Fisheries Enhancement of Small Reservoirs and Floodplain Lakes in India

Edited by

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CENTRAL INLAND CAPTURE FISHERIES RESEARCH INSTITUTE
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Inland fisheries resources of India and their utilization

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Introduction

India is endowed with a vast expanse of open inland waters in the form of rivers, canals, estuaries, lagoons, reservoirs and lakes. The river systems of the country comprise 14 major rivers each draining a catchment of 20,000 km^2, 44 medium rivers having an average catchment between 2,000 and 20,000 km^2 and the innumerable small rivers and desert streams that have a drainage of less than 2,000 km^2. Indian rivers carry a surface runoff of 167.23 million ha metres (mhm) which is 5.6% of the total runoff flowing in all the rivers of the world. Dotted with floodplains, oxbow lakes, quiescent backwaters and interspersed deep pools, the rivers possess a mosaic of varying biotopes ranging from lotic to lentic habitats. A large number of river valley projects have been commissioned since independence as a part of our developmental activities, resulting in a chain of such artificial impoundments. India has more than 19,000 small reservoirs with a total water surface area of 1,485,557 ha and about 180 medium and 56 large reservoirs of 527,541 and 1,140,268 ha respectively (Sugunan, 1995). Extensive areas under floodplain wetlands in the form of *mauns, beels, chaurs, jheels* available in eastern U. P., northern Bihar, West Bengal, Assam, Tripura, Manipur, Arunachal Pradesh and Meghalaya. They together form an area of more than 200,000 ha, offering ample scope for culture-based fisheries. These are shallow nutrient rich water bodies formed due to the change in river course. The estuarine capture fisheries form an important component of fishery resources of the country. The extent of the estuarine waters of India is estimated to be 2.6 m ha offering great scope for developing capture fisheries offer great scope for further development.

The inland fish production in the country has registered a phenomenal increase during the last about four decades. As against 0.2 million t produced in 1951, the present production of inland fish in the country is estimated at 2.2 million t. The projected domestic requirement of fish in the country by 2000 AD is 12 million t, a half of which has to come from the inland sector. To achieve this national goal, a scientific understanding of all the water bodies supporting capture fisheries is imperative to back up their optimum exploitation. However, there exists as many opportunities to augment the fish yield just as there are constraints which operate against them.

Riverine fisheries

The Ganga river system, with its main tributaries like Yamuna, Ganga, Ramganga, Ghagra, Gomti, Kosi, Gandak, Chambal, Sone, etc. is the original habitat of the three major fish species of the sub-continent *viz.* catla, rohu, and mrigal, better known as Indian major carps. Major part of the river Ganga and its tributaries pass through the plains making it the most important river from the fisheries point of view. Ganga is also the major source of the riverine spawn which still meets some of the fish seed requirement. A substantial part of the Brahmaputra and the peninsular rivers pass through rocky steep beds and the fisheries activities in these rivers are restricted to the limited stretches that pass through hospitable terrains. The fishing intensity along river courses varies from stretch to stretch depending upon a variety of factors like current velocity, terrain of the river bed, accessibility and the general productivity of the water.

CIFRI has been monitoring the fish yield in various rivers of the country during the past few decades. A noticeable decline in total fish output and an undesirable change in the species spectrum have been the characteristic features of fish yield from Ganga river system during the past three decades. The average yield of major carps has declined from 26.62 kg/ha/yr during 1958-61 to 6.07 kg/ha/yr during 1980-86 (Table 1). The catch of anadromous hilsa, bountiful till 1972 at all centres above Farakka Barrage in the middle Ganga, has declined by 96% due to obstruction on its up-river migration. The mahseers are already under the threat of extinction.

Table 1. Decline in the yield of Indian Major Carps in the river Ganga

Centres	1958-61	1961-69	1980-86
Kanpur	83.5	24.3	-
Allahabad	15.6	21.5	9.29
Buxar	17.1	3.8	7.00
Patna	13.3	13.3	5.08
Bhagalpur	3.6	7.5	2.90
Mean	*26.62*	*14.08*	*6.07*

Factors influencing fish yield

It is evident from the studies that the biology and ecology of the river fish communities make them extremely sensitive to changes in flood regime because of their dependence on the seasonal floods to inundate the grounds needed for feeding and reproduction. Any change in the form and dimension of the flood curve in the rivers results in changes in community structure. A characteristic feature of any river system is the nature of the input governing the productivity pattern. In the rhithron stretch of the rivers, such inputs are mainly allochthonous but in the potamon, covering the floodplains, the major inputs are silt and dissolved nutrients. There is a lack of knowledge on the relationship between these inputs and energy flow and productivity trends in these systems.

The intensity of fishing, nature of exploitation and species orientation in the characteristic artisanal fisheries of Indian rivers are governed by: (i) seasonality of riverine fishing activity; (ii) unstable catch composition; (iii) conflicting multiple use of river water; (iv) cultural stresses leading to nutrient loading and pollution; (v) lack of understanding of the fluvial system and infirm data base; (vi) fragmentary and outmoded conservation measures lacking enforcement machinery; vii) inadequacy of infrastructure and supporting services; (viii) defective marketing and distribution systems; (ix) demand directed by availability; affordability, and palatability, and (ix) socio-economic and socio-cultural determinants (Jhingran, 1984).

A successful management strategy has to take into consideration the key parameters of hydrology, fish stocks and the dynamics of their population together with regulatory measures for fishing. Observance of closed seasons and setting up of fish sanctuaries have proved their efficacy in fostering recovery of impaired fisheries. Experience has indicated that gear control measures are liable to fail in yielding results until the artisanal level of fisheries exploitation is significantly changed (Welcomme, 1979).

Prediction of catch

For prediction of future catches, Welcomme (1979) has summed up a number of methods based on statistical correlations between some environmental parameters and the catch, assuming that the dynamics of fish populations as well as the catch in large rivers are close positive correlates of hydrological regime. These methods have been found to give fairly accurate results. A basic Indian model needs to be developed for studying the production potential of Indian rivers. A strong database is the most essential prerequisite for managing a fishery. The scientific task is, therefore, to identify the best ways in which scientific models, data, and other scientific inputs can be used to advice the decision makers.

An integrated riverine resources management envisages:

i) *Basin-wise approach, taking into account, the multiple use of river water and the impact of developmental activities on the biotic wealth;*

ii) *A comprehensive computer model for environmental impact assessment;*

iii) *A judicious water allocation policy for various sectors taking into consideration the biological threshold levels*; and

iv) *Keeping fisheries at par with other developmental and conservation activities in the river basins.*

Estimation of fisheries

Recently, a number of methods have been attempted for estimation of riverine fish populations and prediction of future catch. These have taken into consideration velocity of current, nature of the bottom and the banks, obstacles to flow, etc., as the main factors determining the choice of method to be applied for such estimation. Some of these methods are: (i) estimation of fish stocks from deposited eggs (Rothschild, 1961; Bastl, 1977; English, 1964; and Sabille, 1964); (ii) estimation based on the fish catch data (Nikolskii, 1965; Allen, 1951; Williams, 1965); (iii) catch and effort data (Leopold & Dabrowski, 1975; Beverton and Holt, 1957 and Gulland, 1969; (iv) estimations based on catch studies and biological data (Backiel, 1971; Mann, 1965); (v) Huet's method (Huet, 1949, 1964).

Estuarine fisheries

The fisheries of estuaries of India are above the subsistence level and contribute significantly to the production. The average yield is estimated to sway from 45 to 75 kg/ha. The important estuarine resources of the country with their production levels are detailed in Table 2.

Table 2. Important Estuarine Fisheries Resources of India

Estuarine system	Estimated area level (ha)	Production (t)	Major fisheries
1. Hooghly-Matlah	2 34,000	20,000-26,000	Hilsa, *Harpodon, Trichiurus, Lates,* prawns etc.
2. Godavary estuary	18,000	c. 5,000	Mullets, prawns
3. Mahanadi estuary	3,000	c. 550	Mullets, bhetki, sciaenids, prawns
4. Narmada estuary	30,000	c. 4,000	prawn
5. Peninsular estuarine systems (Vasista, Vinatheyam, Adyar, Karuvoli, Ponniar, Vellar, Killai & Coleroon)	-	c. 2,000	Mullets, prawns, clupieds, crabs
6. Chilka lagoon	1,03,600	c. 4,000	Prawns, mullets, catfishes clupeids, perohes, threadfins, sciaenids
7. Pulicat lake	36,900	760-1,370 (20.6-37.2 kg/ha)	Prawns, mullets, perches, crabs, clupeids
8. Vembanad lake and Kerala backwaters	50,000	14,000-17,000 (fishes) (280-366 kg/ha) 88,000 (live clams) 1,70,000 (dead shells)	Prawns, mullets, bhetki, pearlspot, chanos
9. Wetlands of West Bengal a) *Freshwater bheries* b) *Saline bheries*	 9,600 33,000	10-14 (1 258 kg/ha) c. 25,500 (775 kg/ha)	Prawns, mullets, tilapia bhetki
10. Mangroves	3,56,500	-	No data available on catch

(After Jhingran, 1992)

The Hooghly-Matlah estuarine system, Chilka lagoon, Adyar and Mankanam estuaries, Pulicat lagoon, coastal belt of East Godavari, Vembanad lagoon and Mandovi estuary have been identified to be excellent sources of naturally occurring fish and prawn seed for exploitation for aquacultural purposes. As the country looks forward to its emerging coastal zone management needs, guidelines evolved at the Central Inland Capture Fisheries Research Institute (CIFRI) provide valuable insights and possible solutions for their beneficial use, protection and sustainable development, following a holistic approach (Jhingran & Chakrabarti, 1990). During recent past, there has been specific decline in the salinity of the Hooghly-Matlah estuarine system on account of regulated discharge from the Farakka Barrage. This has brought about distinct changes in the species composition apart from natural fluctuations caused by density dependent and density independent factors. However, there are no indications of decline in hilsa abundance so far, the prime fish constituting 8-10% of the catch from the estuary.

Unfortunately, the hilsa fishery has almost disappeared from its freshwater strongholds. Hilsa, which used to contribute a lucrative fishery in the middle reaches of Ganga up to 1,500 km above the estuary, suffered a serious setback due to the construction of Farakka barrage at 476 km from the river mouth. Collapse of the Gangetic hilsa fisheries (Table 3) has affected the lives of thousands of fishermen along the riparian stretches in Uttar Pradesh and Bihar.

A recent significant development in hilsa fisheries has been the attempts to practise aquaranching for its revitalization. The CIFRI has been striving to develop hatchery management practices for hilsa and to restock the depleted stretches of the river with artificially produced seed. Attempts in this direction have borne fruits and a sample consignment of hilsa seed has been stocked in the Ganga above Farakka barrage. This is the beginning of an ambitious plan to set up a hatchery at Farakka and to undertake regular stocking programme. But the success of ranching programme is still a subject of controversy.

Table 3. Average landings (t) of hilsa in river Ganga during pre-Farakka and post-Farakka periods

Centres	Pre-Farakka	Post-Farakka
Allahabad	19.30	1.04 (94.61)
Buxar	31.97	0.60 (98.12)
Bhagalpur	3.95	0.68 (83.05)

Parentheses denote % decline

Reservoir fisheries

Indian reservoirs are classified into large, medium and small based on their area and the total water spread under all categories is estimated to be > 3 million ha (Table 4). The CIFRI's research over the last two decades has led to sound technological approaches that can substantially augment production from Indian reservoirs. This was amply demonstrated in the past when a production of 100 kg ha^{-1} was achieved in Gularia reservoir near Allahabad in the late 1970s. Later, a newly created 140 ha impoundment, the Bachhra reservoir, in the Meja Tehsil of Allahabad was studied and development measures were formulated for its fisheries. During 1986-87, the package of stocking and harvesting developed by the Institute resulted in a yield of 139 kg/ha from the reservoir. Encouraged by the increased production rate in the above

Table 4. Reservoir fishery resources of India

Category	Number	Area
Small < 1000 ha	19134	1,485,557
Medium 1000-5000 ha	180	527,541
Large < 5000 ha	56	1,140,268
Total	19,370	3,153,366

(Sugunan, 1995a)

reservoirs, the U. P. Government leased out the Baghla reservoir to the CIFRI for scientific management. In recent years, similar remunerative results have been achieved from Aliyar and Thirumoorthy reservoirs in Tamil Nadu where a yield up to 190 kg/ha and 182 kg/ha have been achieved. Table 5 shows the production rates demonstrated by CIFRI in different reservoirs of the country. Reservoir management for fisheries is capable of generating additional national income of the order of 100 crores per year and providing employment to lakhs of rural poor through fishing, transport, marketing and ancillary industries (Srivastava, 1984). Small reservoirs also offer opportunities for integrating agriculture and livestock farming with fisheries and establishing self-sustaining villages.

Large dams are increasingly becoming a characteristic component of river basins. In Rihand and Gandhisagar reservoirs, fish yield reached its initial peaks in the fourth year of impoundment (Jhingran, 1982; Dubey and Chatterjee, 1977). However, this high production is not sustained for long. After a period ranging from one to several years, it declines to much lower level, partly due to diminution of bottom leaching as volume of impounded water increases and partly as nutrients are used up by aquatic vegetation when it becomes established in greater quantity. The productivity ultimately gets stabilized somewhere near half the magnitude of initial phase (Bhukaswan, 1980), getting adjusted to the basic productivity levels of the basin and allochthonous nutrients from the inflows and watershed runoff.

Table 5. Yield obtained before and after adopting scientific management in reservoirs

Reservoirs	State	Area (ha)	Yield (kg/ha)	
			Before	After
Gularia	Uttar Pradesh	150	33	100
Bachhra	-do-	140	*	140
Aliyar	Tamil Nadu	646	27	190
Thirumoorthi	-do-	234	70	182

*New reservoir

Floodplain lakes

Floodplain lakes can be grouped into two main categories. Those which have retained their connections with the parent river through narrow channels at least during monsoon are called open *beels.* While the ones which are cut off from the parent rivers are called closed beels. The list of river basins in which the major oxbow lakes are distributed is given in Table 6.

Table 6. Distribution of floodplain wetlands in India

State	River basins	Local names	Area (ha)
Arunachal Pradesh	Kameng, Subansiri, Siang, Dibang, Lohit, Dihing and Tira	*beel*	2,500
Assam	Brahmaputra and Barak	*Beel*	100,000
Bihar	Gandak and Kosi	*Mauns & Chaurs*	40,000
Manipur	Iral, Imphal, and Thoubal	*Pat*	16,500
Meghalaya	Someshwari and Jinjiram	*Beel*	213
Tripura	Gumti	*Beel*	500
West Bengal	Ganga & Ichamati	*Beel*	42,500
Total			**202,213**

(Sugunan, 1995b)

Ecological status

Nutrient-wise, these bodies are extremely rich as reflected by their soil quality and bottom sediments. In terms of potential, *beels* are capable of giving an annual fish crop of 1000 to 1500 kg/ha. Their ecologically degraded condition and lack of proper management measures have resulted in a rather paltry yield (120-320 kg/ ha) from most of the *beels*, leaving a significantly wide gap between the actual yield and their harvest potential.

Environmental stress

In most of the *beels*, marginal areas are utilised for agricultural purposes. These water bodies are subjected to a variety of environmental stresses especially from pesticides and other agricultural runoff, municipal wastes and siltation. DDT, endosulfan, methyl parathion, HCH, ethyl parathion quinalphos, carbaryl and dimethoate phosphamidon are the most commonly used pesticides. The fish food organisms are very sensitive to these chemicals. The siltation can adversely affect the reproduction of fish by the accumulation of sediments in the marginal areas of the beels which form the breeding grounds for the fish. Siltation can adversely affect the benthic community by covering the lake bottom.

CONCLUSION

Inland Fisheries resources of India are rich and varied. They also hold enormous production potential to meet all the inland fishery requirements of the country. However, irrational norms of exploitation can endanger the delicate balance of these ecosystems leading to poor yields. Open water fisheries are managed on the basis of exploitation of natural stocks. Therefore sound environmental protection norms are to be set and followed to develop the inland fishery resources in a sustainable manner. CIFRI is providing research back up to combine the environmental norms and sustainable development of the resources in order to meet the requirement of the country.

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Floodplain wetlands, small water bodies, culture-based fisheries and enhancement- conceptual framework and definitions

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Introduction

In the recent years, there has been a spurt in aquaculture activities throughout the world. This renewed interest in aquaculture emanates chiefly from the stagnation in growth rate of marine capture fisheries and the growing uncertainties about their sustainability. The scarcity of fossil fuel, the most crucial input for marine capture fisheries, and the fast depleting marine fish stocks have also resulted in this shift towards aquaculture. In many developing countries, aquaculture has been given high priority to improve the availability of protective food for their under-nourished peoples and also to cater to the overseas trade. However, the rapid growth of aquaculture seems to have bred more problems than it sought to solve. Irrational growth of aquaculture ventures impervious to environmental norms can open a floodgate of new concerns as evident from the recent Asian experience of prawn culture boom. Apart from the environmental degradation, the rich biodiversity of the wetlands and other ecosystems are under threat. There is also a human side of the problem in the form of social disruptions. Traditional inland fishers, especially the local communities surrounding the open water bodies are hit hard by the new developments. They suffer on many counts. Various developmental activities have already resulted in the loss or degradation of many ecosystems, taking a heavy toll on their faunistic wealth. Often, there were no avenues for alternative employment for the marginal fishers rendering them vulnerable. Now they are totally marginalised by the shift in accent towards intensive farming with excessive dependence on monetised inputs.

There is an increasing trend of dichotomy between intensive aquaculture and more eco- friendly options such as fishery enhancement. While the protagonists of intensive aquaculture advocate for high input culture systems to produce maximum biomass from a unit area of water, there is an equally strong view point in favour of settling for environment-friendly, sustainable system of production, even if it means a lower yield rate. This debate throws open the whole gamut of options available in managing our aquatic ecosystems.

Capture and culture fisheries

One of the useful criteria for demarcating the *culture* and *capture* fisheries is the extent of human intervention in the management process. In a typical capture fishery, the wild untended stock of organisms is harvested with little human intervention on either habitat variables or the biotic communities. On the other hand, in a culture fishery, the whole operation is based on captive stocks with a high degree of effective human control over the physico-chemical water quality and other habitat variables. The marine fisheries is the example of capture fisheries and the intensive aquaculture of fish and prawn in small ponds is the typical culture fishery.

Fishery management purely on capture fishery lines, as understood in case of marine fisheries seldom operates in the inland waters of India, with the possible exception of rivers and estuaries. Catches from rivers are actually falling drastically in the world over, due to the negative impact of human activities on the aquatic environment. Most of the open waters which contribute substantially to fish production such as reservoirs, *beels, boars, chaurs*, *etc* are managed on the basis of *culture-based fisheries* or various forms of *enhancement*, which are intermediate to culture and capture fishery norms. However, these norms lack conceptual clarity due to the absence of clearcut definitions. Since semantic confusion regarding definition of water bodies and management norms is very much evident in the literature, an attempt is made here to define and explain some of them.

Resources

Floodplains, wetlands and floodplain wetlands

Floodplains: Floodplains are the flat land bordering rivers that is subject to flooding which tend to be most expansive along the lower reaches of rivers (Matlby, 1991). In many cases, floodplains are associated with coastal lowlands and often end in estuaries and deltas. They can also spread out into large deltas at a considerable distance from the coast. The floodplains are either permanent or temporary water bodies associated with rivers that constantly shift their beds especially in the potamon regimes. The frequency with which a river changes its course depends on a number of variables like flow velocity, sediment transportation rate, slope, channel pattern, water and sediment yield, amount and duration of precipitation over the catchment area, texture and lithology of soil, tectonic status, and so on. According to Leopold *et al.* (1964), a typical floodplain will include the following:

i) *The river channel*

ii) *Ox-bows or ox-bow lakes:* These represent the cut-off portion of meander bends of a river, usually serpentine or horse-shoe shaped.

iii) *Point bars:* These are loci of deposition on the convex side of curves in the river channel.

iv) *Meander scrolls*: Depressions and rises on the convex side of bends formed as the channel migrates laterally down-valley by the erosion of the concave bend.

v) *Slough:* Areas of dead water formed in the meander scroll depressions and along the valley walls as flood flows move directly down valley scouring adjacent to the valley walls.

vi) *Natural levees:* Raised berns or crests above the floodplain surface adjacent to the channel, usually containing coarser materials deposited as floods flow over the top of the channel banks. These are most frequently found at the concave bank and are submerged annually. They are most frequently found at the concave bank and are submerged annually. They may be absent or imperceptible where most of the silt load in transit is fine grained.

vii) *Backswamp deposits:* Overbank deposits of finer sediments deposited in slack water ponded between the natural levees and the wall or terrace riser. These are submerged for long periods of the year.

viii) *Sand splays:* Deposits of flood debris usúally coarser sand particles in the form of splays or scattered debris:

According to flow of water, the floodplains can be divided into two groups:

a) The plain (lotic component): Includes the river channel (s), the levee region which more or less follows the river channel course and the flats (extending from the levees to the terrace or plateau delimiting the plain. While the main channel (s) of the river usually retains waters (not necessarily flowing water) throughout the year, the levee regions and the flats are seasonally inundated but remains dry for at least some parts of the year.

b) The standing water (lentic component): Receding floods leaves permanent or semi-permanent standing waters in the form of sloughs, meander scroll depression, backswamps or the residual channel (ox-bow lakes). These water bodies expand or contract in area according to annual flood cycle and tend to merge into a continuous sheet or water covering the whole plain during the highest floods.

From fisheries point of view, the division of floodplains into *fringing floodplains, internal deltas,* and *coastal deltaic floodplains* is also important (Welcomme, 1979).

Wetlands : Wetlands continue to be a nebulous concept, evading a universally acceptable definition. Ramsar Convention defined wetlands as *areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres*, not a precise definition indeed. However, it is generally understood that wetlands occupy the transitional zone between permanently wet and generally dry environments. They share characteristics of both the environments, yet cannot be classified exclusively as either aquatic or terrestrial (Maltby, 1991). Wetlands play a pivotal role in supporting plant and animal life, maintaining the quality of the environment on earth. There is an important link between wetlands and the welfare of people in terms of health, safety, food security, navigation, agriculture, post-harvest activities, fishing and a host of other activities. This relationship is particularly relevant in case of developing world, where many communities depend on wetlands for the maintenance of traditional subsistence activities, including livestock herding, hunting, fishing and farming. This dependence is much less in the economically developed countries where the problems related to higher population density and poverty are fewer. Conversely, in the resource poor developing countries, the wetlands are regarded as a source for a number of life supporting economic activities. Therefore, conservation measures need to be tailor-made to suit the local requirements, lest it may be harsh on a number of local communities whose lives are linked to the wetlands. Moreover, there is a traditional wisdom in conserving the natural resources which are followed through generations to keep the developmental activities sustainable and eco-friendly. Thus wetlands embraces a board category of water bodies which includes riverine floodplains, swamps, marshes, estuaries, backwaters, lagoons, and so on.

Floodplain wetlands: As the wetlands of India are mostly situated on floodplains of major rivers which form a rich and varied inland fishery resource, they are better designated as *floodplain wetlands* or *floodplain lakes*. India has extensive floodplain wetlands (*mauns*, *chaurs*, *beels*, *jheels* and *pats*, as locally called), especially in the states of Assam, Bihar and West Bengal. They can be typical oxbow lakes (*i.e.,* cutoff portion of meander bends), sloughs, meander scroll depressions, backswamps, residual channels or tectonic depressions (Sugunan, 1995a), though it is very often difficult to establish their identity due to natural and man-made modifications to the environment. *Bheries* are the estuarine wetlands associated with the lower reaches of the river Hooghly and Matlah rivers receiving tidal waters. Irrespective of their origin, these lakes are considered as biologically sensitive areas as they have a vital bearing on the recruitment of populations of fishes in the riverine ecosystem and provide nursery grounds for numerous fish species, besides a host of other fauna and flora. They also regulate the water regime and nutrient exchange and act as natural filters. A combination of the processes of river bed evolution and the effects of extensive flood control and irrigation works have reduced the production levels of many of these lakes through siltation, habitat destruction, heavy weed infestation and isolation from the seasonal floods and natural sources of fish stock.

Tanks, reservoirs and lakes

Reservoirs are man-made impoundments, which are created by obstructing the surface flow by dams, anicuts barrages *etc*., compared to lakes which are natural water bodies. Reservoirs have been classified as small (< 1000 ha), medium (1000 to 5000 ha) and large (> 5000 ha) for the purpose of fishery management. India has 1,485,000 ha of small, 527,000 ha of medium and 1,140,000 ha of large reservoirs (Sugunan, 1995b) which constitute the single largest inland fishery resource both in terms of resource size and the productive potential.

Enumeration of the medium and large reservoirs is relatively easy, as they are less in number and the details are readily available with the irrigation, power and public works authorities. However, compilation of data on small reservoirs is a tedious task as they are ubiquitous and too numerous to count. The problem is further confounded by ambiguities in the nomenclature adapted by some of the states. The word *tank* is often loosely defined and used in common parlance to describe some of the small irrigation reservoirs. Thus, a large number of small man-made lakes are designated as tanks, thereby precluding them from the estimates of reservoirs. There is no uniform definition for a tank. In the eastern states of Orissa and West Bengal, pond and tank are interchangeable expression, while in Andhra Pradesh, Karnataka and Tamil Nadu, tanks refer to a section of irrigation reservoirs, including small and medium sized water bodies.

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

Small water bodies

Small water bodies (SWB) is a loosely defined concept, embracing in it, an array of natural and artificial water bodies, such as small reservoirs, lakes, ponds, floodplain lakes and small river stretches. Although a precise and universally acceptable definition is yet to be made, Anderson (1987) included the following water bodies under SWB:

Small reservoirs and lakes less than 10 km^2 in area,
small ponds,
canals including irrigation canals,
small, seasonal, inland floodplains and swamps, and
small rivers and streams less than 100 km in length,

Excluding :

Mangroves,
Large coastal and inland floodplain,
coastal lagoons with intensive, well-established fisheries, and
fish ponds specifically constructed for intensive aquaculture.

Culture-based fisheries and Enhancement

Culture-based fishery : When the fish harvest in an open water system depends solely or mainly on artificial recruitment (stocking) it is referred to as a *culture-based fishery*. Many of the small reservoirs closed *beels*, and a number of community water bodies in India fall under this system. The main focus of management here is stocking and recapture. The size at stocking, growout period and the size at capture are the important criteria in culture-based fishery management.

Enhancement : Fisheries enhancement is the process by which qualitative and quantitative improvement is achieved from water bodies through exercising specific management options. This can be in the form of improving the stock, changing the exploitation norms, changing craft and gear, introducing new forms of access and so on. Apart from improving the production of absolute biomass from the water bodies, it can also be in the form of interventions on access to the fishery or improvements in their monetary and aesthetic value. The common norms of enhancement which are relevant to inland water bodies of India are:

i) Stock enhancement,
ii) Species enhancement,
iii) Environmental enhancement,
iv) Management enhancement, and
v) Enhancement through new culture systems

Stock enhancement (increasing the stock): Augmenting the stock of fish has been the most common management measure that is followed in the reservoirs in most countries of the world. Augmentation of the stock is necessary to prevent unwanted fish to utilize the available food niches and flourish at the cost of economically important species. Stocking of reservoirs with fingerlings of economically important fast-growing species to colonize all the diverse niches of the biotope is one of the necessary pre-requisites in reservoir fishery management. The main aspects of stock enhancement are selection of species of stocking, determination of stocking rate and the size at stocking.

Species enhancement is planting of economically important, fast-growing fish from outside with a view to colonizing all the diverse niches of the biotope for harvesting maximum sustainable crop from them. It can be just stocking of a new species or *introductions*. Introduction means one time or repeated stocking of a species accidentally or deliberately with the objective of establishing its naturalised populations (Welcomme, 1988). This widespread management practice has more relevance to larger water bodies, where stocking and recapture on a sustainable basis is not feasible. Introduction of exotic species is a subject of hot debate due to its possible impact on the biodiversity of our aquatic ecosystems.

Environmental enhancement is improvement of the nutrient status of water by the selective input of fertilizers. Although this is a common management option adopted in intensive aquaculture, a careful consideration of the possible impact on the environment is needed before this option is resorted to in reservoirs.

There are other forms of enhancement such as management enhancement when new management options are exercised. For example a water body can be thrown open for sport fishing to attract fishers or a community management approach can be adopted. The new culture systems such as cage and pen culture can be resorted to augment yield and increase revenue.

