avoids risk to the resource, the environment, and the people, to the extent possible, taking explicitly into account existing uncertainties and the potential consequences of being wrong.

Primary Production

Synthesis of organic carbon by chlorophyll bearing organisms.

Primary Producers

Plankton, periphyton, macro-vegetation and other communities that synthesize carbon.

Recruitment

Adding of individuals into the fish stock through natural breeding and or stocking (artificial recruitment).

Renewable Natural Resource

Natural resources that, after exploitation, can return to their previous stock levels by natural processes of growth or replenishment.

Reservoir Morphometry

Measurement of various dimensions of dam and reservoir that has bearing on productivity such as dam height, mean depth of the reservoir, shoreline length of reservoir, etc.

Riparian

Land adjacent to a stream/river.

Runoff

Portion of rainfall, melted snow or irrigation water that flows across the ground's surface and is eventually returned to streams.

Saprophobes

Relatively hardier organisms that multiply and occupy the niches vacated by saproxenes.

Saproxenes

Organisms that are extremely sensitive to habitat changes, which get eliminated first as organic pollution increases.

Scampi

The freshwater prawn, *Macrobrachium rosenbergii*.

Species Enhancement

Inducting new species into the system to enhance productivity.

Species Introduction

Inducting species outside its normal range of distribution.

Species Diversity

The variety of species in a community, which can be expressed quantitatively in ways which reflect both the total number of species present and the extent to which the system is dominated by a small number of species.

Specific Conductance

A measure of a material's ability to conduct an electric current.

Stakeholders

Individuals/groups who have an interest or derive benefits from the system.

Stock Enhancement

Enhanced capture fisheries. Augmenting stock by stocking to build a breeding population.

Sustainable Use

The use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations.

Sustainable Yield

The amount of biomass or the number of units that can be harvested currently in a fishery without compromising the ability of the population/ecosystem to regenerate itself.

Thermocline (Thermal stratification)

Sudden decline in temperature at a particular depth in deep water bodies.

Trawling

A method of fishing that involves pulling a large fishing net through the water behind one or more boats.

Tropholytic Zone

The dark region below the euphotic zone is called *the tropholytic zone.*