Conclusion

India is one of the richest countries in the world in terms of small water bodies. With more than 1.5 million ha of small reservoirs, 200,000 ha of floodplain wetlands and 40,000 ha of estuarine wetlands *(bheries)* there is ample scope for developing culture-based fisheries and various forms of enhancements. Considering the possible environmental impact and the socio-economic scenario of the country, it is perhaps not feasible to develop intensive aquaculture in the inland sub-sector, beyond certain limit. Enhancements and culture-based fisheries, therefore hold the key for future efforts towards yield optimization.

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Floodplain wetlands- an important inland fishery resource of India

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Introduction

Fisheries sector has made great strides during the last five decades with the production levels increasing from mere 0.75 million t of fish and shellfish in 1950-51 to over 4.9 million t in 1995-96.The fish production has increased by 6.6% on an average per annum since the beginning of Seventh Five Year Plan. Out of the total yield of 4.8 million t during 1994-95, the marine and inland sectors have yielded 2.8 and 2.04 million tonnes respectively. In the inland sector, it is reported that about 70% of the production is met through aquaculture and the rest from open water fisheries.

In spite of this impressive performance, there is a wide gap between the demand of fish from the rapidly increasing population and its availability due to steady decline in fish yield from open waters especially rivers, estuaries, and other such water bodies. It is suggested that this gap will be bridged by aquaculture production but it seems unlikely because intensive aquaculture will require high investment which is a big constraint. Therefore, to meet the targeted production of 6.36 million t at the end of IX Five Year Plan, apart from promoting aquaculture, we will have to focus our attention to achieve optimum sustainable yield from the floodplain wetlands, reservoirs and other small impoundments, which can be subjected to ecological management and fishery enhancement strategies.

Inland Resources

Rivers, the lifeline of our country, are the vast repository of unmatched biological wealth. The 14 large, 44 medium and innumerable minor rivers are characterised by their highly diverse fish fauna. While the 14 large systems form 83 percent of total drainage area of the country, the next group of 44 rivers constitute another 7 percent of the total area. The area under different resources is reported at 1.64 lakh km of rivers and canals, 31.50 lakh ha of reservoirs, 22.54 lakh ha of ponds and tanks. The floodplain lakes are a continuum of the river and this resource constitutes an area of about 2 lakh ha in the Ganga and the Brahmaputra basins. These ecosystems are important as they have a vital bearing on the fisheries and ecology of the river system.

Wetland types in India's geographical zones

- Reservoirs, and other water bodies of the Deccan peninsula
- Backwaters and estuaries of the west coast of the peninsula
- The vast saline expanses of Rajasthan and Gujarat (mainly Rann of Kachh)
- Freshwater lakes and reservoirs from Gujarat eastwards through Rajasthan and Madhya Pradesh.
- Deltaic wetlands (including mangroves), lagoons, and salt swamps of India's east coast
- Marshes, *jheels*, terai swamps, and *chaur* lands of the Indo-Gangetic plain
- Floodplain of the Brahmaputra and the marshes and swamps in the hills of north-eastern India
- Lakes and rivers of the montane (primarily Palaearctic) region of Kashmir and Ladakh
- Wetlands (primarily mangroves associations and coral reefs) of India's island arcs

Floodplain wetland resources

The eastern states *viz.,* West Bengal, Bihar and Assam are dominated by the floodplains of the Ganges and Brahmaputra and many smaller rivers. They also support some of the densest human populations in the sub-continent. Thus, the wetland resources in this region are of enormous importance to the economic and social development of these three states but are also under ever increasing pressure of over-exploitation, conversion to other land uses through drainage or reclamation projects and pollution and degradation of their catchment. The resources in these states and adjoining areas are tabulated in Table 1.

Table 1. Floodplain wetland resources of India

State	Area (ha)
Bihar	40,000
West Bengal	42,500
Assam	1,00,000
Other NE States	19,213
Total	**2,02,213**

Definition of Wetland

The term wetlands is used for such diverse habitats in different climatic zones of the earth that it is indeed difficult to define it in simple terms. Accordingly, wetlands have been defined variously in the past two decades. The definitions range from simple working definitions to highly technical ones.

The IUCN defined wetlands broadly for the purpose of the Ramsar Convention on Wetlands of International Importance (IUCN 1971) as *areas of marsh, fen, peatland or water , whether natural or artificial , permanent or temporary, with water that is static or flowing , fresh , brackish or salt , including areas of marine water the depth of which at low tide does not exceed six metres.* Cowardin *et al.* (1979), on the other hand, used detailed scientific criteria to define wetlands and according to them : *Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water and wetlands must have one or more of the following three attributes (1) at least periodically , the land supports* *predominantly hydrophytes ,(2) the substrate is predominantly hydric soil, and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year.*

In India, there is no single word equivalent to wetland. The marshes are known as *chaurs*, *mauns* and *pats* in Bihar , and *beels, boar, jheel* in West Bengal, Assam and the Northeast. Large shallow lakes are called *tals* in Uttar Pradesh and Madhya Pradesh and they are called *Sar* and *Dal* in Jammu & Kashmir. But wetlands have to be identified and distinguished from other ecosystems by their ecological characteristics alone for their proper management. However, the Ministry of Environment and Forests, Government of India, has adopted the IUCN definition which is used by the Ramsar Convention for the purpose of its wetland conservation programme.

Floodplain formation and its importance

It is important to remember that floodplains and their unique wetlands have evolved over many millennia through the natural processes of flooding and river bed movement caused by extreme climatic and geological events. In tropics and sub tropics, these events (particularly the monsoon rains) are even more extreme. Floodplain wetlands therefore play an extremely important role in the maintenance of stability in lowland ecosystems, providing effective floodwater retention and release as well as absorption and cycling. It is therefore not surprising that due to physical modification of floodplains to suit human needs, many of these functions have been lost or reduced. This, in turn, has led to more catastrophic events as extreme flooding and loss of human lives.

These wetlands provide abundant drinking and irrigation water, protein and other nutrient requirements for human survival (plants, fish, birds etc.) building materials (reeds and timber), transport and communication routes, effective sewage treatment systems, fertile soils for agriculture and buffer against flooding, erosion and nutrient loss. In addition, floodplain wetlands are areas of high biodiversity. They often support large numbers of resident waterbirds and provide essential (and often internationally important) re-fuelling and over-wintering sites for huge numbers of migratory waterfowl and waders.

Benefits from Floodplains

Apart from other benefits that accrue from these resources, the fisheries is one of the most important activity which is directly linked with rural economy. The ecological data generated in many ecosystems indicate that floodplains in the Indo-Gangetic belt are either eutrophic or in the process of attaining higher trophic levels. These nutrient-rich and biologically diverse ecosystems generally possess high potential for *in situ* fish production and in some cases the topography of the system is such that all the fish from its catchment get collected in the wetland. The average annual production from such water bodies is estimated in range of 100 - 300 kg/ha/yr depending upon the level of management.

In floodplains which have retained their connection with the parent river, adult and juveniles of Indian major carps undertake migration during monsoon to breeding and feeding pastures in the freshly inundated floodplains. In the closed lakes (those which have lost connection with main river), the fishery comprises catfish and small sized species. Devoid of auto-recruitment of major carps, the fish yield in these closed systems is low, which can be increased by species enhancement carried out through stocking.

Typical Ecological Status of a Wetland

Wetlands usually are at higher trophic levels having enriched water and sediment quality. This helps in maintaining sustained high primary productivity both in terms of phytoplankton and macrophytes, and at times basin is overgrown with macrovegetation. This high detrital and nutrient loading from the catchment is favourable for raising good fish crop, provided proper management strategies are followed. Some of the ecological features in a *beel* in West Bengal are tabulated in Table 2.

Fish & Fisheries in Indo-Gangetic floodplains

Composition & Recruitment

In the Indo-Gangetic wetlands, fisheries is the most important activity. The fishery is dominated by miscellaneous species followed by major carps, catfish and live fish. The contribution of detritus feeders is generally poor. The main species encountered are *Catla catla, Cirrhinus mrigala, Cyprinus carpio, Hypophthalmichthys molitrix, Ctenopharyngodon idella*, and *Labeo calbasu* among Indian and exotic carps. Catfish are represented by *Wallago attu* and *Mystus aor*. Other groups present are murrels, featherbacks, air-breathing catfish and climbing perch. The variations encountered in fish composition and different varieties of predatory and weed fish are tabulated in Table 3.

In live floodplain lakes, the migratory habits of certain fish, especially commercial groups, is of special significance. Adults and juveniles of Indian major carps exhibit such migrations during monsoon to breeding and feeding sites in freshly inundated floodplains. In closed lakes, the fauna comprises catfish and small-sized species. Devoid of carps, the productivity of such lakes is low. The situation in live lakes is typical in that the recruits come from the river, majority of them entering the fishable stock during their very first year of life, on an average when they are only 6-8 months old. Although the population of such species is caught regularly, the stock is supplemented through fresh recruitment every year. Decreasin mesh sizes of nets used in the fishery and shallow water throughout the fishing season can, however, cause complete annual removal of the fish stock. Further, all fish small and big, are utilised for human consumption with none discarded at any stage.

Table 2. Ecological features of a floodplain lake in West Bengal

Parameter	Values (range)
pH	7.6-8.0
Dissolved oxygen (mg/l)	5.6-7.78
Alkalinity	9.6-167
Conductivity (µmhos/cm)	252-650
Dissolved organic matter (mg/l)	1.0-2.4
Phosphate-P (mg/l)	0.03-0.06
Nitrate-N(mg/l)	0.12-0.25
Plankton density (units/l)	315
Zooplankton density (units/l)	174
Macrophyte biomass (g/ m^2/dry wt.)	760
Benthic biomass (g/ m^2/dry wt.)	2.52
Detritus (g/m^2/dry weight)	367
Fish yield range (kg/ ha/yr)	150-450
Algal photosynthesis (Cal/ m^2/y x 10^{-8})	29-48.2
Fish yield (Cal/ m^2/y)	48,080-58,200
Transfer efficiency % (primary to fish production)	0.156-0.390

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Table 3 : Percentage composition of fishes in Indo-Gangetic wetlands

Fishery	Bihar	West Bengal	Assam
Carp	3-22	20-65	12-21
Catfishes	10-62	Nil-9	7-10
Murrels	-	Nil-15	-
Featherbacks	-	Nil-25	3-5
Air breathing catfishes	-	10-25	6-24
Hilsa	-	-	0.01-0.59
Shrimps	3-11.4	-	-
Miscellaneous	19-61	15-43	48-60*

* Including prawn

Craft & Gear

Usually *dinghy, catamaran* and other country boats are used by fishermen to catch fish from the wetlands. The length of these boats ranges from 4.8 to 18.3 m. Also a rich assortment of traditional fishing gear are used by these fishermen. Active gear like drag, gill, cast and scoop nets are used mainly during the post-monsoon period. Certain improvised fishing methods, *viz., Katal* fishing is also used during some part of the year. However, in weed-infested areas, the retrieval of fish is beset with many problems.

Productive potential

Floodplain lakes by virtue of their higher trophic level are capable of giving high fish production to the tune of about 0.2 million t yr. It has been reported that a production rate up to. 1000 kg/ha/yr can be achieved through scientific management. Fish yield can be further enhanced by adopting pen and cage culture in selected water bodies where production level up to 4 t/ha has been demonstrated. The investigations on energy transfer conducted in some of the West Bengal *beels* have shown that, on an average, efficiency of 0.246% is achieved. This was increased to 0.5% by stocking a biomass equivalent of 10980 cal/m^2/yr and harvesting 53520 cal/m^2 /yr as fish biomass in a pilot scale experiment conducted in a *beel* in West Bengal. Further, attempt was made to develop stocking norms on energy input- output relationship.

Conclusion

The wetlands are a valuable national resource and fishery (aquaculture) is an acceptable use for economic development. However unchecked growth of this activity especially the intensive aquaculture involving heavy organic and chemical inputs should not be permitted without prior knowledge about the ecological status of a particular wetland. There is no serious ecological impact in allowing fishery based on sound management principles in wetlands. A wise use policy for wetlands is essential.

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Soil quality parameters and their significance in the fisheries management of small water bodies

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Creation of reservoirs, large or small, by impounding the river run off, for irrigational, hydroelectric, water supply, navigational and flood control purposes brings about radical changes in the riverine ecosystem. Organic suspensoids, brought in by the running water, settle down, disintegrating and releasing nutrients in to the water phase. These changes in the existing bottom sediments and water quality provide a favourable environment for settling of the various aquatic life. Such biomass rarely attains the degree of stability as in natural lakes; on account of the frequent changes in hydrological conditions but get only partially adjusted. Productive potential of reservoirs, however, increases with ageing, as they change from oligotrophic to eutrophic condition.

These suspended particles and dissolved salts undergo sedimentation and precipitation under altered physico-chemical conditions with the result that the productivity of the reservoir or pond is influenced by the basin soil only for the first two or three years. After this period, the period of trophic depression starts and finally the equilibrium condition of the fertility is reached. In the case of many reservoirs however, complete static eqilibrium is not possible due to withdrawal of water and of the river inflow into the reservoir.

The chemical properties of water in reservoirs and ponds are more or less a reflection of the properties of the bottom soil. Often acid waters result from acid soils and calcareous bottom soils give rise to alkaline waters. However, because of the complexities involved in the production of soluble nutrients in the soil, a direct correlation between soil-water-nutrient relationship is not possible. The underwater soil acts as a laboratory to release the nutrients required for water productivity from the raw materials which consist of organic matter and mineral constituents of clay fraction of the soil by chemical and bio-chemical means.

Reservoir productivity is very much influenced by the quality of the basin soil and the water column standing over it. Water quality of reservoirs vary widely from one part to the other. It is known that water with high alkalinity and dissolved salts are more productive than those with low values of these parameters. The major chemical factors of importance are pH, total nitrogen, organic carbon, C/N ratio, available nitrogen, available phosphorus, exchangeable calcium and free calcium carbonate which play vital role in pond productivity.

The soil formation under water in ponds and reservoirs differs from that of the land soil in many respects. Firstly, they are formed as a result of the mixture of different soil profiles and being permanently water logged, gas phase is usually absent. Secondly, reservoirs and ponds receive dissolved and sedimentary particles imported by the rivers and from its catchment area carried by precipitated rain water.

The soil substrate generally consists of two biologically significant layers. The upper layer is loose, well aerated and consists of colloidal organic matter and the lower layer is the anaerobic zone containing mineral matter in varying composition. The proportion of these two layers play an important role in directing the physical, chemical and biological processes like I) release of minerals ii) absorption of ions as colloidal layers and iii) decomposition of organic matter by micro-organisms. Mechanically, the bottom soil should not be so adsorptive as to impoverish the water off all its nutrients and at the same time it must not be so inactive to permit excess loss of nutrients. The superficial soil layers should have well aerated structure facilitating the oxidative decay of organic matter.

pH of the soil, like water, is dependent on various factors. In an ill aerated mud layer, when the oxygen supply falls short, the decomposition areas are mainly reduced or partially oxidise compounds and short chain fatty acids. These acids makes the soil strongly acidic. It is naturally buffered; with low rate of bacterial action, ultimately leading to less productivity. pH of the soil also influences translocation of soluble phosphates to unavailable forms and controls the adsorption and release of essential nutrients at soil water interface. Both for soil and water, a slightly alkaline pH (7.5) has been considered optimal for fish production. Productive soils range mostly between slightly alkaline to slightly acidic (6.5-7.5) in reaction, highly acid soil (below pH 4.5) and highly alkaline soil (pH above 8.5) are generally unproductive and in these soils, available phosphorus is very poor. An acidic reaction favours the precipitation of soluble phosphate into insoluble form rendering it unavailable to phytoplankton. An acidic reaction may also result in inadequate supply of calcium. Under usual photosynthetic activities, the pH of pond water increases and reaches alkaline range during day time. This helps to maintain the pH of water slightly alkaline, which is conducive for a long period even during the night time. A neutral to slightly alkaline reaction is favourable for the growth and activity of the microorganisms which carry out the process of mineralisation of the organic matter already present in the mud or the organic manure added to it resulting in the release of nutrients particularly nitrogen present in available form.

It is well recognised that phosphorus is as an assimilator of nitrogen into cellular matter. Due to its reactive nature, phosphorus ions form insoluble compounds with iron and aluminium in soil under acid condition and with calcium under alkaline condition rendering them unavailable to water. A considerable amount of phosphate ions also remain adsorbed on colloidal complexes. Thus, it is not the total phosphorus but its different forms and conditions controlling their release to water which are important. Except under high acid conditions most of the inorganic phosphorus in soil is bound up as insoluble calcium phosphorus and adsorbed phosphates on colloids. Both these forms are rendered soluble under acidic and reducing condition. In addition, phosphorus is also present in organic form in soil which is mineralised to soluble inorganic phosphate by bacteria, a process much imbedded under acid condition soils with available phosphorus. The organic form of phosphorus unless it is mineralised to the inorganic form, is of no use to phytoplankton. Such transformation from the organic to inorganic form is primarily carried out by some aerobic group of micro organisms. But in the environment prevailing in the bottom mud, which is mostly anaerobic, the population and activity of the above group of microorganisms is at low level and hence the contribution of the organic form of phosphorus present in the mud is of little consequence in maintaining a good phosphorus status in the pond. Under prevailing anaerobic environment in the bottom mud some chemical changes take place resulting in the solubilization of insoluble in-organic phosphate which include I) reduction of molecule ferric phosphate to more soluble ferrous phosphate ii) dissolution of insoluble tricalcium phosphate to more soluble mono calcium phosphate by the dissolved oxygen, weak carbonic acid-organic acid formed as a result of decomposition of organic matter. Phosphorus below 3.0 mg/100 g soil is said to be poor, 3-6 average and above 6 mg/100 g is high productive.

Nitrogen is present in the mud mostly in organically combined complex form. Unless it is transformed into inorganic form *viz.*, NH^+ and NO_3^- through a chain of biochemical reactions, the element can not be taken up by phytoplankton. Such transformations from organic to inorganic form which is known as mineralisation is carried out by various groups of micro- organisms. In the absence of sufficient oxygen in the bottom mud, obligate and facultative anaerobic micro organisms participate in the process; the end product of the process being ammonical nitrogen (NH_4) which when diffuses into overlying water and comes in contact with oxygen, gets nitrified to nitrate by nitrifying bacteria. The nitrate ion being highly diffusible, diffuses in an aerobic zone of the bottom mud due to the development of concentration ingredient and it gets denitrified there. Due to the occurrence of the nitrification and denitrification process in the mud water system, there is a considerable loss of nitrogen, both native and applied from water. Further during the noon time when the pH of the water rises to the alkaline range due to vigorous photosynthetic activity of the chlorophyll bearing organisms present in water, considerable amount of ammonical nitrogen (NH_4^+) formed as a result of mineralisation is lost through volatilization as NH_3 gas.

Nitrogen a basic and primary constituent of protein, is no less important than phosphorus. Nitrogen in soil is present mostly in inorganic form, the fraction present in organic form being amino acids, peptides and easily decomposable proteins. Available nitrogen below 25 mg/100 g soil gives poor production, in the range 25-75 mg/100 g soil production may be high. Organic compounds are more varied and complex as compared to mineral constituents of the soil. Organic carbon less than 0.5% can be considered low for pond soil, the range 0.5-1.5% is average while 1.5 to 2.5% is considered to be optimal for productivity. The study of C/N ratio is considered as important as the carbon content itself. C/N ratio below 5.0 indicates poor productivity while 5-10 shows average production.

Specific conductance of the pond bottom mud is an index of the water soluble salts which is usually higher than that of the soil of an adjacent agricultural field. Total soluble salts in the bottom mud of a fish pond gradually increases with the time it remains continuously under water. Changes in specific conductance are associated with release or depletion of soluble ions in the mud water system and they are likely to have an indirect role to play in the productivity of pond water. Specific conductance of soil is commonly used as an indicator of total concentration of the cations (or anions) in the soil and it is closely related to the total dissolved solids.

Potassium ranks as a major nutrient element with nitrogen and phosphorus. Exchange of potassium between soil and water is less dependent on carbon cycle. It does not form insoluble compounds and its passing off from soil to water is favourable by hydration of soil colloids with the result that potassium compounds deficiency in impounded water is rarely met with.

Bottom mud is usually rich in clay and humus and hence exhibits high cation exchange capacity. This helps in keeping applied potassium in the mud in exchangeable form where from it can be easily released to overlying water. The NH_4^+ or Fe^{2+} ions which are formed in the mud due to reductive process can displace K^+ from the exchange complex of the mud resulting in its release to the water to be available to the phytoplankton. There are some types of clay minerals *viz.* illite, which have the capacity to fix or bound K^+ ions within their lattice. Such lattice bound K+ remains strongly held and is released very slowly to the exchangeable form and then to the water soluble form. Hence, if bottom mud contains predominantly such type of clay minerals, then much of the added potassium is reduced and remained temporarily unavailable due to the lattice fixation mechanisms. Similarly, the ponds which are situated in the lateritic soil zone have predominantly kaolinite types of clay minerals in their mud, which have very low cation exchange capacity. Further, humus content in the muds of such ponds is also comparatively low. Accordingly, the total cation exchange capacity of the mud is also low. Hence in such cases, there is possibility of much losses of added K^+ through leaching. It is, therefore, essential to know the nature and properties of bottom mud particularly the type of dominant clay mineral while formulating an efficient potassium management programme. Calcium is generally present in the soil as carbonate. The amount of exchangeable phosphate in bottom mud is inversely related to the marl-organic matter ratio, so that phosphate in highly organic soil with low calcium soluble phosphate, remains absorbed in an exchangeable form. Where sediments are very low and inorganic matter is very high in marl, phosphorus probably remains fixed in insoluble precipitation.

Among the trace elements, probably manganese has been more extensively studied. Manganese in soluble form in bottom soil contributes to the soluble managenese in water which play an important role in plankton productivity. The role of soil manganese as a mineralising agent for organic matter has also been studied and found to compare well with lime and phosphorus.

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Microbial indices for assessing aquatic productivity

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It is well know that the concentration of dissolved oxygen (DO) plays a major role in aquatic production in any water body but its concentration does not remain fixed at one point of the sunlight with the advance of the day and gradually decreases after sunset and finally becomes minimum before dawn and once again the cycle is repeated. On a cloudy day, DO increases very slowly and decline in DO becomes more conspicuous after dusk. Under high planktonic bloom, particularly, when the secchi disc transparency at noon is below 15 cm, the depletion of DO after sunset becomes very fast and fish suffer at night due to low DO in the ambient water. Therefore, it is essential for a farmer to know the DO position at night before hand and take proper measure in advance so that DO value does not fall below 3.0 ppm at night or before dawn (Boyd, 1982) as the DO value below 5.0 ppm for more than 8 hours is harmful for growth and reproduction of fish.

From our diurnal studies in different water bodies, we have seen that the position of DO at night can be understood by estimating the microbial consumption of DO per hour by Winkler's method. In this method two black bottles filled with ambient water are to be suspended in water one with one drop of formaldehyde (A) and another (B) without formaldehyde for four hours from 10.0 AM to 2.0 PM, after estimating the initial DO in ppm in another white bottle (I). Now DO values in the two black bottles are also to be estimated after 4 hours of suspension in water. From the above three DO values the microbial consumption of DO per hour (K) in ppm can be calculated as follows:

K= I (A-B)/4 in ppm per hour.

It has been seen that when K is less than 0.5 ppm/hr, DO does not act as the stress factor for fish and prawn in any water body but when K is above 0.5 ppm/hr or near 1.0 ppm/hr, DO at night or before dawn becomes severe stress factor for fish and prawn and heavy loss in production occurs in such cases either due to mortality or due to out break of diseases. Thus, by measuring microbial consumption of DO per hour in the day time we can take requisite measures to any loss in production in due course.

Measurement of productivity by direct count of bacteria and plankton of a water body

Fish often occupies the tertiary position in the food chain of a water body. Consequently, it has to depend on the primary and secondary organisms for the supply of food materials. The direct microscopic count of the bacterio-plankton gives a quantitative estimation of the productivity of the water body. This method gives the number of all the cells of microorganisms present in a given sample of water (Razumov, 1947; Kuznetsov, 1959).

Microbial population in a water body is counted on the membrane filters after filteration of a definite volume of water sample. The pore size of the membrane should not exceed (0.3 mm). The working surface of the filters must be smooth and free from contamination.

The filtration is done through a glass millipore type glass funnel, diameter of the working surface of which is carefully measured. Membrane filters are numbered with a pencil. The volume of water to be filtered depends on the productivity level of the water body. About 10-25 ml is required for low productive water, 5-10 ml is required for eutrophic waters and 0.5 to 1.0 ml is required for heavily contaminated waters. 2-3 ml of previously filtered distilled water is to be added during filteration so as to get a uniform distribution of the microorganisms. The filters are then stained. On a petri dish two to three pieces of ordinary filter papers, moistened with 3% erythrocin solution in 5% phenol are placed. Now millipore membrane filter paper having small square grids is placed on the erythrocin moistened filter paper overnight and then dried in a desiccator for 20 minutes.

The stained membrane filter is decolourised by placing it on the surface filter paper moistened with distilled water. Membrane filters now look weakly pink in colour. For microscopic examination the filters are placed on a drop of immersion oil placed on the surface of a glass slide. Onto the surface of the membrane of the membrane filter a further drop of the oil is put. By this, the filter becomes quite transparent showing the coloured microorganisms. The filter is covered with a cover glass and put under the microscope for counting. The number of micro organisms in a small square of the filter is counted. Ten such squares on each stained membrane are counted and then average is made per each small square. Ten squares of 10 such membranes are to be counted for each water sample and then average is to be made. Now knowing the volume of water filtered, average number of microorganisms per small square of the membrane filter, diameter of the working surface of the membrane filter and of the small square, the number of micro organisms per ml. of water can be found out and can be compared with the values of other productive water bodies.

$$N = \frac{N}{a} \times \frac{S}{v} \text{ cells/ml.}$$

N = no. of microorganisms per ml.
n = no of microorganism per small square
a = area of the small square
s = area of the filtering surface
v = volume of water filtered.

Boyd (1973) reported a mean rate of carbon fixation by photosynthesis of 2.55 g/m^2 of carbon per day during the growing season. Assuming that dry phytoplankton is 48% carbon (Boyd and Lawrence, 1966), 5.32 g/m^2 of dry matter were produced daily by photosynthesis. Assuming, that half of the total production takes place 10.00 hr to 14.00 hr, 2.66 g/m^2 of dry matter were produced daily by photosynthesis.

Estimation of productivity from the consumption of phosphate-phosphorus

Primary production of a water body has been found to be a function of water soluble inorganic phosphorus when the concentration of other essential nutrients are in their optimum range (Das and Dehadrai, 1986). Rodhe (1965) indicated that for a fixation of 500 mg of C/m^2 an absorption of 10 mg of P/m^2 is essential. This provides the basis for calculation of carbon fixation from the estimation of microbial consumption of phosphate-phosphorus. Thus for each mg consumption of phosphate- phosphorus 50 mg of carbon fixation will occur. So by estimating initial and final concentration of phosphate from phosphorus within a period of four hour of incubation between 10.00 hr and 14.00 hr, primary productivity or carbon fixation rate of a water body can be calculated and this can be compared with the values obtained other water bodies.

Average gross primary productivity estimated between 10.00 hr to 14.00 hr has been found to be 1.76 mg/l of carbon per hour in fertilized ponds and 0.18 mg/l of C per hour in unfertilized ponds (Boyd, 1973). Hall *et al.,* (1970) reported that primary productivity was 10-15 times greater in fertilized ponds than in control ponds. Therefore, by determining initial phosphate-phosphorus concentration and the same after 4 hours of incubation under ambient condition between 10.00 hr to 14.00 hr, it is quite easy to calculate the carbon fixation rate and consequently, the productivity of the water body.

Measuring productivity through estimation of bacterial load

Bacterial load of a water body is measured in nutrient agar medium at a temperature of 35 °C, gives a good indication of its productivity and quality of water, as the bacterial load is directly proportional to its nutrient availability and consequently to the availability of fish food organisms. When this load exceeds critical concentration (10^5/ml of water), bacteria invade various organs of fish and reach its muscle (Buras, *et al.,* 1985) and consequently the manifestation of bacterial disease takes place. It has been observed that productive waters are having a bacterial load of 10^2-10^3 /ml of water or little more than this and polluted waters having bacterial load of 10^4/ml and above. Bacterial load below 10/ml is indicative of low productivity.

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Abiotic habitat variables in the reservoirs and beels and their role in the production processes

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Introduction

Impounding the surface runoff for irrigation, power generation, flood control navigation, *etc.* resulted in the creation of a number of man-made ecosystems. More than 3 million ha of water area are available in the country in the form of large, medium and small reservoirs while more than 2 lakh hectares in the form of both open and closed *beels* mainly in eastern U. P., .north Bihar, West Bengal, Assam and other Northeastern States. Reservoirs are characterised by release of deep waters, existence of both lotic and lentic components and wide seasonal fluctuation in water level although in small reservoirs some of these characters do not exist. *Beels*, on the other hand, are comparatively shallow in nature and rich in soil status with penetration of light at the bottom resulting in infestation of aquatic macrophytes with varying magnitudes. Several workers have studied the ecology and production dynamics of lakes, reservoirs and *beels* and have suggested management norms for the development of these water bodies (Rawson 1952, Northcote and Larkin, 1956, Ryder *et al.,* 1974, Sreenivasan 1971, Ganapati 1970, Natarajan and Pathak 1987, Pathak 1979, Pathak 1989). A few small reservoirs have also been described as case studies (Khan *et al.,* 1990). Although these water bodies provide immense potential resource for fisheries development, the actual fish production trend is not encouraging (about 10 kg/ha in large reservoirs and around 100 kg/ha in case of *beels*). It is thus essential to have a critical examination of the ecosystem itself and the various factors responsible for its production process. The abiotic habitat variables, dynamics of chemical constitutents and effective circulation of nutrients examined in the present communication, are some of the basic processes which have great bearing on the production of the ecosystems. In addition to *beels* and small reservoirs, some large reservoirs have also been considered for better understanding of role of these parameters in the production process.

Indices of productivity

The biological productivity of any water body is influenced by climatic, edaphic and morphometric features. The climatic factors like air temperature, wind velocity and rainfall have great bearing on reserovir productivity. The wide seasonal variation in air temperature with low volues during winter and high during summer have great influence on the thermal features of the subtropical reservoirs although in southern peninsular India the seasonal differences are narrow. The incident solar radiation on the water surface also shows considerable variation with the location (latitude).

The fertility of both reservoirs and *beel*s is very much influenced by the quality of the basin soil as well as that of the catchment area. The status of soil in *beel*s was generally rich with high values of organic carbon, available nitrogen and available phosphorus (Table 1). But reservoirs have shown wide variations in their soil characteristics. Baring a few the soil status was comparatively poor in reservoir under examination (Table 1). It is interesting to note that though the soil quality was relatively poor in reservoirs, this was not reflected in the water quality which appeared to be related more to the soil conditions of the catchment area than to those of the basin alone. Similarly, in case of *beel*s the rich nutrient status of soil was not reflected in the water phase probably because of accumulation of large amount of nutrients by the macrophytes and effective removal from circulation.

The morphometric factors like water levels, depth, water discharge (both in and out), shore development, volume development, etc. also have great bearing on the circulation of nutrients and energy in the reservoir biotopes. Both water level and depth have shown wide fluctuations from reservoir to reservoirs. As the climatic and edaphic factors provide essential source of energy and nutrients they may be considered to be the first in order of importance. Morphometric factors which serve as modifying factors that determine heat and nutrient characteristics are second in order of importance. Rawson (1952) obtained an inverse relation between mean depth and productivity based on the fact that shallower water bodies provide better circulation of nutrients. Northcote and Larkin (1956) found that waters with high dissolved solids (TDS) are more productive than those with low values and reported a direct relation between TDS (an edaphic character) and productivity. The two ideas were combined by Ryder *et al.* In Morphoedaphic Index (MEI) which is the ratio of an edaphic character (dissolved solids) and mean depth, a morphometric character, and he used this as an index of productivity. Although this index gives correct indication of productivity in natural lakes when applied in reservoirs, with fluctuating morphometric characters and the edaphic characters being more influenced by catchment this index does not always yield accurate results. For example many shallow reservoirs with high values of morphoedaphic indices are low productive while many deep reservoirs are highly productive as illustrated in Table 2 where total alkalinity (a correlate of total dissolved solids) has been used for index calculation. Thus one has to be very cautious in using this index for productivity evaluations. This is more true in case of small reservoir where depth is generally less with more dominant edaphic characters.

Productivity trends from hydrological parameters

Reservoirs and *beels* both vary widely in respect of their water quality parameters. It has been observed that water with high alkalinity, conductance and dissolved salts are more productive than those with lower values of these parameters (Northcote and Larkin, 1956). In general water with moderate alkaline pH, alkalinity above 50 mg/l, conductance above 200 micromhos hasrdness abaove 25 mg/l, organic carbon around 1 mg/l, or above, nitrate above 0.5 mg/l are considered to be productive.

The water quality parameters of some reservoirs and beels have been presented in Table 3. Water was alkaline in all the reservoirswith pH values ranging between 7.7 to 8.8. Except Rihand the water quality parameters in all the reservoirs were in moderate to productive range. But the nutrient status in respect of both nitrate and phosphate were poor. Assam waters have shown distinctly different water quality than Bengal. In the *beels* of West Bengal (Kulia and Media) water was alkaline in reaction (pH 7.5 to 7.8) with comparatively high values of alkalinity, conductance, hardness and dissolved salts whereas the Assam *beels* showed acidic to near neutral pH with low alkalinity, conductance, dissolved salts etc. except Bilmukh which had comparatively much higher values. The nutrient status in the water phase was generally poor in all *beels*, despite the very high values in the soil phase. As most of the nutrients are used and locked by the infested macrophytes and removed from circulation, water always showed nutrient deficiency.

Dynamics of chemical constituents and evaluation of productivity trends

From the point of view of biological productivity the water in an aquatic system consists of two fundamentally different regions one below the other, in which opposing processes take place. These are the regions of photosynthetic production (the trophogenic zone) over the regions of break down (tropholytic zone). In photosynthetic zone carbon dioxide is taken up by the photosynthetic organisms, resulting in decrease in bicarbonate and increase in carbonate and pH ($2HCO_3 = CO_2 + CO_3 + H_2O$). Oxygen is liberated and increase in concentration ($6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$). In the tropholytic zone oxygen is consumed, carbondioxide is liberated, carbonate is converted to bicarbonate ($C_6H_{12}O_6 + 6O_6 = 6CO_2 + 6H_2O$; $CO_2 + CO_3 + H_2O = 2HCO_3$) and pH decreases with increase in hydrogen ion concentration increases ($CO_2 + H_2O = H_2CO_3 = H^+ + HCO^-_3$). At night when there is no photosynthesis, the reactions at trophogenic and tropholytic zones are the same. If the rates of reactions in the two phases are high the water body will show sharp variations in the chemical parameters either with the progress of the day (diel variations) or in depth profile during stagnation period. In deep waters the two zones are separate (in case of resrvoirs) but in shallow waters variations in the chemical parameters reflect the intensity of reactions in both the zones. As the rate of above reactions are directly related to the production (P) and consumption (C) processes the relative productivity of the water body can be evaluated from the magnitude of their variations.

In impounded waters the dynamics of chemical constituents is reflected by the phenomenon of chemical stratifications (Ruttner, 1964). Depth wise distribution of chemical constituents in four reservoirs are presented in Table 5. Sharp changes in chemical parameters like oxygen, carbondioxide, pH and bicarbonate were noted in Bhavanisagar, Govindsagar and Nagarjunasagar from surface to bottom during summer stagnation period. High photosynthetic production in the trophogenic zone cause the klinograde oxygen distribution. Hence the oxygen curve gives important clue for determining the degree of productivity in reservoirs. The klinograde oxygen distribution in Bhavanisagar, Govindsagar and Nagarjunasagar reflect high productivity of these reservoirs. The reservoirs showing orthograde oxygen distribution are relatively less productive (Rihand).

The decomposition of bottom organic sediments and subsequent decline in oxygen is always accompanied by accumulation of carbondioxide. The enriched carbondioxide leads to an increase in hydrogen ions ($H_2O + CO_2 = H_2CO_3 = H^+ + HCO^-_3$) and thus lowers the pH of bottom layers. The bottom accumulation of CO_2, fall in pH and increase in bicarbonate due to dissolution of carbonate deposits by accumulated carbondioxide along with decline of oxygen from surface to bottom all reflect high productivity in a reservoir. In low productive reservoirs such changes are not marked.

In shallow waters where the two different zones are not marked the diel changes in chemical parameters reflect better productivity trends. The diel variation in chemical parameters in three *beel*s have been shown in Table 4. A sharp variation in dissolved oxygen pH, carbondioxide, carbonate and bicarbonate was recorded in all the *beel*s with considerable variations in their magnitude.. The intensity was maximum in Kulia *beel* and minimum in Muktapur. The most important among the chemical changes is the diel cycle of oxygen which is directly linked with both production and respiratory consumption process of both phytoplankton and macrophytes. Dissolved oxygen which was quite low in the morning (0600hrs) in all the *beel*s, registered a phenomenal increase to 13.6 mg/l in Dhir, 15.5 mg/l in Kulia and 11.3 mg/l in Muktapur (14 hrs). In dark phase (night) oxygen reduced sharply. These findings clearly reflect high productivity of *beels*. Other chemical parameters also showed similar changes (Table 4). As the diel changes in chemical parameters are directly related with production processes they can be used to evaluate the productivity potential of such systems.

Nutrient cycle

The effective functioning of any aquatic ecosystem depends on the circulation of nutrients. Like energy nutrients enter the cycle through autotrophic photosynthetic production. A portion of the material is passed on to the next trophic level and the remainder reaches the bottom after the death of producer organism. This process is repeated at each trophic level upto the top which has no predator and now all the material reaches the bottom. Here the organic matter is oxidised by decomposers and nutrients are again released and become available to be used by producers again. In shallow waters (small reservoirs) the circulation of nutrients is not a problem but in deep waters with stratification nutrients are locked in the tropholytic zone ('nutrient sink') and become unavailable to the system. However, in reservoirs the stagnation is broken by the influx of flood waters and nutrient locking (if any) is for a very short period. In *beel* ecosystem the locking of nutrients is by infested macrophytes for longer period and release is only after the death and decomposition of those macrophytes. Studies have shown that circulation of nutrients is very fast once macrophytes are removed from the system.

Conclusion

Studies of habitat variables and dynamics of chemical parameters are very useful for evaluating the productivity trends of reservoirs and *bee*ls. In *beels* the diel curve has been used to evaluate the productivity potential of the system but these studies coupled with energy dynamics gives more clear picture about the effective utilization of the potential resources.

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Table 1. Soil quality of some beels and reservoirs

Ecosystems (Reservoirs/beels)	pH	Organic carbon (%)	Available Nitrogen (ppm)	Available Phosphorus (ppm)
Govindsagar	8.7	0.36	160	5
Nagarjunasagar	7.5	0.98	150	35
Rihand	7.1	0.69	14.2	17
Bhavanisagar	5.8	2.25	256	39
Aliyar	6.2	2.82	284	44
Kulia	6.7	6.5	912	173
Media	6.1	4.65	642	90
Dhir	5.45	4.3	694	105
Bilmukh	4.8	5.64	712	108
Bodishisa	5.2	3.82	618	94

Table 2. Morpho-edaphic index and productivity characters of various Indian reservoirs.

Reservoirs	Mean depth (m)	Alkalinity (correlate of TDS (mg/l)	MEI	Productivity characters
Sholayar	27.4	27.0	0.98	Productive
Govindsagar	55.6	69.0	1.24	Productive
Rihand	23.9	43.87	1.83	Low productive
Amaravati	13.7	27.50	2.01	Productive
Nagarjunasagar	40.6	110.50	2.72	Productive
Getalsud	8.4	38.0	4.52	Low productive
Bhavanisagar	11.2	52.11	4.65	Productive
Govindgarh lake	6.12	35.0	5.71	Low productive
Stanley	17.0	106.0	6.23	Productive
Tungabhadra	9.8	65.86	6.72	Low productive
Konar	13.3	32.0	2.46	Low productive

Table 3. Hydrological features of reservoirs and *beels*

Reservoirs

	G. Sagar	N. Sagar	Rihand	B. Sagar	Bachhra	Aliyar
Water temp. (°C)	22.5	27.5	24.0	25.8	26.70	26.2
Transparency (cm)	112.1	260.0	54.0	107.0	66.70	64.2
pH	8.8	8.3	7.7	8.3	7.89	8.2
DO(mg/l)	8.8	8.0	7.7	7.5	6.82	7.54
Total alkalinity (mg/l)	69.3	110.0	43.8	52.1	127.64	60.2
Sp. Cond (μmhos)	215.0	450.0	97.7	268.9	236.52	259.4
Total hardness (mg/l)	54.8	102.0	48.0	50.9	87.60	72.8
Total diss. solids (mg/l)	108.0	232.0	49.2	139.0	112.0	128.0
Dissolved org. matter (mg/l)	0.48	0.98	0.42	1.2	0.68	0.88
Silicate (mg/l)	1.1	30.0	6.4	9.9	10.04	9.5
Nitrate (mg/l)	0.20	0.7	0.4	0.2	0.127	0.28
Phosphate (mg/l)	0.02	0.01	0.08	0.02	0.144	0.06

Beels

	Kulia	Media	Dhir	Bilmukh	Bedishisa	Dighali
Water temp. (°C)	26.5	26.4	25.0	16.0	18.0	20.0
Transparency (cm)		66.6	84.5	B	48.0	B
pH	7.8	7.5	7.0	5.8	6.9	6.7
DO(mg/l)	7.19	5.6	7.74	6.84	6.76	6.43
Total alkalinity (mg/l)	131.86	89.18	27.5	154.7	46.71	28.67
Sp. Cond (mmhos)	615.3	368.1	54.0	266.0	97.77	54.3
Total hardness (mg/l)	105.5	82.55	24.75	120.0	55.0	27.2
Total dissolved solids (mg/l)	308.0	188.0	28.0	134.0	49.37	38.4
Dissolved org. matter (mg/l)	1.70	2.1	3.78	3.27	3.88	2.04
Silicate (mg.l)	10.35	19.0	8.55	6.0	1.7	5.2
Nitrate (mg/l)	0.185	0.53	0.225	0.04	0.03	0.012
Phosphate (mg/l)	0.045	0.105	0.06	0.004	0.005	0.015

B - up to bottom

Table 4. Diel cycle of chemical parameters in Beels

KULIA BEEL

Time of collection	D.O. (mg/l)	pH	Free CO_2 (mg/l)	Carbonate (mg/l)	Bicarbonate (mg/l)
06	2.0	7.5	0.66	0.0	170.0
10	5.7	7.7	0.00	2.7	164.5
14	15.5	8.4	0.00	14.0	140.9
18	11.0	8.2	0.00	13.8	149.2
22	8.6	8.1	0.00	7.4	153.5
02	6.5	7.7	0.00	4.4	164.0
Total fluctuation	**13.5**	**0.9**	**0.66**	**14.0**	**29.1**

DHIR BEEL

Time of collection	D.O. (mg/l)	pH	Free CO_2 (mg/l)	Carbonate (mg/l)	Bicarbonate (mg/l)
06	4.2	6.3	8.00	0.0	36.0
10	10.4	7.0	2.00	0.00	25.0
14	13.6	7.4	0.50	0.00	16.0
18	11.6	7.2	1.0	0.00	19.00
22	10.6	7.1	3.0	0.00	24.0
02	6.4	6.8	6.0	0.00	28.0
Total fluctuation	**9.4**	**1.1**	**7.5**	**0.00**	**20.00**

MUKTAPUR BEEL

Time of collection	D.O. (mg/l)	pH	Free CO_2 (mg/l)	Carbonate (mg/l)	Bicarbonate (mg/l)
06	2.5	7.8	4.0	0.0	110.0
10	8.5	8.1	0.00	6.0	103.0
14	11.8	8.5	0.00	20.0	100.0
18	9.8	8.5	0.00	14.0	100.0
22	7.6	8.2	0.00	5.0	104.0
02	5.8	8.0	1.00	0.0	108.0
Total fluctuation	**8.8**	**0.7**	**4.0**	**20.0**	**10.0**

Table- 5. Dynamics of chemical constituent in Reservoir

Depth	Dissolved oxygen (mg/l)	pH	Free Carbon dioxide (mg/l)	Bicar-bonate (mg/l)	Dissolved oxygen (mg/l)	pH	Free carbon-dioxide (mg/l)	Bicar-bonate (mg/l)
	GOBINDSAGAR				NAGARJUNASAGAR			
0	8.3	8.2	-	62.0	5.98	8.6	-	125.0
3	8.3	8.2	-	63.0	5.98	8.6	-	125.0
6	6.9	8.0	-	65.0	5.98	8.6	-	127.0
9	6.0	7.85	2.0	65.0	5.6	8.6	-	127.0
12	5.7	7.85	2.0	70.0	5.6	8.6	-	130.0
15	5.7	7.85	2.0	72.0	5.6	8.5	-	130.0
18	5.0	7.85	6.0	78.0	2.9	8.2	5.04	141.0
21	5.0	7.85	6.0	80.0	2.9	8.2	5.04	143.0
24	4.5	7.85	6.0	80.0	2.9	8.2	5.04	143.0
27	4.5	7.85	6.0	80.0	2.9	8.2	5.04	150.0
30	4.5	7.85	6.0	80.0	2.9	8.2	4.04	150.0
33	4.5	7.65	8.0	82.0	2.6	8.2	5.07	150.0
36	4.2	7.65	8.0	82.0	2.6	8.2	5.04	150.0
39	4.2	7.65	8.0	82.0	2.6	8.2	5.04	152.0
42	2.8	7.65	8.0	82.0	2.5	8.2	5.04	152.0
60	2.0	7.5	11.0	84.0	-	-	-	-

Table 5 contd. ....

BHAVANISAGAR					RIHAND			
0	7.9	8.35	-	34.0	8.2	8.0	8.0	44.0
3	7.5	8.35	-	34.0	8.2	8.0	8.0	44.0
6	5.0	7.30	4.5	44.0	8.0	8.0	10.0	44.0
9	3.5	6.90	6.0	48.0	7.0	7.9	10.0	40.0
12	2.0	6.80	9.0	51.0	7.0	7.9	10.0	40.0
15	1.0	6.80	11.0	56.0	6.5	7.9	10.0	38.0
18	-	-	-	-	6.5	7.9	12.0	38.0
21	-	-	-	-	6.5	7.9	12.0	36.0
24	-	-	-	-	6.5	7.8	13.0	36.0
42	-	-	-	-	6.3	7.7	13.0	34.0

Community metabolism (energy dynamics) in the context of fisheries management of small reservoirs and *beels*

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Introduction

Biotic communties in an aquatic ecosystem can be divided into various components on the basis of their trophic functions such as primary producers, herbivores, detritivores, carnivores and decomposers. The units which are transferred among these components are energy-rich organic compounds and the system may, thus, be modelled in terms of either energy or material. Energy enters the biological system by fixation of solar energy through photosynthesis and get degraded as it passes from one trophic level to the other according to the laws of thermodynamics.

In order to study the energy dynamics of a water body from solar radiation to the desirable end product (fish), three types of studies are essential.

(i) Qantitative assessment of synthesis of organic matter *i.e. transformation of solar energy into chemical energy by producers*

(ii) the pathways of energy transformation that lead to the end product *i.e. flow of energy from producers to consumers* and

(iii) *Efficiency of energy transformation at different trophic levels.*

Many workers have studied the flow of energy in different aquatic system (Juday 1940; Lindeman 1952; Teal 1957; Odum 1975; Ganapati 1970; Natarajan and Pathak 1980, 1983. Pathak *et al.*, 1985, Pathak, 1990 *etc.*). However, more critical examinations of these systems are essential to fomulate management norms for the better utilisation of the available energy resources. The energy dynamics of different aquatic ecosystems have been discussed in the paper based on the observations made in some big and small reservoirs and *beels*.

Energy transformation through primary production

The energy source for all living organisms on the earth is sun which releases energy by nuclear transmutation from Hydrogen to Helium in the form of electromagnetic waves in a wider range of wavelengths 1A° to 1,35,00 A°. Only a small fraction of energy in the wavelength of 4000 A° to 8000 A° is transformed to chemical energy by chlorophyll bearing organisms. Measurement of rate of conversion of solar energy to chemical energy gives a dependable parameter to assess the productivity potential of an aquatic system. The redox process of energy transformation is represented by basic equation:

$$6CO_2 + 6H_2O \xrightarrow[\text{Solar energy}]{\text{709 Cal of}} C_6H_{12}O_6 + 6O_2$$

$$\text{Or} \quad nCO_2 + n\,(\text{H doner}) \xrightarrow[\text{Solar energy}]{\text{Solar}} (CH_2O)^n + n\,(\text{oxidised doner})$$

This process is endergonic in nature and consequently plants can store large amount of energy in the form of energy rich organic compound. The efficiency of energy transformation, known as photosynthetic efficiency, is equal to-

$$\frac{\text{Energy fixed by producers}}{\text{Solar energy available in water surface}} \times 100$$

From the above equation the energy required to liberate one milligram of oxygen through photosynthesis is approximately 3.68 calories and hence the amount of oxygen liberated gives a measure of solar energy traped as chemical energy by producers. In the water bodies like reservoirs the energy transformation is mainly by phytoplankton while in *beels* aquatic macrophytes are the main primary producers.

Reservoirs

Seven reservoirs included in the present study differ considerably both in the magnitude of available radiant energy and the rate of their transformation into chemical energy by the producers. Available light energy was in the range of 1,720,000 Cal/m^2/day (Gobindsagar) to 2,150,000 Cal/m^2/day (Aliyar) and the rate of energy transformation by producers ranged between 2428 Cal/m^2/day (Umrang) to 13,580 Cal/m^2/day (Aliyar). The Photosynthetic efficiency ranged between 0.126 to 0.682 per cent. (Table 1). Gessnor (1960) observed that euphotic lakes in temperate regions have a gross energy fixation rate in the order of 1800 to 18,400 Cal/m^2/day during the period of maximum growth. In lake Victoria the average daily estimate was 26,054 Cal/m^2/day (Talling, 1960). Ganapati (1970) noted average daily production of 20,054 Cal/m^2/day and 10,598 Cal/m^2/day in Amaravati and Stanley, the two tropical reservoirs of south India. The chemical energy fixed by producers in the present study compare well with the findings of the above workers. Studies made in a number of reservoirs have shown that the photosynthetic efficiency rarely exceeded 1%. Part of the gross energy fixed by producers is used by them for their own metabolic activities and lost as energy of respiration and the remainder is stored as energy- rich organic compounds. Studies in seven reservoirs revealed that 41.7 to 80% of energy fixed by producers (gross energy) was actually stored by them.

Beels

The rate of energy transformation both by phytoplankton and macrophytes in four *beels* have been presented in Table 1. The energy transformation by phytoplankton ranged between 2796 Cal/m^2/day (Kulia) to 13,522 Cal/m^2/day (Bilmukh) with photosynthetic efficiency ranging from 0.143 to 0.732% while that by macrophytes ranged between 31,995 Cal/m^2/day (1.73% of light) to 57,483 Cal/m^2 /day (3.08%). Thus, only 4.64 to 29.72% of the energy fixed by producers was contributed by phytoplankton and the remainder 70.28 to 95.36% by macrophytes. In *beels,* where most of the energy fixed was contributed by macrophytes, the photsynthetic efficiency (2.462 to 3.23% total) was much higher than that of reservoirs. Studies in four *beels* have shown that 58.0 to 76.7% of energy fixed by both groups of producers was actually stored by them and the remaining 23.3 to 42.0% was lost as heat respiration.

In addition to the energy fixed by autotrophic producers both the ecosystems receive considerable amount of energy in the form of organic matter brought in by the inflowing waters through catchment run-off.

Thus:

Total energy available in the system = Energy import from allochtho-nous source + Energy fixed by photosynthetic organisms

Pathways of energy transformation
(Flow of energy from producers to consumers)

The biotic communities present in the system are interlinked with one another with energy chains therefore proper understanding of the trophic dynamics of the aquatic ecosystems help in formulating policies for stock manipulation. There are two main routes through which the energy flows in an aquatic system. The first of these involves grazing of green organisms (producers) by herbivores or plant feeders which are, in turn, taken by predators and thus the energy from the producer level flows to various levels of consumers. This is commonly known as grazing food chain. All the energy represented by producers is not always utilised by consumers directly and the unutilised energy is deposited at the bottom after the death of the organisms. In *beels* which are generally infested with macrophytes, the primary energy fixed by macrophytes is not utilised directly by herbivores and the unused materials gets deposited at the bottom after their death. When decay occurs, these macrophytes contribute to rich organic detritus pool. The second pathway, which was largely been neglected, involves flow of energy through dead organic matter or detritus complex and the path is known as detritus food chain. The two pathways are shown below.

Herbivores → Predators → Grazing food chain

Energy at first trophic level (or producer level)

Dead Organic matter (organic detritus) → detritus feeders (detritivores) → Predators → (Detritus food chain)

There are a number of restricting conditions for the transfer of energy from the primary producers to secondary and tertiary consumers due to selective feeding nature of the consumer organisms. Thus, all the energy represented by producers is not always utilized by consumers directly and the unused energy is utilized through detritus chain. In some aquatic systems, grazing path predominates while in others most of the energy flows through detritus chain. Functionally the distinction between grazing and detritus chain is of importance as there is a time lag between direct consumption of living plants and the ultimate utilization of dead organic matter.

The pattern of energy utilization in some reservoirs and *beels* has been presented in Table 2. Among the three large reservoirs only Govindsagar, where 70% of the energy harvested as fish was contributed by primary consumers (mainly grazing herbivores) has shown better utilization of energy while in other two reservoirs either the available energy was not fully utilized or utilized mainly by secondary and tertiary consumers. The conversion efficiencies from primary to fish or light to fish were much better in Govindsagar (0.20% or 0.0013%) than both Nagarjunasagar (0.055% or 0.00016%) and Rihand (0.934% or 0.00007%). The energy utilization in three small reservoirs was mainly through detritus chain as 60 to 80% of the energy harvest from them was contributed by primary consumers (mainly detritivores). These reservoirs have shown better conversion efficiencies ranging between 0.132 to 0.355% (Table 2). The four *beels* have also shown very interesting pictures. In Dhir and Media *beels* the flow of energy was mainly through grazing chain as 72.0 to 78% of energy harvested from them was contributed by primary consumers (mainly herbivores) whereas in Kulia *beel* 73.4% of the energy harvested was contributed by detritivores. In Bilmukh, herbivores and detritivores together contributed 51.3% while 40.5% of the total was contributed by tertiary consumers. The energy conversion efficiencies in the four *beels* ranged between 0.131 to 0.417% (Table 2). It is important to mention here that *beels* are very rich in detritus energy (16.4 to 37.44 x 10^4 K cal/ha) and to increase the energy harvest from such systems the vast energy resource in the form of detritus must be fully utilized.

Nikolsky (1963) stated 'the nearer the useful end product (fish) stands to the first link in the food chain the higher the yield from the water mass as the loss of energy will be much higher, if the chain is longer'. Accordingly, if the water body has the dominance of primary consumers (either herbivores or detritivores) the efficiency of conversion and the energy harvest will be higher. Odum (1975) and Mann (1969) applied the energy flow approach for calculating fish productivity potential of aquatic ecosystems keeping in view that in passing from one trophic level to the next almost 90% of the energy is lost. Odum, (1960 and 1962) felt that large water bodies, which have wide range of fish population belonging to various trophic levels, the productivity potential can be taken as 1% of gross or 0.5% of the energy fixed at producer level. Natarajan and Pathak (1983 & 1985) calculated the productivity potential of a number of Indian reservoirs by taking energy at fish level as 0.5% of the energy fixed by producers. The energy dynamics of an ecosystem do take into account the various trophic levels but this approach has disadvantage that many animals are omnivorous and thus can not be assigned to a particular level. Moreover the feeding habits of the animal do change with the availability of the food. Thus, one has to be very cautious while grouping the consumers at different trophic levels. It has been established by many workers that the most important single channel of energy flow leading to fish production is organic detritus complex.

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Table 1. Energy transformation through primary production in Reservoirs a

Ecosystem	Producer group	Solar Energy Cal/ m²/day	Energy fixed by producers Cal/ m²/day	Photosyn-thetic efficiency (%)	Net energy assimilated Cal/ m²/day	Energy lost as respiration Cal/ m²/day	I
							Energy assi lated to gro (%)
Large							
G'sagar	Phytoplankton	1720000	11696	0.682	7626	4070	6
N' sagar	-do-	2050000	5959	0.290	3450	2509	5
Rihand	-do-	1883750	3802	0.202	1586	2216	4
Small							
Aliyar	-do-	2150000	13580	0.580	8370	5210	6
B' sagar	-do-	2130000	8781	0.412	4610	4171	5
Bachhra	-do-	1867000	9547	0.512	7669	1878	8

Ecosystem	Producer group	Solar Energy Cal/ m²/day	Energy fixed by producers Cal/ m²/day	Photosyn-thetic efficiency (%)	Net energy assimilated Cal/ m²/day	Energy lost as respiration Cal/ m²/day	Energy a lated to g (%)
Table 1 contd.......							
Umrang	-do-	1913000	2428	0.126	1578	850	
Kulia	Phytoplankton	1960000	2796	0.143	1622	1174	
	Macrophytes	1960000	57483	3.08	35065	22418	
Media	Phytoplankton	1965000	11242	0.57	7307	3939	
	Macrophytes	1965000	52358	2.18	30368	21990	
Dhir	Phytoplankton	1855000	10311	0.55	7424	2887	
	Macrophytes	1855000	43408	2.34	24308	19100	
Bilmukh	Phytoplankton	1850000	13533	0.732	10385	3148	
	Macrophytes	1850000	31995	1.730	21977	10018	

Table 2. Patterns of Energy utilization in Reservoirs and Beel

Ecosystems	visible radiant energy Kcal/ha/yr x 10^6	Autotrophic energy Energy fixed by producers Kcal/ ha/ yr x 10^4	Contribution of fishes at different trophic levels Major primary consumers (Kcal/ha/yr)		Major secondary consumers (Kcal/ ha/ yr)	Major tertiary consumers Kcal/ ha/ yr	Total energy harvest as fish Kcal/ ha/yr	Conve en
			Herbivore	Detritivore				Photosyn to fish (%)
Large								
Govindsagar	6278	4270	49080	9840	24840	170	85680	0.
Nagarjunasagar	7480	2175	1545	645	4125	4725	12000	0.
Rihand	6875	1390	4320	-	480	-	4800	0.0
Small								
Aliyar	7847	4937	4344	48528	9912	2592	65376	0.1
Bhawanisagar	7775	3204	24860	40200	6480	20640	95000	0.
Bachhra	6825	3485	29520	43560	13800	36960	123840	0.3
Beels								
Media	7154	21780	140772	109488	-	30144	284400	0.1
Dhir	6770	19580	206736	78312	14381	96571	396000	0.2
Bilmukh	6753	16607	161568	193692	566448	280320	692028	0.4

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Methods of evaluating primary productivity in small water bodies

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Introduction

Primary productivity is defined as the rate at which inorganic carbon is converted to an organic form. Chlorophyll bearing microscopic organisms such as phytoplankton, periphyton, algae and also macrophytes serve as primary producers in the aquatic food chain. Photosynthesis results in the formation of a wide range of organic compounds, release of oxygen and depletion of carbon dioxide in the surrounding waters. Rates of phytosynthesis in small water bodies are related to phytoplankton abundance and light intensity. Assuming equal light intensities, the photosynthetic production of dissolved oxygen will increase as function of phytoplankton abundance. In fish ponds phytoplankton is the major source of turbidity, so light penetration is generally related to phytoplankton abundance. Hence phytoplankters are limited to shallower depths as their abundance increases and there is a strong vertical stratification of photosynthetic rates and dissolved oxygen concentrations. In intensely manured fish ponds, primary productivity increases in upper layers of water, where favourable light conditions exists, but decreases in lower layers where overshading by the plankton reduces light penetration (Hepher, 1962).

On clear days, photosynthesis rates increase rapidly after sunrise and remain high up to afternoon, although the afternoon rates may be somewhat less than morning rates. Cloudy skies always cause a decrease in phtosynthetic rates.

The primary productivity in oxbow lakes may be quite different to that of pond ecosystem. The *beel* ecosystem generally contains large amount of submerged aquatic weeds, so greater photosynthetic rates and oxygen concentrations were noted in the weed beds of the *beels*.

Factors regulating primary production

The factors which regulate the magnitude, seasonal pattern and species composition in phytoplankton photosynthesis are light, temperature, nutrients, physical transport process and herbivory. Photosynthetically active radiation or light from 400-700 μm is a most important factor for photosynthesis which provides the major source of energy for these autotropic organisms.

During sunny days, the photosynthesis is generally poor at the surface layer. After a little depth maximum photosynthesis was noted. Rate of photosynthesis diminishes at higher depth due to poor light availability. At very high light levels, photosynthesis may decrease because of light inhibition (associated with photochemical destruction of pigments). The depth at which gross photosynthetic rate is equal to algal respiration rate is called the compensation depth which is equal to 2.5 times the secchi depth. For deep and turbid lake water the light regime in the top layer of a stratified system is often more congenial for phytoplankton photosynthesis than a vertically well mixed system.

Phytoplankton require N, P, Si, Mo, Zn, Mn, Ca, CO_2 and vitamins for their growth and sustenance. However, the most important are the macronutrients (C, N, P, Si). Phytoplankton growth and photosynthesis are in general congenial in the temperature range of 20 to 25 °C. Above 30° C the phytoplankton productivity may be affected adversely.

Methods of estimation of primary production: (A. P. H. A. 1980)

a) Oxygen method by measuring the changes in oxygen and CO_2 concentration (light and dark bottle method)
b) by recording the change in pH
c) Diurnal studies in D. O. Concentration
d) the ^{14}C technique.

Oxygen method

The basic reaction in algal photosynthesis is

$$(CO_2)n + (H_2O)n \xrightarrow[\text{Chlorophyll Catalyst}]{\text{light}} \underset{\text{Carbohydrate}}{Cn(H_2O)n} + nO_2$$

Thus, during photosynthesis, the phytoplankton and other aquatic plants absorb carbon dioxide and liberate oxygen. In oxygen method, clear (light) and darkened (dark) bottles are filled with water samples and suspended at regular depth intervals for an incubation period of 3-5 hours or the samples may be incubated under controlled conditions under artificial illumination in environmental growth chambers in the laboratory.

The advantage of oxygen method is that it provides estimates of gross and net productivity and respiration which can be performed with inexpensive laboratory equipment and common reagents. The DO concentration is estimated at the beginning and end of incubation period. Productivity is calculated on the assumption that one atom of carbon is assimilated for each molecule of oxygen released.

Procedure

1) Estimate the solar radiation with a pyrheliometer.

2) Determine depth of euphotic zone (the region that receives 1% or more of surface illumination) with a submarine photometer. Select depth interval for bottle placement.

3) Introduce samples taken from each pre-selected depth into duplicate light bottle, dark bottle and initial analysis bottle, use water from the same grab sample to fill a set *(i.e.,*one light, one dark and one initial bottle).

4) Determine the DO of the initial bottle by Winkler method with Manganous sulphate, alkaline iodide, sulphuric acid and standard sodium thiosulphate using starch as indicator. DO may also be determined with an oxygen probe.

5) Suspend the light and dark bottle at the depth from which the samples were taken and incubate for 3-5 hours.

6) At the end of the exposure period, estimate the DO of both light and dark bottles by Winklers method or by an oxygen probe.

Calculation

$$\text{Gross production} = \frac{\text{LB-DB}}{T} \times \frac{12}{32} \times \frac{1000}{\text{PQ (1.2)}}$$

$$= \frac{\text{LB-DB}}{T} \times 312.5\ \text{mgC/m}^3\text{/hr}$$

$$\text{Net production} = \frac{\text{LB-IB}}{T} \times 312.5\ \text{mgC/m}^3\text{/hr}$$

where LB= light bottle, IB = initial bottle, T = Time in hours.

PQ = Photosynthetic coefficient

$$\text{Respiration} = \frac{\text{IB-DB}}{T} \times 375\ \text{mgC/m}^3\text{/hr}$$

Primary productivity is generally reported in grams carbon fixed per m^2/day. Estimate the propductivity of a vertical column of water 1 metre square by plotting productivity for each exposure depth and graphically integrating the area under the curve. Using the solar radiation profile and photosynthesis rate during incubation adjust the data to represent phytoplankton productivity for the entire photoperiod.

Primary productivity estimation by recording the change in pH

Primary productivity can also be determined by measuring the changes in oxygen and CO_2 concentrations. In poorly buffered waters, pH can be a sensitive property for detecting variations in the ecosystem. As CO_2 is removed during photosynthesis, the pH rises. This shift can be used for estimating the primary production and respiration. However, the method is not very useful where the aquatic system is highly buffered (*e. g.* Sea, estuaries *etc.*) but it has been applied successfully in productivity studies in some lake waters.

Primary productivity estimation from diel changes of Dissolved oxygen

The dissolved oxygen content in a water body continually changes over a 24 hour period because of the effects of respiration and photosynthesis and due to slow rates of diffusion. The DO content is minimum during early morning, increases during day time and reaches its peak during the afternoon before declining again during night time. The highest content of DO is found in ponds with the greatest abundance of phytoplankton. However, water of these ponds also has high rates of respiration, hence they have the minimum content of DO in the early morning.

The oxygen method (light and dark bottle techniques) is widely used for determination of primary production. However, ^{14}C technique is more precise and can be used in cases where the productivity is very low. Moreover, certain bacteria such as green sulpher bacteria, purple sulpher bacteria *etc.* absorbs CO_2 and produce carbohydrate in presence of light, but in this photosynthesis oxygen is not evolved.

The overall reaction is as follows:

$$6CO_2 + 12H_2S \xrightarrow[\text{709 K.Cal}]{\text{light}} C_6H_{12}O_6 + 6H_2O + 12S$$

(Purple sulpher bacteria)

Similarly,

$$6CO_2 + 15H_2O \xrightarrow[\text{709 K.Cal}]{\text{light}} C_6H_{12}O_6 + 6H_2O + 6NaHSO_4$$

(green sulpher bacteria)

Determination of primary productivity by ^{14}C technique

This is a method of measuring carbon fixation by using the radioactive isotope ^{14}C as a tracer. Samples of water are collected from different depths and pH, total alkalinity and free CO_2 content in each are measured.

Borosilicate glass bottles (2 light and 1 dark) are filled from these samples and a measured quanity (5 μ Ci ^{14}C/ml) of Sodium bicarbonate containing ^{14}C is added to each The bottle are then sealed and suspended in water *in situ* for a duration of 3-4 hours. If temperature and illumination at the sampling depths are known, the bottles can be immersed in artificial tanks at corresponding temperature and provided with artificial illumination at the correct intensity. After *in situ* incubation, the bottles are taken out, fixed immediately with formalin and taken to laboratory for filtration. The water is filtered to collect the phytoplankton on membrane paper (0.45 x 10 - 6 m) in Millipore Filtration unit by applying pressure of about 0.5 atmosphere. The filter paper is treated with HCL fumes for 20 minutes to remove excess ^{14}C in filter paper and then placed in a vial containing 5 ml of Scintillation liquid. The Scintillation liquid is a mixture of xylene (400 ml/1), Dioxane (400 ml/1), Ethyl alcohol (200 ml/1), PPO (2.5 g/1) and POPOP (0.25 g/l). The activity of ^{14}C in the vial is estimated by a liquid scintillation analyser by measuring the β - radiation.

Calculation

Total alkalinity = T
Free CO_2 = A

$$\text{Bicarbonate alkalinity} = \frac{T-5 \times 10^{pH-10}}{1+0.94 \times 10^{pH-10}} = B$$

$$\text{Carbonate alkalinity} = 0.9 \times B \times 10^{pH-10} = C$$

Then total CO_2 = A + 0.44 (2B +C) in water

Sodium bicarbonate content in the radioactive ampoule = D

Then, total CO_2 = A+ 0.44 (2B +C) + D = E

$$\text{Total inorganic carbon} = \frac{12}{44} \times E = F$$

Now if the light bottle count = X_1
Dark bottle count = X_2

Total volume of bottle = X_3, Volume filtered = X_4,
Time of incubation = X_5, Total activity added to each bottle = X_6,
Efficiency of the counter X_7 = appx. 40%.

Then, Net primary production =

$$\frac{(X_1 - X_2) \times \frac{X_3}{X4} \times 1.064 \times 100 \times F}{X_5 \times X_6 \times X_7} \text{ mgC/m}^3\text{hr}$$

Here 1.064 is a corection factor for isotope effect.

Primary productivity for the entire depth of euphotic zone may be integrated and expressed as gram carbon fixed per square meter per day. Using the solar radiation records and photosynthesis rates during incubation, phytoplankton productivity for the entire photoperiod may be estimated.

Since , oxygen is not evolved, the oxygen method can not give reliable information about the bacterial photosynthesis. Thus, the ^{14}C technique is the best method for productivity studies of inland waters where different organisms contribute towards the primary production without releasing oxygen in the systems. The primary production of 20 fish ponds, located in 4 districts of West Bengal was studie (Nath, 1986, Nath *et al.,* 1994). Highest primary production was recorded during November-December and during March-May. Maximum production was observed just below the surface. The compensation depth in different centres ranged between 66.5 cm and 128.5 cm. Gross primary production of the ponds ranged from 2.4 to 9.14 gC/m^3/day.

Primary production of Hooghly-Matlah estuary was studied during 1982-1993 (Nath *et al*., 1996). Maximum primary production was recorded at Canning in Matlah estuary, which was free from aquatic pollution. In Hooghly estuary, maximum production was noted at Frazerganj in marine zone. Among freshwater centres Nabadwip had higher gross production, but Medgachi had higher net production. Minimum primary production was recorded at Nawabganj centre, presumably due to industrial pollution. The Hooghly estuary showed higher gross production during 1986, 1988 and 1992, while higher net production was observed during 1986, 1988 and 1990. The net primary production of different centres of Hooghly Matlah estuary ranged between 0.241 and 0.523 gC/m^3/day and its average net production was 0.380 gC/m^3/day. The gross production of different centres ranged between 0.44 and 0.794 gC/m^3/day, while the average gross production was 0.629 gC/m^3/day. The flood plain lakes of Ganga and Brahmaputra basins had moderately rich primary production which was contributed both by phytoplankton and macrophytes, the contribution of phytoplankton being comparatively lower than that of macrophytes. In macrophyte dominated *beel*s, the photosynthetic carbon production was 6.138 gC/m^3/day (Pathak *et al.* 1989).

Indian reservoirs vary widely in productivity depending on nutrient availability and other factors. Thus, poorly productive Bhatghar reservoir (Maharashtra) had low primary productivity (gross 20.8-145.8 mgC/m^3/day, net 10.4-83.3 mgC/m^3/day). However, Gangapati (1972) and Sreenivasan (1972) have reported some reservoirs having higher productivity where GPP values ranged from 1.6 to 3.228 gC/m^3/day and NPP ranged from 1.36 to 1.64 gC/m^2/day.

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Relevance of biological monitoring of environmental quality in inland water bodies with special reference to floodplain lakes and small reservoirs

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Introduction

Functioning of all ecosystems depends on the availability, conservation and recycling of natural resources such as water, land minerals and energy sources. Any perturbations in the broad framework of the inter-relationships among living organisms and their environments may influence the availability of resources to human societies. Rapid population growth has placed enormous stress on our life support systems of land, water, flora and fauna and the atmosphere. Therefore, sustainable development implies economic activities where both the local environment and the biosphere as a whole are protected.

Eco-degradation

The decline in environmental quality has however, underlined the need for harmonising the needs of economics with those of ecology. It is reported that globally 15% of total earth surface has undergone man- induced soil degradation, about 24% of humans occupy territory of the earth that is degraded by anthropogenic factors and about 1 million ha of prime land is lost to urbanisation alone annually. Further, there is a gradual diversion of forest lands for a variety of other uses resulting in the loss of habitats rich in biological diversity. All these changes have had adverse impact on aquatic ecosystems located in their catchment. Further, discharge of sewage and industrial effluents has also contributed to this decline in ecosystem health.

Therefore, it is not only important to accelerate effective *in-situ* and *ex-situ* conservation of genetic resources but the concerned organisations should also pay adequate attention to evaluation, classification, and monitoring, of ecosystems. In this connection, apart from standard procedure of chemical monitoring, greater emphasis is being given on biomonitoring which reflects true impact of stress on an ecosystem.

History of biomonitoring

The biological surveillance of fresh waters started with the development of the Soprobian system at the turn of the twentieth century (Kolkwitz and Marsson, 1902, 1908, 1909). But early attempts to use biological information to detect pollution utilising both the flora and fauna were made by Butcher (1928, 1946) in U. K. But gradually among all flora and fauna it was macro-invertebrates which assumed increased importance (Hawkes, 1956, Hynes, 1959). It was, however, the publication of the Trent Biotic Index (Woodiwiss, 1964), a method based entirely upon macro-invertebrates, establishing its utility for routine biological surveillance of pollution. Subsequently, the Trent Biotic Index (TBI) has been modified in many European countries for their local use. In U.K., the appearance of TBI was followed by a proliferation of score and index systems based on macro-invertebrates. Many of these were developed for limited geographic areas but recent one, Biological Monitoring Working Party (BMWP) score, was devised by a committee of freshwater biologists for national use (Chesters, 1980; Armitage *et al.,* 1983).

Despite a variety of indices and the often vigorous debate on their relative merits, the principle underlying all of them is effectively the same. Each individual taxon can be attributed a score, value or category that is indicative of its tolerance to environmental stress, normally in the form of organic enrichment. An integration of the scores of all taxa present at a site provides a measure (index) of the extent to which the site is, or has been, stressed (organically polluted).

Why biomonitoring? Its relevance

Biomonitoring is vital. Firstly, it enables us to assess aspects of water quality from the presence/absence of certain organisms, where more expensive chemical analytical instrumentation is unavailable. Secondly, biota often persist even where other evidence of a pollutant (textile mill effluent; sediment discharge) has been reduced to undetectable limits by dilution or dispersion. The longer the series of monitoring observations the greater the likelihood of distinguishing between inter-annual and seasonal differences due to variation in the weather, well mixed or stratified conditions, and changes due to 'real' pollution or other perturbations by man.

Biological monitoring enhances knowledge on wetland structure (biodiversity) and functioning (trophic interactions) and it identifies threats to the systems. This is facilitated by the continuing need to measure physical and chemical parameters, in order to extend the inventory of indicator species; for example, even where a dense population of an organic enrichment indicator species appears (oligochaete worms) more knowledge is required to establish the main cause of change. The multi-disciplinary requirement of monitoring thus also enhances understanding about problems due to eutrophication (pisciculture, agriculture, urbanisation), deforestation (sedimentation), afforestation (nutrient enrichment and acidification) and the burning of fossil fuels (acidification).

It generally follows from the above, that biomonitoring can strengthen our ability to manage wetlands. Prevention, rather than cure, of wetland degradation, also increases the revenue-raising potential of such water bodies.

Methods used in Biomonitoring

Many approaches could be used to understand the ecosystem changes at species community and physiological level, to understand the gravity of the impact so that suitable mitigation plan could be formulated. Some of the approaches are indicated below.

A. Eco-toxonomical Methods

Indicator species
Score system
Algal index
Trent biotic index

Community structure
Species diversity index
Dominance Index
Evenness Index
Similarity Index.

B. Physio-biochemical Methods

Biological function analysis
ATP
Primary Productivity
Chiolorphyll

Toxicity Testing

Short term acute

Long term

Avoidance studies.

What to monitor

Biomonitoring can not yet completely replace chemical monitoring programmes where detailed inventories of pollutants are required. Nevertheless, the shifts in the species composition and abundance of biotic assemblages may indicate pollution where the chemical cause such as a brief discharge or spill of material, has passed undetected. The organisms, species, populations and assemblages that can be used for biomonitoring are many and varied (from attached and planktonic micro-algae to macrophytic vegetation; from Protozoa to fish). Many argue that while the condition of a river or lake is reflected most noticeably in the appearance of the water (algal blooms; turbidity), organisms associated with sediments and other surfaces may provide the earlier indication of change in quality.

By definition, the ecology of best indicators of ecosystem quality or *health* is well-established (planktonic *Anabaena* (eutrophic) and *Asterionella* (mesotrophic-eutrohic); benthic invertebrates from Plecoptera (many species indicating *'pristine'* water), to Chironomidae, Oligochaeta and larval Diptera (organic pollution); acid indicating diatoms). Some of the best indicator organisms are also reasonably abundant and relatively easy to detect. In this connection, communities of organisms such as benthic invertebrates which are attached to, or loosely associated with surfaces, are perhaps more *convenient* than planktonic species (blue-green algae and diatoms on sandy and stony stream bottoms and lake shores).

Changes in organism morphology (algal size due to grazing pressure, fish caudal ray deformities due to acidification), in addition to shifts in the abundance of a species itself, can be used as *indicators of change.* Care must be exercised at all times in interpreting the indicator potential of a change in a population or assemblage.

Where to monitor

All zones of wetlands harbour biota that are, or have the potential to be, *indicators of water quality* (open water plankton; littoral zone; epipelic diatoms (on mud surfaces), epipsammic forms (on sand grains), epiphytic species (on submerged plant leaves) and filamentous green algae *(periphyton)* loosely attached to submerged plants. Habitats and communities must be assessed (*e.g.* by stratified random sampling; transects or quadrats) to ensure repeatability and comparability of data that may be collected by different operators and/or at different times; otherwise the significance of a change or lack of change can not be assessed.

When to monitor

In addition to focussing on major pollution events (industrial discharges; storm runoff of sediment), sampling schedules must take account of the life cycles and generation times of the organisms of interest (daily sampling *e.g.* phytoplankton, Protozoa and Rotifera; weekly for crustacean zooplankton; seasonal for macrophytic vegetation and benthic invertebrates; and possibly yearly or even less frequently for certain fish populations). Schedules may well need to be altered in order to chart events such as the recovery of a fish population following a kill due to pollution or disease.

Advantages of macro-invertebrates:

Several advantages of using freshwater macro-invertebrates for pollution assessment have been cited (Hellawell 1977; Hellenthal, 1982).

i) The wide diversity and abundance of species in almost all freshwater habitats.

ii) Their relatively sedentary habit which allows the presence of most taxa to be related directly to environmental conditions at their place of capture.

iii) The length of life-cycle of many species which provides a perspective of conditions which pertain to at a site over several months.

iv) The ability of invertebrate communities to integrate and to respond to a range of environmental stresses simultaneously.

v) Many species are important accumulators and concentrators of toxic substances.

vi) Qualitative sampling is easy and inexpensive.

RIVPACS - A multivariate approach

One of the most advanced, yet simplest and most successful programmes for assessing water quality from the invertebrate assemblages, is the UK's River Prediction and Classification System (RIVPACS). One of its main strengths is its ability to assess whether a species/assemblage is absent due to pollution or simply a lack of available habitat. Under this programme, analysis of the data has a two stage process. Firstly, sites are classified according to the taxa present. Criteria here is that the resulting classfications should be ecologically interpretable and that new sites could be easily attributed to a classfication group without recourse to detailed further analysis. The next stage is to use the environmental data to interpret the biological information. An essential pre-requisite here is that the method should provide a procedure for predicting the likely occurrence of macro-invertebrates from the knowledge of chemical and physical features of sites. The classification of sites is achieved by TWINSPAN, the two way indicator species anlaysis, (Whittaker, 1981). TWINSPAN is used to successively divide a set of entities (sites) according to their attributes (presence of macro-invertebrates) and the resultant classification is commonly presented as a dendrogram. Similar approaches developed on river systems are being adopted for the littoral benthos of standing water (lakes and reservoirs).

Some shortcomings and gaps in knowledge

Biomonitoring can *fail* for a number of reasons. One of these can arise due to statutory authorities' reluctance or inability to respond rapidly enough to reports on the appearance of pollution if plankton, especially algae, are taken as indicator species. If biomonitoring establishes the presence of a nuisance organism or an increase in its numbers to *'undesirable'* levels, the ecosystem is already in decline. Secondly, inadequate temporal and/or spatial sampling can lead to false interpretations as to the state of a water body. Dense, but patchy aggregations of surface-blooming blue-green algae which are very noticeable, may be perceived as *'serious'* even though such populations are likely to be very moderate if expressed on a lake-wise basis. An extremely dense and well mixed diatom populations can pass relatively unnoticed since they simply impart a general cloudiness to a water. Dense populations of organic pollution indicators are restricted to the immediate vicinity of a *spill*. The third shortcoming of biomonitoring stems from the lack of knowledge about the potential indicator value of many organisms (numerous chrysophycean species; the colonial green alga *Botryococcus braunii* can produce very striking orange blooms; red *Euglena* bloom). Fourthly, there is the problem over the very identity of organisms recorded, and fifthly, among very small *(pico)* forms, some are likely to be completely overlooked even when present in enormous numbers, *e.g.*, *Synechococcus* (cyanobacterium).

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Biotic communities and their relevance in the production processes of reservoir ecosystem with special emphasis on plankton and benthos

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Introduction

Biotic communities specially plankton and benthos play an important role in production processes of reservoirs as fishes are mostly dependent on these biotic communities for their food. Biological activity of a reservoir is influenced by its climatic, edaphic and morphometric features. The geographical location affects the metabolism of a reservoir through food supply, shape of basin and the efficiency with which the climatic factors are able to act in the dynamic exchange. The measurement of plankton productivity, both at primary and secondary levels, is essential for proper management of reservoirs. Many workers have suggested that an understanding of the production process of invertebrates would facilitate management of fish stocks of reservoirs. Hanson & Leggett (1982) showed that fish yield is related to the mean standing biomass of macrobenthos in a lake, and thus a general relationship probably exists between secondary productivity and fish production. The importance of secondary producers to the study of fish dynamics is underscored by their trophic intermediacy between fish populations and energy sources.

The success of an organism and its productivity in reservoir ecosystem are determined in part by the suitability of the environment. Among the most obvious aspects of the environment that affect animal production are temperature, concentration of dissolved oxygen, the ability of the ecosystem to produce sufficient fish food organisms and the character of the substrate. Effect of these factors in the production processes of reservoir are being dealt under following heads.

Temperature

Temperature influences the rates of activity from a molecular to an organismal scale. Many ecologists have found that rates of secondary production increased with temperature. However, production (P) / mean biomass (B) is believed to rise with increased temperature on a linear or curvilinear scale. The general positive effect of temperature on secondary production is a result of the reproductive biology of plankton and benthos. Many workers suggested that with increase in temperature growth rate and feeding rate increased, and the eggs development time decreased . These factors tend to increase productivity of biotic communities in reservoirs at high temperature. But Aston (1973) suggested that egg production by oligochaetes declined at high temperature. Pidgaiko *et al.,* (1972) concluded that temperature variation could have either a positive or negative effect on the productivity of biotic communities depending upon geographic location and basin morphometry of reservoir. The temperature regimes of reservoirs in north India are lower than that of the south. Variation of temperature from surface to bottom has been recorded only 3-4 ºC for peninsular reservoirs (Nagarjunasagar) whereas the same for north India has been registered as 10 ºC. (Konar). This can be attributed to less-marked seasonal differences in temperature as one progress towards lower latitudes.

Reservoirs in temperate region often develop thermocline with the formation of epilimnion, metalimnion and hypolimnion. But in tropical reservoirs no such thermal stratification occurs although some ill-defined thermal gradient, (Table 1) has been reported by Sreenivasan (1969) in few south Indian reservoirs and Patil (1989) in a Waghyanala reservoir from central India.

Table - 1. Thermal Features of Some Reservoirs

Thermal features	South India								Cent. India
	Pykara	Sandy-nulla	Amara-vathy	Krish-nagiri	Sath-anur	Aliyar	Bhavani sagar	Stan-ley	Waghyanala
Surface 0ºC Max.	22.4	22.6	28.8	31.4	30.4	32.8	31.0	32.0	33.0
Min.	19.0	16.4	24.0	23.5	25.0	26.0	23.8	24.2	21.0
Bottom 0ºC Max.	20.2	20.0	27.0	28.0	28.5	31.0	30.2	30.0	31.0
Min.	18.0	15.1	21.5	23.0	24.0	24.2	22.2	24.0	20.0
Thermal Stratifi-cation	Nil	Rare	Nil	Very rare (ill-defined)	Nil	Very rare (ill-defined)	Very rare (unsta-ble)	Rare (unst able)	Rare (unstable)

(Modified from Sreenivasan, 1969)

Production of fish food organisms in the reservoir ecosystem

A community of heterotrophs can fix no more energy than the amount made available to them by primary producers, specially phytoplankton . The rates of production of benthos and zooplankton are positively related to food availability in reservoir ecosystem fixed through autotrophs. Thus, production of zooplankton and benthos is directly related to rates of primary production. Winberg (1971 b) has been more specific while hypothesizing that secondary production (Ps) is about 10 % of primary production (Pp), on the average. This suggests that Ps = a + b Pp , where a = 0 and b = 0.1. But Brylinsky (1980) indicated that phytoplankton primary production is a better predictor of zooplankton production than phytoplankton biomass, but the relationship may not be linear. Thus, this equation probably overestimates zooplankton production at low phytoplankton production and makes underestimates at high phytoplankton production. The relationship between phytoplankton production and secondary production is probably responsible for apparent relationships among secondary production, nutrient conditions and alkalinity. It should also be remembered that quality of fish food organisms is important in determining the secondary production of both zooplankton and benthos.

Chemical factors influencing the productivity

Values of certain important chemical parameters of reservoir water and soil suggesting high biological productivity are depicted in Table 2.

Table 2. Chemical parameters of reservoir water and soil suggesting high biological productivity.

Parameters in mg/l except pH	Water	Parameters	Soil
pH	> 6.5	pH	7.5
Alkalinity (bound CO_2 as carbonate)	> 50.0	Available Phosphorus (mg/100 g)	> 6.0
Total alkalinity	> 90.0	Available N (mg/100 g)	> 75
Dissolved N	> 0.2	Organic carbon (%)	> 1.5
Dissolved P	> 0.1		
Calcium	> 25.0		
Total hardness	> 25.0		
Sp. conductivity (μmhos/cm)	> 200		

The oxygen curve is an important chemical parameter to indicate the biological productivity of a reservoir. Oxygen deficit at the bottom is a characteristic feature of productive reservoirs. Photosynthesis at the surface and tropholytic activity at the bottom cause *klinograde oxygen distribution* as recorded in Bhavanisagar, Amaravathi, Nagarjunasagar, Gobindsagar and a number of other reservoirs in India. In unproductive reservoirs, the oxygen curves parallel the temperature curve since it is temperature-dependent (Sreenivasan 1971). In Konar, Tilaya, Rihand and Tungabhadra reservoirs, such orthograde oxygen distribution was observed along with low productivity.

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

In a number of south Indian reservoirs, Sreenivasan (1965,1968 and 1970) recorded a range of 4.1-10 mg/l dissolved oxygen concentrations strikingly similar to central Indian reservoirs. The availability of oxygen is thought to be critical, specially to the benthos because they often live in areas that are oxygen-poor. Brylinsky (1980), however, has found that zooplankton production in a wide range of reservoirs is also influenced by oxygen concentration in the epilimnion. Jonasson (1978) suggests that sufficient oxygen is important to benthos production because food cannot be metabolised efficiently at low oxygen level. Aston (1973) suggests that egg production in freshwater oligochaetes is constant with decreasing oxygen concentration until some critical low level is reached.

Influence of miscellaneous environmental factors and reservoir morphometry

Many workers suggest that secondary production decreases with increasing water flow rate. Selin & Hakkari (1982) have suggested a positive relationship with intensity of solar radiation. Burgis (1971) and Paterson & Walker (1974) reported that high zooplankton and benthos production rates should be found in the most stable ecosystems.

Mean depth, defined as the volume of the reservoir divided by area, is considered the most important morphometric parameter. It is indicative of the extent of *euphotic-littoral* zone *i.e.,* the depth zone which permits the light penetration for growth of planktonic algae and also provides shallower shore areas for attachment of sessile algae and macrophytes. It is an inverse correlate of shore development, a direct correlate of area (Hayes,1957) and an exact correlate of volume when area is held constant. Thus, mean depth portrays many morphometric features of a reservoir which contribute to the potential productivity of biotic communities in ecosystem. Rowson (1955) has observed distinct inflection in the mean depth curves at 18m (10 m in some Indian reservoirs). This suggests that water mass below this depth serves as a *nutrient sink* as the nutrients from trophogenic zone in the form of settling seston and phytoplankton are shifted to tropholytic zone.

Shallower reservoirs generally support higher rate of secondary production (Johnson, 1974 & Brylinsky, 1980). Johnson also suggest that the surface area of a reservoir might be important, since in larger reservoirs the profundal zone was less enriched by the littoral zone or allochthonous materials to secondary production. Possibly due to high primary production in the littoral zone, it is generally believed that secondary production in near-shore areas and macrophyte beds is greater than all other areas (Kajak *et.al.*,1980).

Status of biotic communities in Indian reservoirs :

Plankton

Generally two plankton pulses are recorded in Indian reservoirs, one in February-June and the other in October-December. The dominance of various groups of phytoplankton over zooplankton, vary from year to year. By and large, the predominant group is blue-greens (mostly *Microcystis*) a group not noted for passing their high productive capability directly to the higher trophic levels. Bacillariophyceae are mainly constituted by *Synedra, Navicula, Fragilaria, Melosira* and *Gyrosigma*; Chlorophyceae include *Oedogonium, Spirogyra, Pediastrum, Botryococcus, Pandorina* and *Eudorina* as dominant forms.

Zooplankton is predominately represented by copepods comprising *Diaptomus* and *Cyclops* while rotifers are represented by *Keratella, Brachionus, Polyrathra* and *Filinia.* The general trends of abundance were found to change due to rainfall and nutrient from runoff. Maximum numbers are recorded from April-June and minimum during July-August in most of Indian reservoirs. Since as zooplankton is the main food constituent of major carp species as well weed fishes, these play a major role in the production process of reservoirs.

Periphyton (Aufwuchs)

Aufwuchs or periphyton forms the food source of browsing fishes and takes the form of a brown or green layer at the surface of submerged objects in reservoirs. This group is represented mainly by diatoms, green algae and blue-greens. Periphyton colonises best in littoral areas of the reservoir.

Macrobenthic invertebrates

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

Importance of bottom biota as fish food is well established. Many of bottom feeding riverine species have adopted themselves to lacustrine conditions. They are *Puntius dubius, P. hexagonolepis, P. kolus, Labeo calbasu, L. dero, Cirrhinus cirrhosa, C. mrigala* and *Pangasius pangasius*. Thus, the benthos represents an important link in the production process of the reservoir ecosystem.

Energy sources and energy transformation in reservoirs

Reservoirs get energy from both autotrophic energy fixation and allochthonous sources. The energy fixed by the producers was in the range of 3,803 to 11,696 cal/m^2/day in Rihand, Gobindsagar, Bhavanisagar and Nagarjunasagar (Natarajan,1976). The two tropical reservoirs, Bhavanisagar and Nagarjunasagar received almost similar amount of solar energy but the efficiency of energy transformation from primary producers to fish or light to fish in Bhavanisagar was much more compared to Nagarjunasagar (Table 3). Among the two sub-tropical reservoirs, Gobindsagar has shown better conversion efficiency from photosynthetic energy to fish or light to fish than Rihand. Energy transformation through primary productivity of few Indian reservoirs is given in Table 4.

Table 3. Photosynthetic energy fixation and energy conversion in four reservoirs.

	B. Sagar	N. Sagar	Rihand	G. Sagar
1. Location	11°5'N	16°34'N	24°N	31°25'N
2. (a) Total visible radiation K cal/m^2 /day	2,130	2,050	1,884	1,720
(b) Total radiant energy cal/m^2 /yr x 10^5	7,775	7,483	6,877	6,278
3. Photosynthetic production				
(a) gO_2 /m^2 /day	2.380	1,620	1,003	3,178
(b)gO_2 /m^2 /yr	870.890	590.93	377.04	1159.97
(c) Energy cal/m^2 /yr x 10^6	3.205	2.175	1.387	4.269
4. Efficiency of energy transformation from light to chemical (%)	0.412	0.290	0.202	0.682
5. Fish Production				
(a) kg /ha/yr	79.200	10.0	4.0	71.4
(b) g /m^2/yr	7.920	1.00	0.40	7.14
(c) Energy cal/m^2 /yr	9.500	1.200	480	8.568
6. Conversion of energy				
(a) Fish/photosynthesis 5(c) - 3(c)	0.290	0.055	0.034	0.20
(b) Fish/light 5(c) - 2(b)	0.001	0.00016	0.00007	0.0013
7. Fish production 5(b) - 3(b)	0.900	0.17	0.105	0.61
8. (a) Photosynthesis (gC /m$^{2/}$ yr)	326.580	221.6	141.39	435.0
(b) Fish yield as (gC /m$^{2/}$ yr)	0.792	0.100	0.04	0.714
(c) % conversion	0.240	0.045	0.028	0.164

(Jhingran, 1991)

Table 4. Energy Transformation through primary production in different reservoirs.

Reservoirs	Location	Incident visible /radient energy (Cal/m²/day)	Energy fixed by producers (Cal/m²/day)		Photosynthetic efficiency (%)		Net energy stored by producers (Cal/m²/ day)	Energy lost as respiration (Cal/m² /day)
			oxygen	carbohydrate	oxygen	carbohy-drate		
B. Sagar	11°5' N	21,30,900	8,781	9,168	0.412	0.430	4,610	4,172
N. Sagar	16°34' N	20,50,300	5,959	6,221	0.290	0.303	3,450	2,509
Ukai	21°15' N	19,55,000	6,175	6,671	0.320	0.340	4,910	1,227
Getalsud	23°27'N	19,25,000	2,721	3,100	0.148	0.161	1,368	1,353
Rihand	24° N	18,83,750	3,803	3,970	0.202	0.211	1,580	2,217
G. Sagar	31°25'N	17,19,900	11,696	12,210	0.682	0.710	7,626	4,071

(Jhingran, 1991)

Production processes and energetics of reservoir ecosystem

In a newly constructed reservoir, nutrients leaching from unflooded substrate, submerged forests and other organic matter, contribute to high initial fertility in the ecosystem. This accelerates the growth of bacteria, phytoplankton, zooplankton and benthos. The maximum productivity in newly filled reservoirs is obtained within the first few years of their existence. In Rihand and Gandhisagar reservoirs, fish yield reached its initial peak in the fourth year of impoundment. However, this high production is not sustained for long and after a period, ranging from one to several years, it declines to nearly half the magnitude of initial phase (Bhukaswan, 1980) partly due to increase in the volume of impounded water and partly due to aquatic vegetation which uses up the nutrients. Thus, status of the reservoir is getting adjusted to the basic productivity levels of the basin depending on the quantum of allochthonous nutrients.

Although variable from season to season, considerable allochthonous energy accumulates in the reservoir system which either gets deposited accelerating eutrophication or else it enters the food chain in significant quantities. Reservoirs differ considerably not only with respect to incident light energy but also the efficiency with which this energy is converted to chemical energy by primary producers. Also efficiency of energy flow from producers to different trophic levels of consumers differs considerably from reservoir to reservoir depending upon the qualitative and quantitative variations in biotic communities inhabiting the reservoir.

For trophic dynamics concept of ecology, Lindeman (1942) suggested that if one could reduce the interactions among components of a community to a common currency (*e.g.,* energy), then one could quantify the interactions and learn to predict changes such as succession within ecosystems. Lindeman also introduced the major concept that an organism's success in an environment might be a function of its ability to fix and retain energy. Thus, the role of important biotic communities like plankton and benthos may be expressed according to Edmondson (1974) that secondary production cannot be thought of as a distinct process by itself. Rather it is part of a larger scheme of the movement of material through the ecosystem, and this is based on the activities of individuals and populations of animals. Precisely, the trophic-dynamic goal of production ecology of reservoir is a formidable one. But productivity potential of reservoirs can be assessed through chemical parameters, rates of primary and secondary production, energy assimilation efficiencies at different trophic levels, morpho-edaphic and morpho-drainage indices etc. Accordingly, appropriate management practices may be applied for augmenting fish yield from reservoirs.

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Role of plankton, benthos and periphyton in the production cycle in the floodplain wetland ecosystem

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Introduction

Floodplain wetlands show great promise in increasing fish production through appropriate management measures. Recently, even in some *bee*ls, by adopting pen culture practices, raising of *Macrobrachium rosenbergii* in place of carps was made possible. In the context of such an advancement, studies on the role of ambient ecosystem on the aquatic production cycle assumes significance for better adoption of management measures. Aquatic ecosystem can be divided into two broad aspects, the abiotic features dealing with physico-chemical parameters and the biotic features dealing with various biotic communities. At the basic level, temperature, water current, transparency, available nutrients, dissolved oxygen, alkalinity, organic loads, carbondioxide, light intensity for photosynthesis, load of pollutants, etc. are controlling the production of various biotic communities which, in turn, contribute directly or indirectly to the fish yield in an aquatic ecosystem.

Biotic communities

The biotic communities in different categories of *beel*s exhibit high level of diversity in qualitative and quantitative terms . Moreover, different types of biotic communities exert their influence in different ways on the fish production process. These biotic communities are grouped as :-
Plankton: comprises the world of drifting or weakly swimming aquatic beings that are mostly minute in size and at the mercy of water movements.

Benthos: The members of this community are animals and microplants that are attached to, crawl over or burrow into the bottom soil, sand, silt or mud.

Neuston: The community that floats on the surface of the water, either under or above the surface film and composed of partly aquatic weeds, partly aquatic insects and partly plankters.

Aufwuch: This community is formed by the attachment of some unicellular and filamentous algae to some submerged substrate where protozoans, bryozoans, rotifers, annelids, insect larvae, crustaceans, *etc*. usually remain lodged. Sometimes, only the phyto-forms of this community are called *periphyton* for convenience. However, many authors consider all phyto- and zoo- forms attached to the submerged substrata as periphyton or *heptobenthos*.

Aquatic macrophytes: These are plants which draw their nutrients either from the ambient water or from the bottom soil substrate or the bank soil and are present in the aquatic system as marginal, floating, bottom rooted (submerged and emergent) forms.

Nekton: These are free swimming organisms that can negotiate with the normal water current and that include fishes, shrimps, etc.

Epiphyte and epizoons: These communities remain attached to nekton, aquatic weeds or macrobenthos populations as parasite, symbiots or commensals. Epiphytes include bacteria, algae, fungi, etc. and epizoons include protozoans, coelenterates, copepods, isopods, helminths, leeches, *etc.*

Bacteria and viruses are found to be present everywhere, being associated with all types of these biotic communities as well as in the soil and ambient water.

Interdependence and food-chain

When intra-community dynamics and the food chain of aquatic biota (Fig. 1) are analysed, it is generally observed that the primary producers *i.e.,* phytoplankton, phytobenthos, periphyton and epiphytes along with aquatic weeds are at the lowest level of the food-chain pyramid where various communities show their interrelationship and proportionate abundance after food conversion into biomass at every stage. However, the food conversion rate is always < 1. So, the secondary producers are much less in their abundances and are dependent on the primary producers for their subsistence. At the top of the food chain, however, the principal consumers, nekton appear just after the macrobenthos population which act as either food augmentors or as competitors in consuming primary and secondary producers. The roles of saprophytes and detritivores in the food-web of floodplain wetlands are shown in Fig. 2.

Since most of the floodplain wetlands receive monsoon run-off from the catchment areas, especially where man-made small reservoirs are created by erecting dykes across the flow line of the water, the aquatic food-web is greatly influenced by the ecological conditions of the surrounding territory of those water bodies. On account of the effect of drainage into the floodplain wetlands, colour, transparency, nutrient levels, pollutional loads, *etc.* of the water undergo changes, influencing photosynthetic activities of holophytes. This, in turn, affects the entire food web. Likewise, the nature of the bottom substrate of a floodplain wetland also indirectly regulates the variations and abundances of different members of the food-web. Fig. 3 shows how the terrestrial ecosystem of the catchment area and the bottom substrate of the floodplain wetland exert influences on various biotic communities.

Characters of floodplain wetlands

The deeper floodplain wetlands become shallower and shallower as the organic deposits, detritus and silts continue to accumulate at the bottom through growth and decay of densely populated weeds, dumping processes of catchment run-off and severing of linkages with the connecting river due to gradual elevation of drainage beds, *etc.* Newly formed floodplain lakes are generally deeper. Initially they possess oligotrophic conditions with low plankton densities. In course of time, they turn into eutrophic water bodies with enough bulk of plankton. Deeper floodplain wetlands with longer evolutionary history, however, have heavier growth of planktonic diatoms. Altitude and latitude may alter temperature and photoperiod of floodplain wetlands and provide changes in the production cycle. Floodplain wetlands in desert region are usually alkaline, but they are somewhat neutral in high rain-fed areas while swampy and boggy wetlands are quite acidic. Their biotic communities vary greatly, bringing in changes in the productive cycle. In other words, floodplain wetland ecosystems are characterised by two things *viz.,* (I) variation of living conditions and (ii) temporary existence of such conditions. Epilimnion in such water bodies provide high DO, good illumination, and conditions both favourable and uniform for high plankton density whereas hypolimnion with not much temperature variations in a warm country like India shows low level of DO, stagnancy and pollution to some extent, allowing protozoans, worms, molluscs to be more.

Variations in biotic communities and production cycle

It is well known that if the production at the lower trophic level increases, the yield of nekton is proportionately improved. Phytoplankters and nannoplankters hold the prime position among the biotic communities in the aquatic system. Among net plankton, though most of the members belong to the microplankton population, the abundance of macroplankters in monsoon months are also not very uncommon.

Quite a good number of lecithotrophic and nannoplanktivorous macroplankton, basically belonging to meroplankters enter into the floodplain wetlands with the flood water along with fish spawn and prawn larvae. Initially such plankters occupy the same niche with other members of infraneuston *viz.,* snails, flatworms, dipteran larvae, etc. and impede proliferation of phytoplankton through predation and competition for space in the euphotic zone as also offered by the supraneuston. Unlike *Azolla* sp., *Lemna* sp. and other supraneuston, the hemipterans never contribute towards the productivity of nekton in a positive manner.

The plankton maxima in floodplain wetlands are usually encountered during spring and autumn seasons and minima in winter and summer months. Local variations and effect of latitude, temperature, water current, nutrient level, photoperiod, *etc.* on plankton abundance are well known. Deleterious effect of strong sunlight on surface plankton barring *Microcystis* sp., *Anabaena* sp., *etc.* is always noticed. So, the density at the sub-surface layer is the highest as seen in Fig. 4.

Water bodies with faster water current have obviously less plankton. Among plankton community, the drifting neuston such as dinoflagellates and blue green algae are more affected by the wind action. Littoral region *i.e.,* the shallow shore area in floodplain wetlands are mostly weed infested and if not, usually have thick coverage of benthic algae. So, natural development of plankton is much hindered for nutrient diversion, competition for space in the shallow euphotic zone. In such a situation, planktonic growth is generally overshadowed by the growth of attached forms like periphyton and epiphytes. In floodplain wetlands, if the incoming water is mainly from the catchment area, then the concentration of plankton in the littoral zone is further diluted. But, where flooding is due to river in spate, the concentration of littoral plankton greatly depends on the concentration of rheoplankton rather than limnoplankton. In such environment haliplankter is absent. However, due to the effect of domestic sewage effluents in some floodplain wetlands, the occurrence of a few hypalmyroplankter cannot be ruled out.

Towards the centrally located deeper regions *i.e.,* in limnetic or pelagic open water areas, more extensive occurrence of plankton is seen where quite a few dominating forms exist. Most of these euplankters are holoplankters. At places with greater depths, the plankton community is distinctly divisible into epiplankton of the upper layers of water column and hypo or bathyplankton of the lower layer and that too irrespective of presence or absence of any aphotic zone in the ecosystem. Wherever, disphotic condition exists, the mesoplankton production is boosted up. If shallow littoral region is affected by turbulence of any sort, the benthic, periphytic and other forms come in suspension towards the surface and constitute the pseudoplankton community which are obviously members of tychoplankton. Such tychoplankters, along with filamentous algae and diatoms, form the bulk of the littoral plankton in the floodplain wetlands. Further, if there is any stagnancy, the prevalence of blue green algae and desmids, like *Closterium* sp., *Cosmarium* sp., etc. are noticed. When such water bodies are polluted, they usually encourage growth of *Microcystis* sp., *Euglena* sp., *Phacus* sp., *Pediastrum* sp., *Coelestrum* sp., *Amphora* sp., *Cladophora* sp., *Pithophora* sp., etc.

It is well known that in such water bodies zooplankton constitutes hardly 15-30% of the total plankton. In spite of zooplankters feeding mainly on phytoplankton, the latter is not the sole limiting factor for the abundance of the former. Usually zooplankters are more when diatoms are in low density and also quite high in their abundance in the plankton of the upper layer of epilimnion where they exhibit direct relationship with the bulk of nannoplankters and detritus. The growth of zooplankton community always lags behind the phytoplankters. Further, even profusely available zooplankters may disappear or become very scanty. The decline in the zooplankton community is also linked with the grazing of organisms of higher trophic level or interferences of various biotic and abiotic features or due to differential growth and changes in the period of reproductive cycle or perhaps for animal exclusion through algal barrier. There are many species which cannot breed within the system but can thrive only through exogenous replenishment.

Like the blooms of algae appearing through sprouting of dormant spore, the resting eggs of many zooplankters also hatch out during inundation of dry, exposed marginal areas or elevated patches of the bottom. Sometimes dispersal of dormant algal spores and resting eggs of zooplankters by the feet and feathers of birds has also been reported causing sudden blooms in the ecosystem. Similarly, pseudodominances occur as *Helosira* sp. exhibits pulses against non-pulsating type *(Daphnia* sp). Such pulses vary from place to place, year to year and from species to species without maintaining any specific sequence.

Zooplankters generally exhibit diurnal migration between water surfaces and bottoms due to certain factors which may be tropistic reaction or phototropism (positive or negative), geotropism (positive or negative), temperature variation, feeding and physiological rhythm. The exact cause is not readily detectable. During such migration, certain species originally belonging to the littoral zone, move deeper and deeper through the bank slopes to rise again to the surface much away from the shore area. In this manner, they ultimately reach the limnetic zone located centrally to join uferflucht community that always avoids shore areas and prefer to remain in the epilimnion of the deeper areas. Thus, in most of the floodplain wetlands, the zooplankton is more in limnetic zones than the littoral zones. Further, towards the surface, *nauplii* migrate more than the adult crustaceans. Even certain zooplankters exhibit morphological variation with the geographical and seasonal changes. *Keratella* sp., often becomes smaller in size to migrate upwards through summer water of lesser density, but in case of *Daphnia* sp. and *Ceratium* sp., the case is just the reverse. The anterior end expands in *Daphnia* sp. and the forth spine appears in *Ceratium* sp., to expand the body surface for facilitating floatation. Again rotifers and protozoans feeding on settled and sedimented organisms prefer to remain as meso- and hypoplankton and stay in the littoral zone. Similarly, some dipteran larvae and copepods also prefer to remain among the hypoplankton community. Littoral region of a floodplain wetland usually encourages the presence of large cladocerans *(Daphnia* sp.) along with copepods, ostracods and rotifers.

Though plankton density in the littoral region is quite low, the periphyton (aufwuch) community generally flourishes, taking advantage of leaves, twigs or stems of the submerged weeds for attachment and ultimately plays key role in the production cycle. This community encourages the growth of browsers in the higher trophic level. In the floodplain wetlands of the hilly terrain with submerged boulders and rocky banks, the populations of periphyton in most cases settle densely on hard substrates more or less in a permanent manner and show much complexity.

Conclusions

The contribution of periphyton, detritus and benthos is more for the productive cycle of the littoral zone, whereas phytoplankton followed by zooplankton, neuston, *etc.* are the main contributors for the nekton production in the limnetic zone, if the water area is not choked with obnoxious weeds in a floodplain wetland. Generally, benthic populations are less in the limnetic zone and areas quite close to the shoreline respectively due to low depth and susceptibility to drying on exposure when water recedes. So, slightly deeper area that never dries completely shows usually denser populations of benthos which are helpful for their consumers, but are of no avail to filter feeders and periphyton browsers. Hence benthos have both positive and negative roles in the production cycle of the floodplain wetlands.

Thus, the greatest contributor in such a system is the detritus available in plenty, especially when this kind of water bodies are shallow and pretty old. The strip of littoral area of a floodplain wetland having optimal water column permanently is the richest zone which harbour maximum varieties of biotic communities, attracting water birds, snakes, frogs, small fishes, etc. for feeding.

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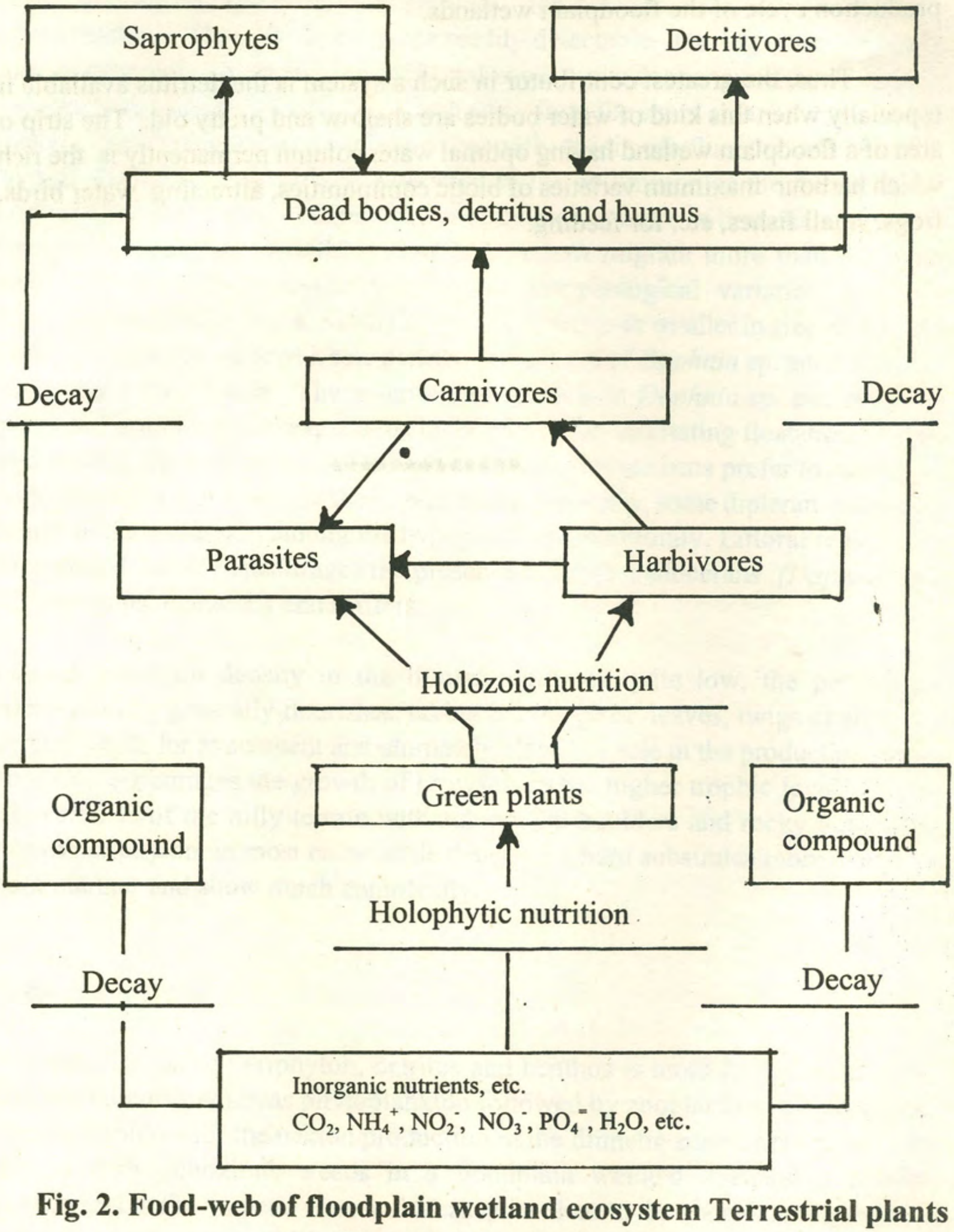

Fig. 2. Food-web of floodplain wetland ecosystem Terrestrial plants Terrestrial animals

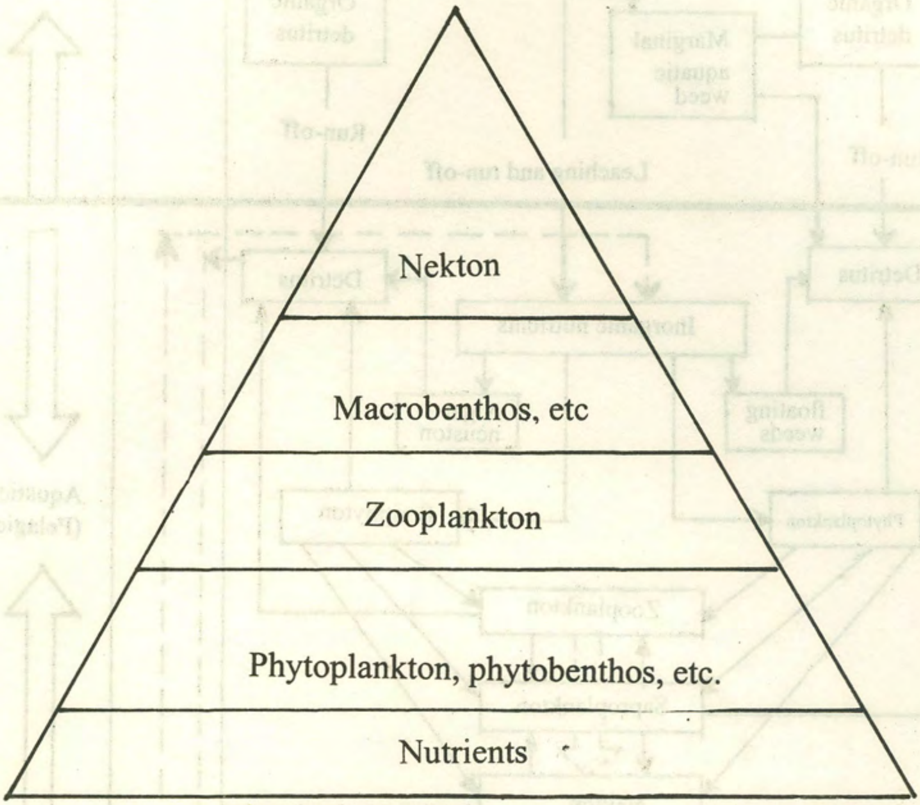

Fig. 1. Food pyramid of floodplain wetland ecosystem

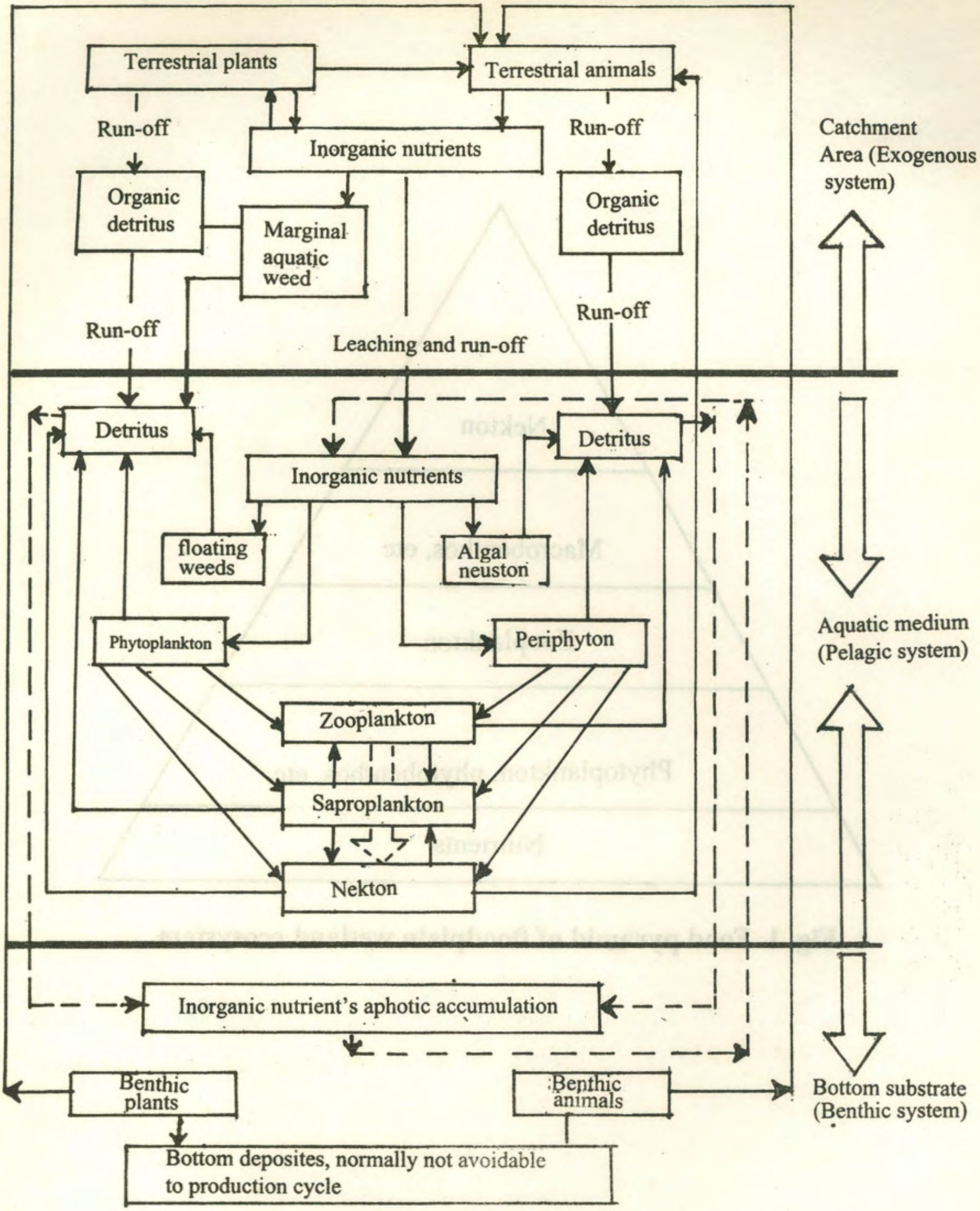

Fig. 3. Biotic and abiotic relationship existing in the catchment area, aquatic media and bottom substrate for production cycle in floodplain wetlands.

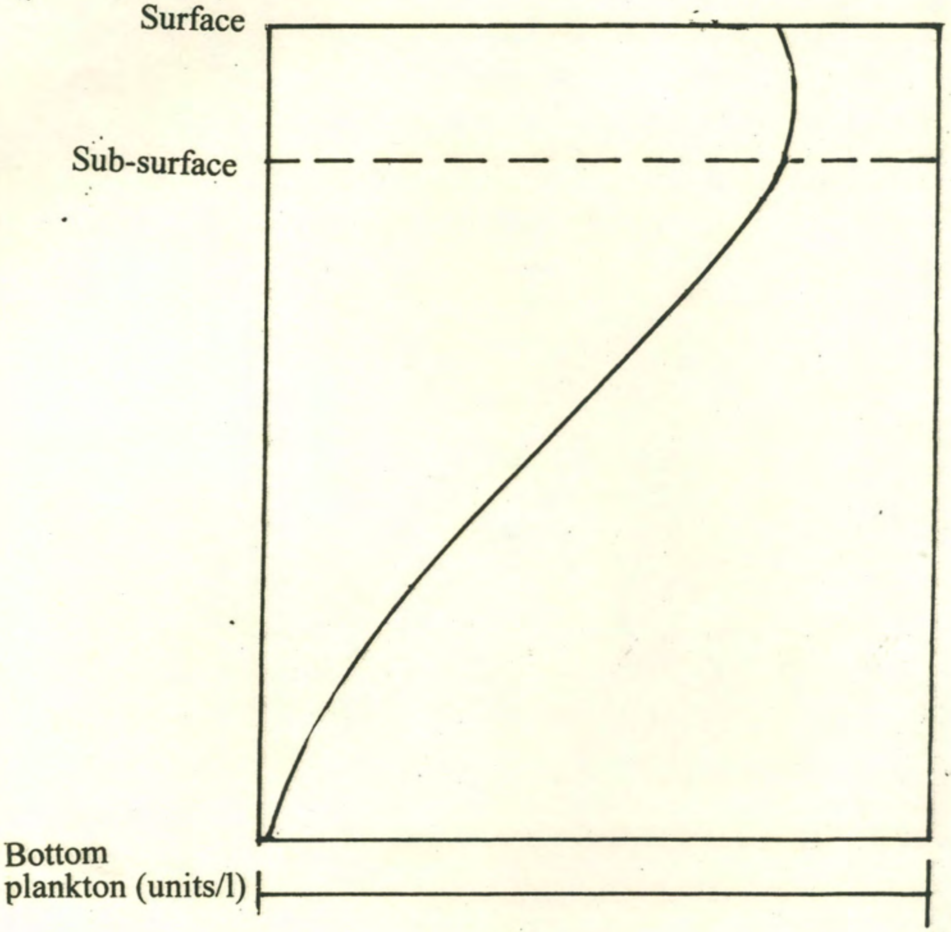

Fig. 4. Plankton density pattern at different layers of water column

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in Small Reservoirs and Floodplain Lakes
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Macrophyte and the associated fauna - a major link in the food chain of floodplain lakes

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Introduction

A water body is considered as live when it harbours organisms, both plants and animals, and promotes recycling of their life processes within the system. Floodplain lakes are one of such dynamic and important ecosystems. These are usually wide and shallow, rich in nutrient status, and thus support a dense growth of flora and fauna. Despite the rich diversity and population density of these organisms, they survive in the system in a coherent manner.

As a group, macrophytes constitute a bulk of the biomass produced in such wetland ecosystems. Obviously, their dominance is also reflected in the multifarious role they play in the aquatic productivity process. They synthesize basic organic elements like protein, fat and carbohydrate and ultimately contribute to the detritus pool of the bottom soil when they die. They act as substrates for periphytic growth, provide shelter to different aquatic fauna and also serve as breeding ground for the associate fauna. Macrophytes and their associates thus constitute a major link in the food chain of such water bodies.

Macrophyte diversity

Floodplain lakes receive maximum precipitation and floodwater from rivers during monsoon. Along with water, they also receive silt, organic and inorganic nutrients as well as seeds, and propagules of many free floating aquatic weeds. Being shallow in nature and resultant good penetration of light, *beels* form one of the most favourable habitats for the growth of innumerable species of hydrophytes, occupying different niches of the ecosystem. Depending upon their zonation pattern in the habitat, macrophytes are usually classified into the following major groups.

i) Emergent macrophytes

These grow along the margin and are either erect or prostate-floating in habit. The common erect ones are *Cyperus procerus, C. exallatus, Eleocharis dulcis, E. spiralis, Scirpus grossus, S. airticulatus, Typha angustata, Monochoria hastata, Polygonum barbatum, P. hydropiper, Aeschenomene indica, A. aspera, etc.* The prostrate floating ones are *Ludwigia adscendens, Ipomea aquatica, Alternanthera philoxeroides, Commelina longifolia, Paspalum paspaloides, Hygrorhiza aristata, Leersia hexandria, etc.*

ii) Floating macrophytes

They may be either rooted with leaves and flowers above the water surface or free floating. The common rooted ones are *Nymphaea pubescens, N. nouchali, Nelumbo nucifera, Nymphoides cristatum, N. indicum, Myriophyllum tetrandrum, M. tuberculatum, Limnophila indica, Potamogeton nodosus, Aponogetan natans etc.* These plants grow in continuous water zone within the depth range of about 0.25 to 3 m. The free floating ones are *Eichhornia crassipes, Pistia stratiotis, Spirodella polyrrhiza, Lemna perpusilla, Azolla pinnata, Utricularia stellaris, U. aurea etc.* They remain spread all over the water area or get drifted towards the bank by wind action. In shallow waters, some of them may anchor their extensive root system and develop into land forms.

iii) Submerged macrophytes

These plants grow in submerged soil up to a water depth of about 10 m. The common forms are *Hydrilla verticillata, Vallisneria spiralis, Nechamendra alternifolia, Blyxa octandra, Ottelia alismoides, Ceratophyllum demersum, Potamogeton crispus, Najas indica, Chara* sp., *Nitella* sp., *etc.*

Macrophyte associated fauna

Aquatic macrophytes support a dense growth of macro-invertebrate fauna by providing them food, shelter, breeding ground and rearing area for their progenies. Bulk of this fauna comprises the ubiquitous molluscs, followed by nymphs, larvae and adults of insects, annelids, ostracods, decapods, arachnids, *etc.*

Molluscs

The molluscs are mainly represented by gastropods and a few bivalves. The gastropods feed primarily on organic matter (mostly decaying weeds and occasionally some dead animals) that constantly accumulate at the bottom of these water bodies. Bivalves, on the other hand, are generally filter feeders (microphytic organisms) and need macrophyte as the main substrate for their movement. Submerged macrophytes like *Najas, Ceratophyllum, Vallisneria, etc.* are some of the important species mostly favoured by gastropods for food shelter and other activities.

The common gastropods are *Gyraulus convexiusculus, Gabia orcula, Bellamya bengalensis, B. varietus, Indoplanorbis exustus, Lymnaea acuminata, Thiara tuberculata, Pila globosa, Digoniostoma cerameopoma, Segmentina* sp., *etc.* The bivalves are *Lamellidens marginalis, Parreysia corrugata, Piscidium* sp., *Corbicula* sp., *etc.*

Insects

Aquatic insects are more prevalent in shallow water mainly because of their partial adaptation to the aquatic life. There are seven or eight groups of insects which depend heavily on macrophytes for their food and breeding activities. Some feed directly on the plant material (Coleoptera, Lepidoptera) while others graze on it. Some lay their eggs inside the tissue of the plants (Hemiptera) while others use plants as a substrate for breeding purposes. There are others which construct dwelling for rearing their larvae with the help of small pieces of twigs and leaves (Trichoptera, Lepidoptera, *etc.*). The insects commonly found in the *beels* of West Bengal are *Diplonychus annulatum, Ranatra filiformes, R.elongata, Lethocerus indicus, Gerris nitida, G. spinolae, Micronecta proba, M. merope, Plea* sp., *Anisops* sp., *Canthydrus morsbachi, C .laetabilis, Hydrocoptus subvittulus, Hydrovatus confertus, H. bonovouloiri, Regimbertia attenuata, Berosus indicus, Helochares* sp., *Sympertum* sp., *Libellula* sp., *Erythemis* sp., *Pachidiplax* sp., *Chironomus* sp., *Tendipes* sp., *Stratiomys* sp., *Culex* sp., *Ceratopogon glabra, Tabanus* sp., *Caenis* sp., *Beatis* sp., *Nymphula* sp. and *Leptocera* sp., *etc.*

Ostracods

Commonly known as seed shrimps, these animals belong to the genera *Cypris, Heterocypris, Stenocypris, etc.* They are mostly free living and omnivorous feeding on algae, periphytic organisms and fine detritus. They are found in the *beel*s of West Bengal throughout the year and occasionally met with in plenty as a constituent of the weed associated fauna.

Decapods

Represented by prawns, shrimps, and crabs, they also use the macrophytes for their food and shelter and themselves serve as the food for carnivorous fishes.

Annelids

The annelids are relatively fewer in number and are mostly represented by oligochaetes (aquatic earthworms) polychaetes and a few parasitic leeches belonging to the genera *Placobdella, Helobdella* and *Hirudo.* The common oligochaetes belong to genera *Nais, Dero, Aelosoma, Branchiura, Chaetogaster, etc.* Some of them feed on periphyton occurring on macrophytes while others (aquatic earthworms) devour algae or algal mats that remain entangled with macrophytes.

Besides, other organisms like ticks, mites, water spiders (belonging to Arachnids) are also met with as constituents of the macrophyte associated fauna.

Aquatic food chains

The two important food chains in the aquatic environments are *macrophytic* and *microphytic*. The macrophyte food chain is comparatively shorter and has the aquatic macrophytes as the primary synthesizer of carbon. On the other hand, microphytic food chain is a longer one, involving phytoplankton as the primary producer and a number of primary, secondary and tertiary consumers. The macrophyte associated fauna is an important link in the food web of the floodplain wetland ecosystem, playing a vital role in the fish production from these water bodies.

Macrophytic food chain

In this food chain system, macrophytes which are the primary producers, are directly or indirectly consumed by the animals of higher strata like herbivorous fishes. Besides being directly consumed, their decaying vegetable remains contribute to the organic detritus stored at the bottom soil, which form an important food item for many of the bottom feeding fishes, molluscs, insects, and so on. Aquatic macrophytes in this way promote the growth of all other communities in the aquatic ecosystem.

Role of macrophyte associated fauna in the *beel* ecosystem

The constitution of the fauna associated with aquatic macrophytes varies greatly depending upon the types of macrophytes and physico-chemical properties of the habitat. Available information on macrophyte associated fauna of the *beel*s of West Bengal reveals that the climatic conditions, hydrobiology and the macrophytic flora of these *beel*s are most conducive for colonization and growth of molluscan fauna mainly composed of gastropods *(Gabia, Gyraulus, Bellamya, Lymnaea,* etc.) Next to molluscs, insects of different sub-groups are found in good numbers in these habitats. Though decapods, ostracods, annelids and arachnids are also met within these habitat their population fluctuates greatly.

The above mentioned species of the macrophyte associated fauna in their different stages of development constitute in general natural food items of many fishes. This food chain system may not appear very significant if evaluated in isolation but the importance of the role played by the macrophyte associated fauna in the beel ecosystem can not be overlooked.

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Fish species diversity in the floodplain lakes and the need for its conservation

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Introduction

Nature of fish fauna in an aquatic system is highly dependent on its ecological conditions. Under a stressed situation, fish species which are well adapted to the adversities thrive and the more sensitive ones perish, leading to a fall in species diversity. Where no such barrier or species selection prevails, the number of fish species available naturally goes up considerably. Ecological features of various floodplain lakes are quite different, so the fish faunal diversity in them are also not identical. The characters of such water bodies are bound to change with the passage of time, the fish species diversity also has to change. Hence, floodplain lakes always demand appropriate conservation measures to protect the fish species diversity. On categorising all such water bodies either into *oligotrophic* and *eutrophic* or *deep* and *shallow* or *fluviatile* and *stagnent* or *perennial* and *seasonal* or some other types, changes in species diversity among ichthyofauna can be observed.

Region-wise variations of floodplain lake fishes

It is well established that the biodiversity is dependent on the geoclimatic conditions of a region. Thus, the floodplain lakes situated in different parts of the country exhibit a rich fish faunistic diversity. Usually available fishes of floodplain lakes in different regions are as given in Table 1 to 4.

Table 1. Common fishes of the Deccan floodplain lakes

Family : Cyprinidae
Catla catla *
Labeo rohita *
L.boga
L.calbasu,
L. fimbriatus
L.kontius
L.pocellus
L.potail
L.pangL.ariza
L.boggut
L.bata
Cirrhinus mrigala *
C.reba
C.fulungee
C.cirrhosa
Cyprinus carpio v. *communis* *
C.carpio var.*specularis* *
Ctenopharyngodon idella *
Hypophthalmichthys molitrix *
Puntius dubius
P.carnaticus
P.chola
P.dobsonii
P.dorsalis
P.filamentosus
P.mahecola
P.sarana
P.ticto
P.punctatus
P.melanampyx
P.stigma
P.conchonius
P.puckelli
P.amphibius
P.aurilius
P.ambassis
P.pulchellus
P.kolus
P.sophore
P.bovianicus
Tor khudree malabaricus
T.putitora
T.tor
Salmostoma phulo phulo
S.chela untrachi
Gonoproklopterus curmuca
Amblypharyngodon melettinus
A.mola
Barilius gatensis
B.bendelisis
B.barila
B.barna
Danio rerio
D.aequipinnatus
Perluciosoma daniconius
Esomus danrica
E.barbatus
Rasbora daniconius
R.buchanani
Chela laubuca
C.atpar
Rohtee ogilbii
Oxygaster clupeoides
O.argentea
Osteobrama vigorsii
O.cotio
Oreichthys cosuatus
Aspidoparia morar
Garra lamta
G.mcclellandi
Acrossocheilus hexagonolepis

Family : Cichlidae
Oreochromis mossambicus *
Etroplus suratensis *
E.canarensis
E.maculatus

Family :Notopteridae
Notopterus notopterus

Family : Anguillidae
Anguilla nebulosa
A.bengalensis bengalensis

Table 1 contd. .....

Family : Chanidae
Chanos chanos *

Family : Gobiidae
Glossogobius giuris

Family : Nandidae
Nandus nandus
Pristolepsis(Malabaricus Marginata)

Family : Bagridae
Mystus malabaricus
Mystus vittatus
M.punctatus
M.cavasius
Aorichthys aor
A.seenghala

Family : Siluridae
Ompok pabo
O.bimaculatus
O.malabaricus
Wallago attu

Family : Ophiocephalidae
Channa marulius
C.striatus
C.leucopunctata
C.gachua

Family : Mastacembelidae
Macrognathus guntheri
M.aculeatus
Mastacembelus armatus
M.pancalus

Family : Belonidae
Xenentodon cancila

Family : Claridae
Clarias batrachus
C.dussumieri

Family Saccobranchidae
Heteropneustes fossilis
Glyptothorax housei

Family : Cobatidae
Noemacheilus denisonii
N.scaturigena
N. rupicola
Lepidocephalus guntea
L.thermalis

Family : Ambassidae
Ambassis baculis
Chanda ranga
C.nama
Parambassis thomasi

Family : Cyprinodontidae
Aplocheilus(=Panchax) lineatus
Oryzius melanostigma

Family : Poecilidae
Gambusia affinis *
Poecilia reticulala

Family : Sisoridae
Gagata itchkeea
Glyptothorax housei

Family : Mugilidae
Rhinomugil corsula

Family : Osphronemidae
Macropodus cupenus
Osphronemus gourami

Family Schilbeidae
Pseudeutropius taakree
Pangasius pangasius
Silonia silondia
S.childreni

* Introduced

Table 2. Common floodplain lake fishes of Central and Western India

Family : Cyprinidae
Catla catla *
Labeo rohita
L.fimbriatus
L.calbasu
L.calbasu
L.boggut
L.bata
L.gonius
Cirrhinus mrigala *
C.reba
Hypophthalmichthys molitrix *
Cyprinus carpio var.communis *
Puntius sarana
P.dobsoni
P.kolus
P.sophore
P.ticto
Tor tor
T.khudree
Chela fulangee
C.bacaila
Barilius barna
B.bendelisis
Osteobrama cotio

Family : Siluridae
Ompak pabda
O.bimaculatus
Wallago attu

Family : Sisoridae
Bagarius bagarius

Family : Bagridae
Aorichthys aor
A.seenghala
Mystus cavasius
M.bleekeri

Family : Schilbeidae
Siolonia silondia
Clupisoma garua
Eutropiichthys vacha

Family : Gobiidae
Glossogobius giuris

Family : Cobatidae
Lepidocephalus guntea

Family : Ambassidae
Chanda nama
C.ranga

Family : Ophiocephalidae
Channa striatus
C.marulius
C.punctata

Family : Mastacembelidae
Mastacembelus armatus

Family : Anguillidae
Anguilla bengalensis

Family : Belonidae
Xenentodon cancila

Family : Notopteridae
Notopterus chitala
N.notopterus

Family : Saccobranchidae
Heteropneustes fossilis

Family : Claridae
Clarias batrachus

*** Introduced***

Table 3 . Common floodplain lake fishes of the northern and eastern India

NORTHERN INDIA

Family : Cyprinidae
Catla catla
Labeo rohita
L.dero
L.dyocheilus
L.calbasu
L.bata
L.diplostoma
L.gonius
Cirrhinus mrigala
C.reba
H. molitrix *
Cyprinus carpio specularis *
Puntius sarana
Chela bacaila
Tor putitora
Schizothorax plagiostomus
S.richardsonii
Garra gotyla
Crossocheilus latius
Family : Salmonidae
Salmo trutta fario *
Family : Clupeidae
Gadusia chapra
Family : Ophiocephalidae
Channa marulius
Family : Notopteridae
Notopterus chitala
N.notopterus
Family : Bagridae
Aorichthys aor
A.seenghala
Mystus bleekeri
Family : Schilbeidae
Silonia silondia
Clupisoma garua
C.montana
Family : Sisoridae
Bagarius bagarius

Family : Mastacembelidae
Mastacembelus armatus

EASTERN INDIA

Family : Cyprinidae
Catla catla
Labeo rohita
L.bata
L.dyocheilus
L.boggut
L.calbasu
L.dero
L.gonius
L.fimbriatus
Cirrhinus mrigala
C.reba
H. molitrix *
Cyprinus carpio communis *
Puntius sarana
P.ticto
P.sophore
P.chola
P.conchonius
Tor mosal
T.mahanadicus
Barilius bola
B.barna
Amblypharyngodon mola
Oxygaster bacaila
O.clupeoides
Esomus danrica
Osteobrama cotio
Crassocheilus latius
Gara gotyla
G.mullya
Aspidoparia morar
Rasbora daniconius
Rohtee cotio
Family : Ambassidae
Chanda ranga
C.nama
Family : Gobiidae
Glossogobius giuris
Family : Cyprinodontidae
Aplocheilus punchax

Family : Notopteridae
Notopterus chitala
N.notopterus
Family : Siluridae
Ompok pabda
O.bimaculatus
Wallago attu
Family : Mastacembelidae
Macrognathus aculiatus
Mastacembelus armatus
M.pancalus
Family : Schilbeidae
Eutropiichthys vacha
Ailia coila
Silonia silondia
Pangasius pangasius
Family : Mugilidae
Rhinomugil corsula
Family : Bagridae
Aorichthys aor
A.seenghala
Mystus tengra
M.cavasius
Rita crysea
Family : Sisoridae
Bagarius bagarius
Family : Saccobranchidae
Heteropneustes fossilis
Family : Clariidae
Clarias batrachus
Family : Ophiocephalidae
Channa gachua
C.striatus
C.punctata
Family : Nandidae
Nandus nandus
Family : Clupeidae
Gadusia chapra

*** Introduced***

Table 4. Common floodplain lake fishes of North-East India

Family : Cyprinidae	**Family : Cyprinodontidae**	**Family : Belonidae**
Catla catla	*Aplocheilus panchax*	*Xenentodon cancila*
Labeo rohita	**Family : Cobatidae**	
L.gonius	*Noemacheilus multifaciatus*	**Family : Ambassidae**
Cirrhinus mrigala		*Chanda ranga*
Hypophthalmichthys molitrix	**Family : Siluridae**	
*	*Wallago attu*	**Family : Saccobranchidae**
Ctenopharyngodon idella *		*Heteropneustes fossilis*
Cyprinus carpio v.specularis	**Family : Bagridae**	
*	*Aorichthys aor*	**Family : Claridae**
Puntius stigma		*Clarias batrachus*
P.sophore	**Family : Ophiocephalidae**	
P.ticto	*Channa punctata*	**Family : Notopteridae**
P.sarana	*C.marulius*	*Notopterus notopterus*
Tor tor		
T.putitora	**Family : Mastacembelidae**	
Amblypharyngodon mola	*Mastacembelus puncalus*	
Acrossocheilus hexagonolepis	*M.guentheri*	**** Introduced***
Danio rario		
D.aequipinnatus		
D.dangila		

A number of Gangetic and exotic carps are present in the floodplain wetlands as shown in the foregoing tables which are the results of introductions. The maximum species diversity is recorded from the floodplain lakes of the Deccan region followed by those of eastern India. Central, western and northern regions of the country show moderate diversity of ichthyofauna and the least diversity is observed in case of floodplain lakes of the northeastern India.

Pooling the fish species diversity of the floodplain lakes of the country as a whole, the following species can be listed as typical ichthyofauna of such water bodies.

Major carps :	*Catla catla, Labeo rohita, L.fimbriatus, L.calbasu, Cirrhinus mrigala*
Minor carps &: other carps	*Labeo kontius, L.bata, Cirrhinus cirrhosa, C.reba, Puntius sarana, P.dubius, P.carnaticus, P.kolus, P.dobsoni, P.chagunio, Thynnichthys sandkhol, Osteobrama vigorsii*

Snowtrout	:	*Schizothorax plagiostomus, Schizothoraichthys niger, S.esocinus, S.carvifrons*
Mahseer	:	*Tor tor, T.khudree, T.putitora, Acrossocheilus hexagonolepis*
Featherback	:	*Notopterus notopterus, N.chitala*
Murrels	:	*Channa marulius, C.striatus, C.punctata, C.gachua*
Large catfishes	:	*Aorichthys aor, A.seenghala, Wallago attu, Pangasius pangasius, Silonia silondia, S.childrenii*
Airbreathing catfishes	:	*Heteropneustes fossilis, Clarias batrachus*
Weed fishes	:	*Chanda nama, Aspidoparia morar, Amblypharyngodon mola, Barilius barila, B.bola, Esomus danrica, Gadusia chapra, Laubuca laubaca, Oxygaster bacaila, Osteobrama cotio, Puntius ticto, P.sophore.*
Exotic fishes	:	*Cyprinus carpio var.communis, C.carpio var.specularis, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Gambusia affinis, Oreochromis mossambicus*

When predominance of *Labeo bata, L.dero, Puntius sarana, P.chagunio, Tor putitora, Cirrhinus reba* and *Schizothorax* spp. are noted in the floodplain lakes and wetlands of north India, the significant occurrence of *Labeo kontius, L.fimbriatus, Cirrhinus cirrhosa, C.reba, Puntius dubius, P.sarana, P.carnaticus, P.kolus, P.dobsoni, Tor tor, Thynichthys sandkhol and Osteobrama vigorsii* are recorded from south India.

Fluctuation in the diversity

Because of the gradual changes of the floodplain lakes from oligotrophic to eutrophic and finally to boggy conditions, the fish species diversity goes on changing. The decline in the number of fish species is more than the addition of new species in such water bodies. It is quite distinct that *Labeo dero* and *L.dyocheilus* in Himalayan ranges; *L.fimbriatus, L.calbasu, Puntius sarana, Rhinomugil corsula, Tor tor, T.mahanadicus*, and *T.mosal* in Orissa; *Labeo kontius, Cirrhinus cirrhosa, Puntius dobsoni, P.dubius,* *P.carnaticus, Tor putitora* and *Acrossocheilus hexagonolepis* in Tamil Nadu; *Labeo fimbriatus, L.calbasu, L.pungusia, Puntius kolus, P.dubius, P.sarana, P.porcellus, Tor putitora and Schizothorax plagiostomus* in Jammu and Kashmir; and *Labeo dero, Puntius chola, P.conchonicus, Crosscheilus latius, Garra mullya, G.gotyla, Macrognathus aculiatus, Oxygaster clupoides* and *Aspidoparia morar* in eastern India are gradually declining as far as floodplain lakes are concerned.

Decline in species diversity has also been aggravated by the introduction of exotic species which are damaging the indigenous carps through competition for food and space in the floodplain lakes. Therefore, further introduction of other exotic carps like bighead *(Aristichthys nobilis),* mud carp *(Cirrhinus molitorella)* and snail carp *(Mylopharyngodon piceus)* which feed on zooplankton, detritus and molluscs respectively, cannot be considered for the floodplain lakes. Moreover, already introduced mirror carp (*C.carpio* var.*specularis*) and indigenous snowtrout *(Osteobrama belangeri)* are becoming unsuitable for floodplain lake ecosystem for their low fecundity and stream breeding habits.

Floodplain lakes need not always cause damage to the ichthyofauna of the parent streams which gave rise to such water bodies. Fish species such as *Salmostoma phulo phulo. Osteobrama vigorsii, Pangasius pangasius, Barilius bola, Mystus kistnensis, Pseudeutropius taakree, Thymichthys sandkhol, Tor khudree, T.mussullah, Aorichthys seenghala* and *Tor putitora* are in the rise in such waterbodies. It is worth noting that the catadromous fish like *P.pangasius* has become endemic species whithin the floodplain lakes.

Food web dependancy of floodplain lakes

Ichthyofaunal dependancy to the food web of the floodplain lakes has always been regulating the species diversity. Owing to the existence of sufficient molluscs, weeds and *Microcystis* sp. in the floodplain lakes, the respective consumer fish species such as *Pangasius pangasius, Puntius pulchellus* and *Thynnichthys sandkhol* are performing well in such water bodies. Weed consumer *Ctenopharyngodon idella* also could have done well in such lakes provided their breeding would have taken place within the floodplain lake itself and had not damaged the indigenous populations of carps. Having gathered the knowledge about the food items available within the floodplain lakes, suitable fish species for such ecosystem can be determined especially when the preferred food of several well suited fishes are analysed (Table 5). It is seen that Gangetic major carps in many floodplain lakes have managed to occupy the ecosystem at the cost of many local species. So, the impact of species interaction may deplete or encourage the fish species diversity in a floodplain lake. Presently, the floodplain lakes gradually loose their ichthyofaunal diversity, especially the quality fishes for selective exploitation and some non-commercial fishes too through over influence of introduced or well adapted fishes. Thus, dominance of minnows and catfishes are observed before the final collapse of the fisheries.

Problems of ichthyofaunal diversities in floodplain lakes

General ecological conditions of water and soil play the key roll for the fish species diversity, but there are other factors too to reduce such diversity drastically. For instance, pollutional load, ingress of runoff from the catchment area, siltation, the process of eutrophication, introduction of exotic fish species etc. can change the complexion of the fish species diversity in the floodplain lakes. Restricted breeding and multiple breeding of various species may favour some fish, placing others into disadvantage. Similarly, recruitment success and failure also play great roll in regulating the species diversity, and so does the random or selective fishing. Thus, management of fisheries by way of stocking, harvesting, simulating conditions for fish breeding, rearing and ranching, and also introducing new species, affect the species diversity although, leading to higher fish production. Depending on the altitude and location of the floodplain lake, the fish species diversity varies greatly. Similarly, shore development, extent of weed infestation, gradient of the bank, species interaction, etc. are other sources of modulation that can bring changes in the fish species diversity in such water bodies.

A rational approach towards fisheries management, stocking, species introduction, species elemination, orienting water and land use patterns, *etc.* is needed to conserve the biodiversity of the floodplain lake fishes which contribute considerably towards the total strength of more than 2000 fish species of the country. Keeping in view, the constant transformation of floodplain lakes and their strides towards boggy condition and ultimate death, the available fish species are required to be conserved against their extin

Table 5. Preferred food for floodplain lake fishes

Floodplain lake fishes	Blue green algae	detr-itus	decayed organic matter	zoopla-nkton	diatom	green algae	other algae	semi-digested org. matter	insect	mollusc	ostrac… other r… organi…
C. catla	*	#	-	#	-	-	-	*	-	-	-
L. rohita	#	*	+	-	-	-	+	-	-	-	-
L.calbasu	#	*	+	-	#	+	+	-	-	-	-
L.fimbriatus	-	*	+	+	#	-	+	*	-	-	-
C. mrigala	+	*	+	-	+	+	-	-	-	-	-
C.reba	-	-	*	-	+	+	+	#	-	-	-
C. carpio	+	+	-	+	+	+	*	-	-	-	-
Puntius sarana	-	-	+	-	-	-	-	#	+	*	+
P.aurilus	-	-	#	+	-	-	+	*	-	-	-
P.dobsoni	-	-	-	-	-	-	-	-	-	*	-
P.kolus	-	#	-	+	+	+	-	-	-	*	-
P.sophore	-	*	-	-	#	+	#	-	-	-	-
Tor khudree	-	*	-	-	-	-	-	-	-	#	-
T.putitora	-	-	-	#	-	-	-	-	-	-	-
O. vigorsii	-	*	-	-	+	-	-	-	+	#	-
S. phulo phulo	+	*	-	+	+	+	-	*	-	-	-
O. cotio	-	*	-	#	+	-	+	-	-	-	-
Rohtee ogilbii	-	#	-	*	-	-	-	-	+	-	-
Chela atpar	+	*	-	-	-	+	+	#	+	-	[illegible]

Table 5 contd............

Floodplain lake fishes	Blue green algae	detr-itus	decayed organic matter	zoopla-nkton	diatom	green algae	other algae	semi-digested org. matter	insect	mollusc	ostracods other mis Organism
Barilius spp.	-	*	-	-	+	#	-	-	-	-	-
D.aequipinnatus	-	*	-	-	-	-	-	-	-	-	-
G. itchkeea	-	-	+	-	-	-	-	*	-	-	-
O.melanostigma	+	*	-	-	#	-	-	-	-	-	-
N. notopterus	-	-	+	-	-	-	-	#	*	-	-
Wallago attu	-	-	+	-	-	-	-	-	+	-	-
O.bimaculatus	-	-	-	-	-	-	-	-	*	-	-
M. cavasius	-	-	#	+	-	-	-	+	-	*	-
Aorichthys aor	-	+	-	-	-	-	-	-	+	#	-
A.seenghala	-	-	-	-	-	-	-	#	+	-	-
S. childrenii	-	-	-	-	-	-	-	+	#	-	-
P. pangasius	-	-	-	-	-	-	-	#	-	*	-
P. taakree	-	-	-	-	-	-	-	-	*	+	-
G. giuris	-	-	-	+	-	+	-	-	#	-	-
O.mossambicus	-	-	-	-	+	-	*	-	-	+	-
R. corsula	-	*	-	+	#	+	-	-	+	-	-
C. marulius	-	-	-	-	-	-	-	+	-	-	-
Chanda nama	-	-	-	+	-	-	-	#	#	-	-
C.baculia	-	#	-	*	-	-	-	-	#	-	-

Food preference: * Preference 1, # Preference 2, + Preference 3, - Insignificant

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Fish fauna of Indian reservoirs and the importance of species management for increasing productivity

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Several reservoirs have been constructed on all major and minor river systems of India for multipurpose use. Each river system has its own distinct fish fauna which is reflected in the reservoirs formed on its basin. Some species flourish in the congenial environment created by reservoir formation and some remain at low level or even disappear unable to withstand the changes in the biotope. The fish productivity of a reservoir depends on the quality of fish derived from the parent river, its basic productivity in terms of morphometric, hydrological and ecological features and the extent of human interference in the management of fish stocks. Many of the reservoirs, however, are poorly managed and the fish productivity in vast majority is based on wild populations. With the result, the fish yields remained at low levels with the national average of about 15 to 20 kg/ha.

Ichthyofauna of Indian Reservoirs

The fish fauna of Indian reservoirs could be categorised broadly into the following groups:

Major carps: The Gangetic major carps, *Catla catla, Labeo rohita* and *Cirrhinus mrigala* occur naturally in the reservoirs of north India, especially those of the Ganga river system. However, these carps have been transplanted repeatedly into peninsular Indian rivers where they appear to have established themselves. *Labeo calbasu* and *Labeo fimbriatus* are the major carps of peninsular Indian rivers.

Minor carps: This group includes species like *Labeo bata, L. kontivs. Cirrhinus cirrhosa, C. reba, Puntius dubius, P. kolus, P. jerdoni, P. carnaticus, P. curmuca, P. sarana, Thynnichthys sandkhol etc.* Minor carps predominate south Indian reservoirs. Some of the important commercial forms which dominated the reservoirs of the region at some time or the other are - *P. kolus* (Tungabhadra, Linganamakki), *P. dubius* (Krishnarajasagar, Stanley) *C. cirrhosa* (Stanley) *T. sandkhol* (Nizamsagar) and *P. curmuca* (Malampuzha). *Mahseers:* These are well known game fishes occurring in all the major river systems and reservoirs generally confining to upper reaches (head waters). The species include *Tor tor, T. putitora, T. khudree* and *Acrossocheilus hexagonolepis. T. khudree* is the peninsular species forming a fishery in Krishna and Cauvery basin reservoirs. *T. putitora* forms flourishing fishery in Pong and Gobindsagar reservoirs (Indus system), while *T. tor* occurr in Vallabhasagar (Tapti) and Ravishankarsagar (Mahanadi) reservoirs.

Catfishes: Next to carps, catfishes enjoy wider distribution. These include larger species like *Mystus seenghala, M. aor, M. krishnensis, W. attu, Bagarius bagarius, Silonia silondia, S. childreni* and *Pangasius pangasius.* Smaller sized catfishes include *M. cavasius, Clarias batrachus, Heteropneustes fossilis, Pseudeutropius taakree* etc. In unmanaged reservoirs, carps generally dominate in early stages of reservoir formation which soon give way to the dominance of catfishes. The catfishes which dominate some reservoirs are *M. seenghala* (Nagarjunasagar, Matatila, Hirakud) *M. aor* (Tungabhadra, Bhavanisagar, Nagarjunasagar, Hirakud) *S. childreni* (Nagarjunasagar, Stanley), *S. silondia* (Hirakud, Rihand) *W. attu* (Bhavanisagar) and *P. pangasius* (Nagarjunasagar). *M. cavasius, H. fossilis* and *C. batrachus* are observed in small reservoirs. Large catfishes are generally absent in small impoundments constructed on minor tributaries.

Featherbacks: The two species of *Notopterus, N. notopterus* and *N. chitala* are included in this group. *N. notopterus* is distributed throughout the country while *N. chitala* is confined to north of Vindhyas. Abundance of *N. notopterus* was recorded in Tilaiya, Konar (DVC reservoirs) and Markonahalli (Cauvery system). Weed infested reservoirs offer favourable conditions for featherbacks.

Murrels: Common species in this group are *Channa marulius, C. striatus* and *C. punctatus.* Though these species enjoy wide distribution, their contribution to reservoir fisheries is negligible.

Weed fishes: These occur in large numbers in all the water bodies, especially in unmanaged reservoirs. Some of the ubiquitous species are *Salmostoma bacaila, S. phulo, S. clupeoides, Ambassis nama, A. ranga, Amblypharyngodon mola, Osteobrama cotio, Puntius sophore, Gadusia chapra* etc. *Salmostoma* spp. *Ambassis* spp. form significant fishery in Tungabhadra, Nagarjunasagar, Bhatgar (Krishna system) and Getalsud (Subarnarekha) and *G. chapra* in Ravishankarsagar and Hirakud reservoirs (Mahanadi). Weed fishes are known to withstand greater fishing pressure and flourish in unmanaged and over-exploited reservoirs such as Tungabhadra, Bhatgar and Getalsud.

Exotic fishes: Besides indigenous fishes, a number of exotic species have been introduced in various reservoirs as a means to improve productivity. These are the tilapia (*Oreochromis mossambicus)* the common carp (*Cyprinus carpio* var. *communis & specularis),* the silver carp (*Hypophthalmichthys molitrix)* and the grass carp (*Ctenopharyngodon idella).*

Tilapia and common carp have established themselves in many reservoirs. Tamil Nadu is the first State to introduce tilapia in reservoirs (Amaravathy, Uppar, Pambar, Vaigai). Now, it occurs in several reservoirs of Karnataka (Kabini, Manchanabele, Nelligudda) and Kerala (Chulliar, Meenkara, Peechi) as well. *C. carpio* forms a good fishery in Gobindsagar (Indus system), Krishnarajasagar (Cauvery) and Vanivilassagar (Krishna). Silver carp and grass carp were introduced in selected reservoirs of peninsular India and Getalsud in Bihar, but they have not made any impact on the fishery. However, in Gobindsagar the accidental entry of silver carp has changed the complexion of the fisheries of the reservoir. It has completly dominated the fishery reducing other species which flourished in the past .

Importance of species management in reservoirs

The objective of species management in reservosirs is two-fold, to increase the fish productivity and to preserve the biodiversity. In small water bodies, especially in peninsular India, these two objectives work at cross purpose. To get good returns from reservoirs it is imperative to stock species which are fast growing and also command good market for which Gangetic major carps are ideally suited. Peninsular carps, in general, are slow growing and have low market value. Hence, propagation of major carps is inevitable in peninsular reservoirs. However, there are apprehensions that these species may affect local carps and the biodiversity of the system adversely. Small reservoirs built on tributaries should be exempted from the purview of preservation of biodiversity and developed as carp reservoirs to enhance productivity. However, large reservoirs on the mainstream of major rivers may be earmarked for preservation of biodiversity. There is an urgent need to breed some of the important peninsular carps such as *P. jerdoni (P. pulchellus*), *P. dubius, L. fimbriatus etc.* for stocking the mainstream reservoirs of peninsular India.

Stocking

Stocking is an important management strategy to enhance productivity. Stocking programme should take into consideration the basic productivity of the impoundment and abundance of various fish food resources. To determine the basic productivity, several indices-morphometric and ecological- are being used independently or in combination. Some important morphometric indices are reservoir size, mean depth, extent of catchment to reservoir area and shore development index. Important ecological parameters are alkalinity, pH, specific conductivity, PO_4-P, NO_3-N, organic matter, primary productivity, plankton and benthos. Studies made in Indian reservoirs have shown that chemical parameters are not dependable indicators to assess the productivity. This is due to the fact that allochthonous inputs from the catchment, especially the organic matter (coarse and particulate), play a major role in the productivity of impoundments. It is widely believed, at least in the Asian context, that morphometric parameters are better indicators of reservoir productivity. As productivity is largely governed by allochthonous inputs, the extent of catchment in relation to lake size could be a good index of allochthonous inputs. The amount of inflow of water in relation to the reservoir capacity also have a bearing on the productivity.

Species for stocking

Catla (*Catla catla*) rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) are the preferred species in reservoir stocking programme. But their individual performance in different reservoirs is not uniform. By and large, the performance of catla has been good both in oligotrophic and mesotrophic reservoirs. However, rohu fared poorly in oligotrophic reservoirs and exceedingly well in mesotrophic ones, especially in those which have submerged aquatic weeds. Common carp recorded impressive growth in reservoirs rich in bottom deposits. The food habits of *Labeo calbasu* and common carp appear to be overlapping and only one species appear to thrive to the exclusion of the other. Common carp being a sluggish species seems to form an easy prey resulting in poor survival in catfish dominated reservoirs.

In some peninsular Indian resevoirs, tilapia (*Oreochromis mossambicus*) has been stocked after considering its capacity to sustain its populations in lentic environment. At some time or the other, it dominated the fishery of Amaravathy, Vaigai, Uppar (Tamil Nadu) and Malampuzha (Kerala) reservoirs. However, a sustained stocking of major carps has inhibited tilapia abundance as in case of Amaravathy. *Oreochromis niloticus,* though introduced in India clandestinely has not yet entered reservoirs. This species has some positive features over *O. mossambicus,* such as better growth rate and capacity to utilize Myxophyceae. This could be a useful species for reservoir management at least for culturing in enclosures such as cages, though not in open waters.

It is desirable to widen the species spectrum covering all the food niches for maximising yields from reservoirs. It is also essential to introduce new systems of culture such as cage and pen with suitable species to culture. Such an approach could lift the levels of maximum yield of 150-200 kg/ha hitherto obtained in some small reservoirs.

Size of stocking

There appears to be a direct relationship between initial stocking size and survival rate. In Chinese reservoirs it has been demonstrated that 13 cm was the ideal stocking size. In India, the All India Co-ordinated Project on Reservoir Fisheries, during early 1980s, suggested a minimum stocking size of 10 cm. This could be implemented only in Aliyar and Thirumoorthy reservoirs by the Reservoir Division of CIFRI, resulting in spectacular increase in fish yield. Even with this stocking size, recapture rate of the stocked fishes has been about 20 to 25% in Aliyar, where the predatory pressure was minimum. In reservoirs of Madhya Pradesh, it has been reported that stocking of fry/early fingerlings has resulted in realisation of about 5% of the stock. In the light of these results, there is a need to reorient our thinking in matters of stocking which has been highly empirical.

In conclusion, it may be mentioned that species management- quality, quantity and size-hold the key for higher yields especially in small impoundments.

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Yield optimization in small reservoirs - a case study in Aliyar reservoir

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Introduction

Of the total of 2,365 reservoirs available in India, about 2,153 fall under the catgegory of small reservoirs of less than 1,000 ha (excluding the peninsular tanks). The small reservoirs are reported to yield high production rates in China and Sri Lanka. However, the per hectare yield from the small reservoirs in India is very unimpressive. Recent studies have revealed a wide gap between the great production potentiality and the actual yield being obtained from these reservoirs. This poor yield is mainly due to the lack of adoption of suitable scientific management techniques. Though there is not much scope for the alteration or improvement of the existing ecological conditions in the small reservoirs because of sharp changes in the inflow and outflow pattern in them, as the water is drawn constantly for irrigation and drinking water purposes, their inherent production potentiality can be harnessed through the adoption of judicious management techniques of stocking and exploitation. In order to evaluate the production potentiality of these small reservoirs, CIFRI undertook detailed ecology-based investigations in Aliyar during 1983-92. The studies have established tremendous scope for the optimization of fish yield from such small reservoirs in India.

Aliyar reservoir

Aliyar reservoir with an average area of 324 ha (maximum 640 ha) and mean depth of 18.2 m is a tail-end reservoir of the chain of reservoirs under the Parambikulam-Aliyar project (PAP) in the Western Ghat region of Tamil Nadu. It receives its main supply of water from Parambikulam reservoir through a contour canal. Though major carps had been transplanted into the reservoir immediately after its formation in 1962, none of them could be established in the reservoir. Hence, the fishery of the reservoir was sustained through stocking of fish seed every year.

Stocking and yield during 1962-85

During the initial stages, the reservoir was stocked heavily (1,272/ha), consisting predominantly of uneconomic species of medium and minor carps, tilapia, murrels, *etc.* (Selvaraj and Murugesan, 1990a ; 1990b and Selvaraj *el al.,* 1990). Though the reservoir was stocked with some major carps from 1964-65 onwards, the size of the seed stocked was so small that they fell an easy prey to the predatory fish populations. The rate and ratio of different species stocked did not have any relevance to the ecological conditions, the biogenic production potentiality of the reservoir, the food spectrum, the growth rate of different fish species, *etc.* All the stocking was done during a short period between August and October every year, resulting in stiff competition among the seed of the same age group for food and space. The exploitation of the fishes was so indiscriminate that even the major carps of less than 1 kg were regularly harvested as there was no restriction on the mesh size of the gillnets operated. It was almost an annual cropping pattern of stocking and harvesting during the same year. The cumulative impact was that the reservoir was yielding a low annual production ranging from 2.67 kg/ha to 54.53 kg/ha, with an average of 26.21 kg/ha. Thus, the reservoir was considered to be oligotrophic with low fish production potential.

Scientific management during 1985-86

Fish production in a reservoir is influenced by the morphological, edaphic and climatological parameters. Hence, detailed investigations on the physico-chemical quality of water and soil, plankton, macrobenthos, primary productivity, existing fish populations including the predatory fishes, food and feeding habits of fishes, maturation and breeding of the major carps stocked, the growth rate of different species, *etc.* were undertaken during 1983-85.

Stocking

The major carps stocked in the reservoir failed and to breed to attain proper maturation in the reservoir due to the unsuitable chemical quality of reservoir water (Joseph *et al.*, 1990; *Selvaraj et al.,* 1990). Hence, the fisheries of the reservoir had to depend solely on the seed stocked every year. Detailed studies were carried out to assess the growth rate of the different species through fin-clipping and tagging experiments

(Murugesan and Selvaraj, 1990; Murugesan *et al.*, 1990). Based on the results of these studies, drastic changes were brought about in respect of stocking and exploitation policies for obtaining a sustained yield of 150 kg/ha/yr as indicated by the studies on the primary productivity of the reservoir. As a result, there was a substantial improvement in the annual fish yield ranging from 75 to 193.58 kg/ha, with an average yield of 132.67 kg/ha during 1985-92.

The usual practice of stocking the reservoir with all kinds of miscellaneous uneconomic species of fishes was discontinued. As the reservoir was harbouring the predatory catfishes like *Ompok bimaculatus* and *O. malabaricus,* the early fry of the major carps were reared in the fish farm located adjacent to the reservoir and only advanced fingerlings of more than 100 mm were segregated and stocked in the reservoir. As against the traditional method of stocking the whole quantity of the seed within a short period, the advanced fingerlings were stocked throughout the year, in small instalments at short intervals (Fig. 1). This helped to reduce mortality of the seed due to stress during transportation. As stocking was phased out over different months, the pressure on population density and the competition for food and space could be minimised. The stocking density was reduced substantially ranging from 176 to 637 /ha during different years, with an average of 316/ha, consisting of catla (39.1%), rohu (19.0%), mrigal (19.3%), common carp (20.2%), silver carp (2.1%) and grass carp (0.3%). The studies on the food and feeding habits of the fishes, the available food niches and the growth rate of different species formed the basis for determining the stocking density and the ratio of the species stocked.

Fish yield

As a result of stocking of advanced fingerlings of good quality, there was a substantial improvement in the fish yield (Fig. 2). The annual yield improved from 77.75 kg/ha in 1985-86 to 193.58 kg/ha in 1989-90, with an average of 132.67 kg/ha during the period from 1985 to 1992. . There was a marked change in the contribution by the major carps, ranging from 87.0% to 99.1% (average 95.0%) during the period. Interestingly, with the new stocking strategy, the medium and minor carps and other miscellaneous uneconomic species have almost disappeared (Fig. 3) from the reservoir.

A strict vigil was maintained to avoid exploitation of fishes of less than 1 kg in size and the fishermen were allowed to operate gillnets of more than 50 mm mesh bar only. As a result, the revenue from the reservoir improved considerably (675%) during 1985-92 through the sale of major carps (95%) of more than 1 kg in weight, against the poor revenue obtained during 1964-85. As only advanced fingerlings of more than 100 mm were stocked in instalments, their survival rate has also improved significantly (catla-14.1%, rohu-25.1%, mrigal- 31.2%, common carp - 22.2%, silver carp- 11.2%, and grass carp - 0.2%), with an average of 21.1%. Along with the increase in yield, the catch per unit effort has also improved, resulting in enhanced earnings for the fishermen (300%).

Conclusions

The investigations on the ecology-based fisheries management carried out in Aliyar reservoir during 1985-92 have given a new dimension to the concept of scientific management of small reservoirs in the country.(Selvaraj *et al.,* 1997). The fish yield from these water bodies is not a function of the quantity of the seed stocked, but there is a direct correlation with the quality of the seed, their size, composition and the phasing of stocking. It has been established that the stocking density can be drastically reduced with the increase in the size of the seed stocked. The fish yield remained low during 1962-65 in spite of heavy stocking and it improved afterwards considerably even at a lower stocking density (Fig 2). The contribution by the major carps of more than 1 kg in size improved substantially, resulting in enhanced revenue for the department as well as the fishermen's earnings. The studies have further indicated that the fish yield can be enhanced several-fold irrespective of the age of the reservoir.

The results obtained from Aliyar reservoir have conclusively established that there was a tremendous scope for augmenting the fish yield from all such small reservoirs. This has been substantiated by obtaining a record fish yield of 182 kg/ha/yr from Thirumoorthy reservoir during 1995-96, with an average yield of 136.54 kg/ha/yr during 1991-96 through the adoption of the management techniques developed at Aliyar reservoir (Selvaraj *et al.*, 1997). The small reservoirs can contribute substantially to the total freshwater fish production in the country, even if a modest yield of 100 kg/ha/yr is achieved through the adoption of these scientific management techniques.

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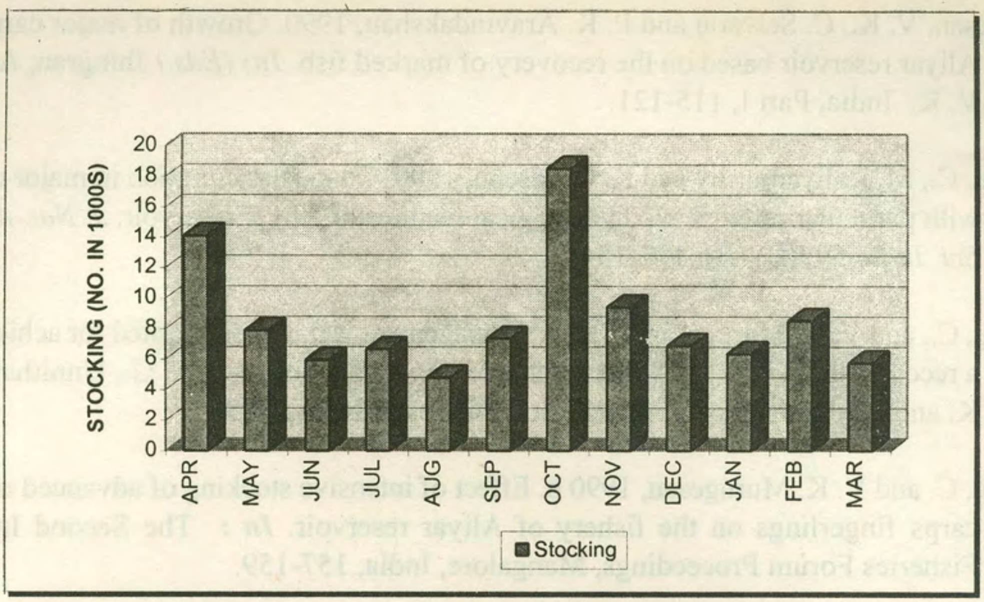

Fig 1. Average monthly distribution of stocking of fingerlings (nos. in thousands) in Aliyar Reservoir during 1985-92.

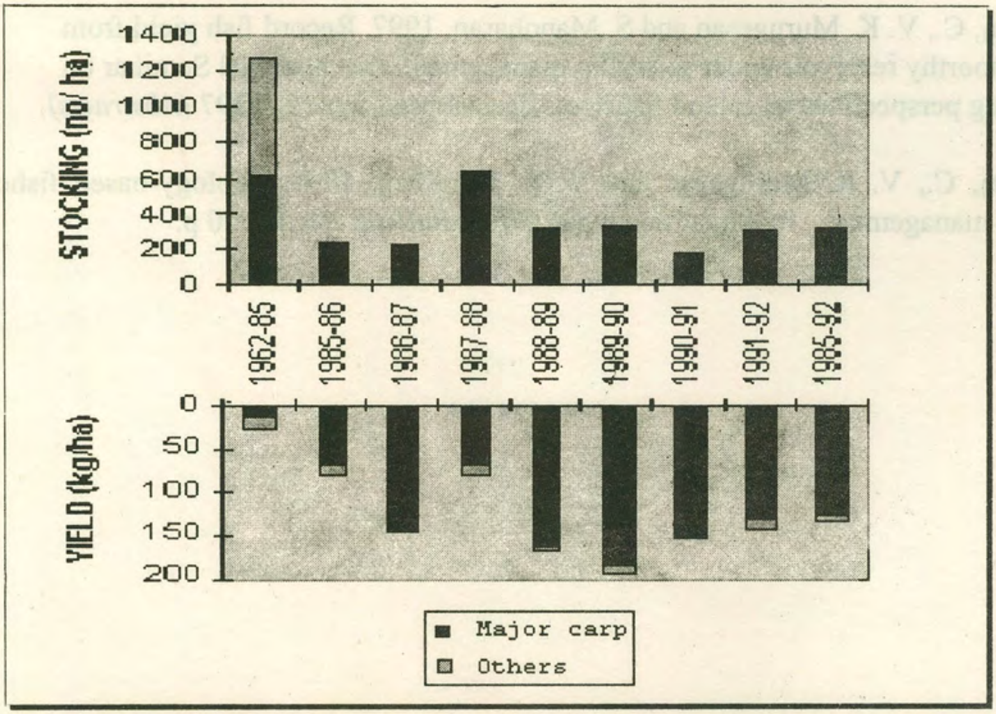

Fig 2. Impact of stocking of advanced fingerlings on the yield from Aliyar Reservoir.

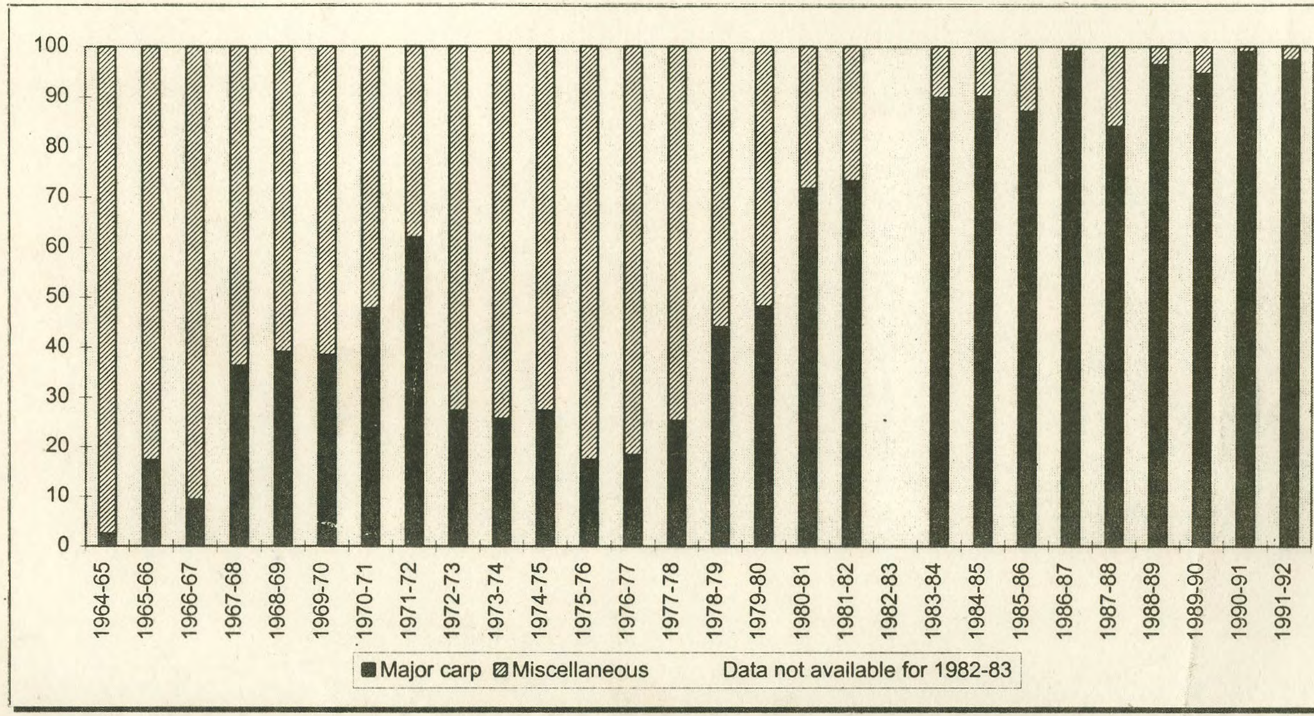

Fig 3. Percentage composition of commercial fish catch Aliyar Reservoir before (1964-85) and a
(1985-92) CICFRI management.

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Yield optimization in small reservoirs - a case study in Thirumoorthy reservoir

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Among the vast reservoir resources of India (19,370 nos. having 3,153,366 ha water area), small reservoirs including major irrigation tanks (10-1000 ha each) account for 98.78% by number and 47.11% by area (Sugunan, 1995). By virtue of easy manoeuvarability, small reservoirs are amenable for culture based capture fisheries or extensive aquaculture. Stock manipulation with appropriate density and right species combination to utilize the food available in the ecosystem and recapture of stocked species efficiently lead to fish yield optimization. A case study made at Thirumoorthy reservoir in Tamil Nadu in this direction is dealt in this communication.

Description of Thirumoorthy reservoir

The reservoir was created in 1967 as a result of construction of a 2,627.9 m long earth dam across Palar river in Bharathapuzha basin during 1962-67. It is a tail end reservoir under Parambikulam-Aliyar Project (PAP). With a water area of 388 ha at FRL and 79.88 ha at DSL, the estimated average area of the reservoir is 234 ha. Apart from a catchment area of 8,029 ha, the reservoir receives water supply from Parambikulam reservoir through a contour canal of 50 km length. Located at 10º 28' N and 77º E, the reservoir irrigates an ayacut area of 80,826.8 ha in Udumalpet and Palladam taluks in Coimbatore District through two canals.

Ecology of the reservoir

Depth: Though the reservoir has the capacity to hold water to a maximum depth of 29.3 m, the mean depth during the study period (1992-97) was only 11.6 m, falling into the category of medium depth reservoirs.

Rainfall: Located in the rain shadow region of the Western Ghats, the reservoir receives an average annaul rainfall of 701.12 mm as against the national average of 1,050 mm.

Soil quality: The basin soil with a pH range of 6.4 - 7.5 (average 7.1) and available nitrogen of 41.0 - 47.3 (average 44.4) mg/100 g indicates medium productivity. While poor available phosphorus content (0.17-0.51 mg/100 g) reveals low productivity of the reservoir, although the rich organic carbon (1.5 - 4.2%) may mislead to high productivity.

Water quality: While high mean water temperature (25.8 °C) normally encountered in a tropical country gives an impression of high productivity, the pH of the water suggests medium productivity. The low total alkalinity (18.0 ppm), total dissolved solids (15.03 ppm) and specific conductivity (31.1 µmhos/cm) reveal a low production potentiality of the reservoir.

Plankton position: The volume of the plankton during the study period varied from 2.0 - 6.0 ml/m^3 (average 4.5). The plankton population was mainly contributed by phytoplankton (95.4%) with dominance of Chlorophyceae (53.0%) followed by Bacillariophyceae (34.2%) and Myxophyceae (5.5%). Rotifers (1.3%), cladocerans (1.7%) and copepods (1.5%) formed the meagre zooplankton population.

Macrobenthos: The average number of macrofauna per square meter area of the reservoir bottom was 1,378 consisting of 493 chironomids, 446 *Chaoborus* sp. and 439 oligochaetes.

Primary productivity:- The mean primary productivity of the reservoir was 894.1 mgC/m^3/day and the energy fixed by primary producers was 0.49%.

Fish fauna: Though, a total of 16 endemic species *viz., Puntius carnaticus, P. sarana, P. filamentosus, P, mahecola, Mystus malabaricus, M. vittatus, Ompok bimaculatus, O. malabaricus, Channa striatus, Clarias batrachus, Mastacembelus* *armatus, Anguilla bengalensis, Glossogobius giuris, Garra sp., Amblypharyngodon sp., Rhinomugil corsula* and *Tor khudree* were recorded from the reservoir, none of them formed a fishery worth mentioning.

Fishery management during 1966 to 91

After completion of the dam and impoundment of water, the State Fisheries Department took up the reservoir for fisheries development in the year 1966-67 and stocked it with available fish seed belonging to major, medium and minor carps, predatory fish like murrels, exotic fishes like common carp, tilapia and silver carp and euryhaline fish like Chanos chanos. By stocking at an annual average of 1,009 fish (53.8% major carps and 46.2% miscellaneous fish) per ha, an annual average production of 15.1 t (64.7 kg/ha) consisting of 16.1% major carps and 83.9% other fishes was obtained from the reservoir during 1968-69 to 1976-77.

The Tamil Nadu Fisheries Development Corporation took over the reservoir on lease to develop its fishery on commercial lines in the year 1977. The Corporation increased the stocking rate to 1,515 seed per ha, giving importance to major carps (83.2%) in the species mix. However, the average annual production declined to 14.6 t during 1977-91 with an improvement in the contribution of major carps (57.2%).

Fishery management by CIFRI during 1991-97

In the absence of natural recruitment of major or medium carps in Thirumoorthy reservoir, it became imperative to stock the reservoir with quality fish seed from extraneous sources. Indian and exotic major carps are quick growing herbivores with short food chain and better conversion of primary production to fish flesh. Fingerlings these carps of in size of > 100 mm, obtained from the Government fish farm located in the vicinity of the reservoir, were stocked in small quantities at periodical intervals throughout the year, maintaining certain species combination and density (Table 1). In order to assess the growth of individual species a few thousand fingerlings (all species) out of the stocking material were subjected to group marking technique in which one of the pelvic fins was removed along with the bone articulation. The injury caused to the fish in the process of marking was cleansed with hydrogen peroxide solution and treated with furacin cream. The marked fish was directly released into the reservoir. The fishermen were instructed to operate gill nets of appropriate mesh size so that major carps less than 1 kg weight were spared.

The fish production increased steadily right from the first year and reached an all time record of 49.9 t (213.4 kg/ha) in 1996-97 (Table 2). The stocked species formed the major fishery (88.5 to 96.4%) in the reservoir. Recapture of marked fish indicated that the growth rate was the highest in *C. catla,* followed by *C. carpio, C. mrigala* and *L. rohita.* Higher stocking rate followed in *C. catla* (29.5%) and *C. carpio* (28.2%) resulted in higher contribution by these two species in the total fish landings. High yield coupled with higher price fetched by major carps of more than 1 kg in weight gave better revenue to the State. The catch per unit effort (CPUE) which was low (5.65 kg) in 1991-92 increased (7.0-12.5) in the subsequent years, improving the earnings and the standard of living of the fishermen. Although, the ecological investigations indicated low to medium production potentiality of the reservoir, the fish yield could be substantially increased through better fishery management. Thus, the study confirmed that judicious stocking with right species and density and efficient exploitation can lead to fish yield optimization in small reservoirs.

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Table 1. Fingerlings stocked in Thirumoorthy reservoir

Year	*C. catla*		*L. rohita*		*C. mrigala*		*C. carpio*		*H. molitrix*		Tota
	Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos
1991-92	17302	34.4	21783	43.3	46	0.1	11163	2.2	-	-	502
1992-93	14422	19.6	20957	28.3	22958	31.3	11858	16.2	3183	4.3	733
1993-94	20327	22.6	21360	23.7	16008	17.7	28792	32.0	3600	4.0	900
1994-95	23069	24.9	18733	20.3	19458	21.0	31250	33.8	-	-	925
1995-96	29975	31.6	13522	14.3	5637	5.9	45809	48.2	-	-	949
1996-97	55386	39.0	34290	24.2	27697	19.5	24530	17.3	-	-	141
Average	26747	29.5	21774	24.0	15301	16.9	25567	28.2	1131	1.2	905

Table 2. Fish yield from Thirumoorthy reservoir

Species		1991-92	1992-93	1993-94	1994-95	1995-96
Group I	*C. catla*	5142.150	9088.700	12962.700	15416.400	17766.600
	L. rohita	6517.700	6502.900	3097.150	3108.600	4432.000
	C. Mrigala	3178.500	5151.800	4660.950	5573.100	5887.300
	C. carpio	329.800	1067.100	6314.400	7690.70	7905.950
	H. molitrix	182.600	649.950	205.900	64.900	-
Group II		1783.250	1469.050	2040.400	2154.800	1442.100
Major carps (Spoiled)		941.500	-	1140.400	1074.000	1636.700
Total in kg **% contribution**		**18075.500** **88.5**	**23929.500** **89.9**	**30421.500** **96.4**	**35082.500** **91.0**	**39070.650** **91.7**
Group III		1632.150	1201.150	607.400	1785.200	1540.300
Group IV		644.700	1255.600	444.800	1640.800	1958.400
Special Group		75.500	224.250	69.650	64.000	31.000
Total (Kg)		2352.350	2681.000	1121.850	3490.000	3529.700

Contribution	11.5	10.1	3.6	9.0	8.3
Total yield (Kg)	20427.850	26610.500	31543.750	38572.500	42600,350
Yield/ha/year	87.3	113.7	134.8	164.8	182.1
CPUE (Kg)	5.65	7.01	9.18	12.50	10.63

Group I : Major carps more than 1 kg
Group II : Major carps less than 1 kg
Group III : Larger tilapia
Group IV : Smaller tilapia and other fishes
Special Group : Eel

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Fisheries of small reservoirs in India- an overview

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Introduction

Reservoirs or man-made lakes constitute an important inland fishery resource of India. Reservoirs are generally classified as small (< 1,000 ha), medium (1,000 to 5,000 ha) and large (> 5,000 ha). Small reservoirs differ significantly from the large and medium ones (Table 1). In large reservoirs, fisheries management lays emphasis on establishing relatively self sustaining populations more or less on capture fishery norms, while small reservoirs essentially requires a stocking and recapture policy on an annual basis which is more akin to extensive aquaculture system.

Aquaculture techniques in small reservoirs

The aquaculture, practised in these impoundments, may be described as *extensive*, where cultured fingerlings are raised in water bodies with few or no modification of the habitat. This is in contrast to the intensive culture practised in ponds, raceways *etc.* where abiotic and biotic components are under control. The capture and culture fishery principles grade into each other in small reservoirs where the fishery depends on stocked fingerlings.

Past and present status of small reservoir fisheries

Fish culture in the small reservoirs, hitherto being practised by the state Governments consists of supplementing the natural stocks of economic fishes with stocking on arbitrary basis without any definite levels or ratios based on the biogenic capacity of the ecosystem. Stocking rates wherever prescribed do not appear to have been followed strictly. Despite the arbitrary stocking, a few reservoirs, have been reported to show high fish production with repeated regular stocking. Keetham reservoir (250 ha) in U. P., for example, produced 530 kg/ha in 1959-60 although the yield declined drastically in the later years. This emphasises the need to focus attention towards fish culture in such ecosystems based on an understanding of the environmental and biological parameters, basic productivity levels and ecological relationships.

Stocking policy

Stocking of fish in small reservoirs has proved to be a useful tool for developing their fisheries potential. Stocking of economically important, fast growing fishes from outside is aimed at colonizing all the diverse niches of the biotope for harvesting maximum sustainable crop from them.

This widespread management practise has been proved to be highly remunerative in such small water bodies where almost complete annual harvesting is possible. This has amply been demonstrated in a number of reservoirs in U. P., Tamil Nadu, Kerala and Rajasthan (Table 3). Stocking is not merely a simple matter of releasing appropriate species into an ecosystem, but an important management option which needs evaluation of an array of factors *viz.,* biogenic capacity of the environment, the growth rate of the desired species and the population density as regulated by predatory and competitive pressure

During summer months, small reservoirs either dry up completely or else the water level in them gets so drastically reduced that through over-fishing no brood stock is left over to contribute to the succeeding year's fishery through natural recuritment. Consequently, the entire catch from these water bodies depend on the fishes stocked from outside to offset this loss. There is, thus, established a direct correlation between the stocking rate and catch per unit effort in such heavily fished waters (Jhingran *et al.,* 1981, Khan *et al.,* 1990). Stocking is, therfore, a useful tool for the management of small reservoirs where stocks can be maintained at levels higher than the natural carrying capacity of the environment through supplemental fertilization. The number of fish to be stocked per unit area to be determined on the basis of natural productivity of the system, growth rate of fishes, natural mortality rate and escapement through the irrigation canal and spillway.

Formulation of stocking policy

A number of methods are in vogue for assessing the potential fish yield from lakes and reservoirs (Jhingran, 1986). Most common approach towards formulation of stocking policy is to assess the potential of the reservoir by any of the methods (MEI, Gulland Model, Trophodynamic model) and adjustment of stocking rate to approach the potential yield. In the Indian context, trophodynamic model is found to be more suitable than MEI approach (Jhingran, 1986, Khan *et al.,* 1990).

Case studies of some small reservoirs

To establish a baseline for evolving suitable management measures towards fishery development in small reservoirs, the Central Inland Fisheries Research Institute (CIFRI) initiated investigations on many small reservoirs *viz.,* Loni, Kulgarhi, Govindgarh, Naktara, Gulariya, Bachhra Baghla, in Aliyar, Nongmahir, and Kyrdemkulai. Investigations on hydrology, primary productivity, plankton, macrobenthos, macrovegetation, soil characteristics, experimental fishing and biology of commercial fishes have been conducted. Range of certain abiotic and biotic parameters in some small reservoirs of India are summerised in Table 2. A critical evaluation of these parameters indicates that they can support moderate to high fish production.

Biotic communities

Plankton: Plankton population density ranged from 58 units/l to a high of 40,000 units/l in Baghla reservoir. The high population was due to *Melosira* and low plankton population was observed in monsoon due to increased inorganic turbidity. Dominance of Myxophyceae was observed in these reservoirs followed by Bacillariophyceae and Chlorophyceae. Myxophyceae was chiefly represented by *Microcystis aeruginosa,* Bacillariphyceae by *Synedra ulna. Fragilaria* spp. and *Melosira granulota,* and *Chlorophyceae* consisted *Pediastrum duplex, Spirogyra* sp. *Oedogonium* sp. *and Pandorina* sp. as dominant forms. Copepods and rotifers were the main constituents of zooplankton, mainly represented by *Diaptomus, Cyclops, Brachionus, Keratella, Filinia* and *Polyarthra*. Maximum abundance was observed in summer and minimum in monsoon.

Macrobenthos communities: Bottom fauna was generally rich and ranged from 95 unit/m^2 (Gulariya reservoir) to a high of 4,620 (Bachhra reservoir). In these water bodies, insects dominated the others. The fauna was represented by chironomids, *phylopotamus* (Insecta), *Pisidium, Corbicula, Lymnaea (Mollusca)* and *Brahchiura* sowerbyi (Annelida).

Fish fauna:- Fish fauna of small reservoirs is well diversified belonging mainly to carps, cat fishes, featherbacks, murrels and clupeids. Only in Kyrdemkulai reservoir, mahseers like *Tor putitora, Tor tor* and *Acrossocheilus hexagonolepis* were observed besides small hill-stream fishes. Recommendations for development of Kyrdemkulai and Nongmahir reservoirs have been submitted to the Northeastern Council for implementation by the State of Meghalaya.

Planning criteria

A systematic and integrated approach towards scientific studies and planning criteria for undertaking fish culture in small reservoirs should have an understanding of the following factors.

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

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

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

    a) *Reservoirs which are best developed as capture fisheries*
    b) *Reservoirs mostly of local interest having significant potential for fish culture*
    c) *Reservoirs intermediate in size and potential yield.*

2) Since the breeding of the major carps has been repeatedly observed to take place above the spillway, resulting in heavy escapement of the brood, this poses a serious problem for building up stocks of desirable fishers in small reservoirs. The situation is further worsened by heavy escapement of fingerlings and adults through irrigation canals. Development of fisheries in such water bodies, therefore requires suitable screening of the spillway and the canal mouth. Such protective measures have already been installed in Loni, Bachhra, Baghla and Gulariya reservoirs and have paid rich dividends in enhancing the fish yield from these reservoirs. In some of the reservoirs fishes have also been observed to move up the spillways into the reservoir whereas in others the spillways provide an insurmountable barrier to fish moving up the dam. To minimize losses by way

of escapement of fish through spillway and canal, it would be an economic proposition to have an annual cropping policy so that the reserovir is stocked in August-September and harvested by June end.

3) Vegetation should not be planted in the reservoir, since the wrong kinds can choke up the reservoir and the canal.

4) Methods for predator control and checking of weed fishes are already available in literature.

5) Aquaculture in small reservoirs can also play an important role in integrated rural development since it can be profitably combined with duckery and piggery.

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

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Table 1. The distinguishing features of small and large reserovirss may be summerised as under:

Small reservoirs	Large reservoirs
Single-purpose reservoirs mostly for minor irrigation	Multipurpose reservoirs for flood-control, hydroelectric generation, large-scale irrigation, etc.
Dams neither elaborate nor very expensive. Built of earth, stone, masonary work on small seasonal streams.	Dams elaborate, built with precise engineering skill on perennial or long seasonal rivers. Built of cement, concrete or stone.
Shallower, biologically more productive per unit area. Water weeds commonly observed in perennial reservoirs but absent or scanty in seasonal ones.	Deep, biologically less productive per unit area. Usually free of aquatic weeds. Subjected to heavy drawdowns.
May dry up completely in summer. Notable changes in the water regimen	Do not dry up completely. Changes in water regimen not so pronounced. Maintaining a conservation-pool level.
Sheltered areas absent.	Sheltered areas by way of embayments, coves, etc. present.
Shore line not very irregular. Littoral areas mostly gradually sloping.	Shore line more irregular. Littoral areas mostly steep.
Oxygen mostly derived from photosynthesis in sthese shallow, non-stratified reservoirs lacking significant wave action	Although photosynthesis is a source of D.O. the process is confined to a certain region delimited by vertical range of transmission of light (euphotic zone). O_2 also derived from significant wave action.
Provided with concrete or stone spillway, the type and size of its structure depending on the runoff water handled.	Provided with much more complex engineering devices.
Breeding of major carps invariably observed in the reservoir above the spill way.	Breeding mostly observed in the head waters or in other suitable areas of the reservoir.

Can be subjected to experiemental manipulations for testing various ecosystem responses to environmental modifications	Cannot be subjected to experimental manipulations.
Trophic depression phase can be avoided through chemical treatment and draining and cycle of fish production can be repeated as often as the reservoir is drained.	Trophic depression phase sets in.
The annual flooding of such reservoirs during rainy season may be compared to overflowing flood-plains. Inundation of dry land results in a release of more nutrients into the reservoir when it fills up, resulting in high production of fish food through decomposition of organic matter, predominantly of plant origin leading to higher growth and survival.	Loss of nutrients occurs which get locked up in bottom sediment. Reduction in benthos also occurs due to rapid sedimentation.
Through complete fishing or overfishing in such seasonal reservoirs, no brood stock is left over to contribute to succeeding year's fishery through natural recruitment. The fish population has to be built up solely through regular stocking. There is thus established a direct relationship between stocking rate and catch per unit of effort.	In contrast, prominent annual fluctuations in recruitment occur and balancing of stock number against natural mortality requires excessive number of fingerlings in such large reservoirs. Their capture requires effective exploitation techniques.

(After Jhingran, 1965)

Table 2 . High yields obtained in small reservoirs due to management based on stocking

Reservoirs	State	Area (ha.)	Stocking rate number/ha	Yield Kg/ha
Aliyar	Tamil Nadu	650	353	194
Meenkara	Kerala	259	1226	107
Chulliyar	Kerala	159	937	316
Gulariya	Uttar Pradesh	300	517	150
Bachhra	Uttar Pradesh	140	763	140
Baghla	Uttar Pradesh	250	570	102
Bundh Beratha	Rajasthan	-	164	94
Chapparwara	Rajasthan	200	300	79

(*After Sugunan, 1995*)

Table 3. Range of certain physico-chemical and biotic parameters of small reservoirs.

Parameters	Reservoirs					
	Gulariya	Bachhra	Baghla	Aliyar	Chappar-wara	Kyrdem-kulai
Transparency (cm)	11-80.0	17-145	9-204	108-182	-	2.20-2.84
D. O. mg/l	4.9-9.0	2.5-8.60	2.40-12.80	4.2-11.6	6.10-10.0	6.70-7.10
pH	7.2-8.4	6.96-8.30	7.32-8.84	6.6-6.8	8.0-8.40	6.8-7.0
Free CO_2 mg/l	Nil-4.0	Nil-7.20	Nil-3.0	Nil-10.0	Nil	2.0-2.60
Alkalinity mg/l	38-80	95-190	42-106	16-72	76-100	22-32
Hardness mg/l	13-34	21-80	-	-	-	18.56-27.84
Nitrate mg/l	0.08-0.20	0.085-0.180	0.28-0.33	-	0.40-1.10	0.02-3.61
Phosphate mg/l	0.05-0.13	0.06-0.250	0.28-0.36	Trace-0.4	0.11-0.16	Trace-0.02
Silicate mg/l	5.0-14.0	6.80-14	2.4-4.9	Trace-0.2	1.92-8.0	1.0-10.0
Plankton u/l	245-4060	70-8432	58-40000	-	3100-20100	8420*
Macrobenthos u/m^2	95-4169	342-4620	976-2132	-	110-947	134*
Macrovegetation u/m^2	Absent	Absent	250-2200	Absent	470-1350	Absent

(* indicates average value)

Yield optimization in small reservoirs-
a case study of Bachhra reservoir

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Introduction

Small reservoirs are being created at a rapid pace in order to meet the demand for agricultural activities and for controlling flood menace. According to an estimate there are about 19,134 small reservoirs (< 1000 ha) covering a water area of 1,485,557 ha (Sugunan, 1995). Past studies conducted by the Central Inland Fisheries Research Institute in Uttar Pradesh and Madhya Pradesh revealed that small reservoirs offer immense scope for fish production (100 to 250 kg/ha) if managed scientifically. Prior to initiation of these research projects, the average production recorded in various states was low (less than 50 kg/ha). These studies further contradicted Ellis (1942) theory that reservoirs are biological deserts. Small reservoirs, being shallow, are biologically more productive per unit area because substantial portions of the reservoir bed are exposed to sunlight during summer and subsequently inundated during rair.y season, resulting in release of more nutrients into the reservoir.

For evolving suitable management technique in small reservoirs, Bachhra, a small irrigation impoundment was selected. Limnological parameters and trophic status were monitored for a number of years (1982-87) based on which potential fish yield of the reservoir was estimated and stocking of desired fish species was so adjusted as to achieve the potential fish yield.

Description of the reservoir

Bachhra reservoir was created in 1980-81 by damming the Bachhra stream. It is situated in Mejha Tehsil at a distance of about 55 km from Allahabad. The waterspread area at full storage level of 111.00 m above MSL is 140 h, the gross storage capacity being 7.42 mcm and dead storage capacity 0.03 mcm. The average depth of the reservoir has been estimated at 5.22 m. The reservoir dries up substantially in summer leaving behind only 4 ha of water area. The catchment area consists of rocky terrain and thin forest around it. Catchment receives on an average 900 mm of rainfall per annum. The basin of the reservoir is undulating and strewn with stone boulders.

Physico-chemical parameters of water

The values of physico-chemical parameters of the water for the period 1982-87 are depicted in Table 1. On the basis of physico-chemical parameters such as alkalinity, calcium, oxygen and nutrients the reservoir can be classified as moderately productive.

Primary production

Two peaks in primary production *viz.,* one in February-March and another in September-October were observed but low values were observed in monsoon months. No relationship between primary production and net phytoplankton production could be established because more than 75% of the total primary production was attributed to nannoplankton. On the basis of carbon production, reservoir falls under *eutrophic* category.

Plankton and Periphyton

Planktonic population varied between 70 units/l in 1986 to 8,428 units/l in 1984 (Table 2), In the initial years of filling of the reservoir, rheophilic algae (Chlorophyceae) formed the bulk of plankton but with the passage of time, Myxophyceae replaced them. Same was found true for Bacillariophyceae. The important components of phytoplankton were: *Microcystis aeruginosa, Aphanocapsa sp.* and *Anabaena sp.* (Myxophyceae) *Scenedesmus* sp., *Oedogonium* spp and *Spirogyra* sp. (Chlorophyceae) and flora like *Melosira granulata, Navicula* spp., *Fragilaria* spp.and *Synedra ulna* represented Bacillariophyceae. The bulk of zooplankton was formed by copepods *(Cyclops* sp., *Diaptomus* sp.) followed by rotifers (*Brachionus* sp. *Keratella* sp., *Filinia* sp. and *Lecane sp.,),* Cladocera (*Ceriodaphnia* sp., *Diaphanosoma* sp.) and Protozoa (*Arcella* sp., *Actinophrys* sp.).

Periphyton of the reservoir ranged from 30 units/cm^2 to 120, 000 units/cm^2 (Table 3). A direct correlation with the ageing of the reservoir and abundance in periphyton biomass was recorded. Myxophyceae continued to dominate throughout the study period except 1984 followed by Bacillariophyceae and Chlorophyceae. Summer months favoured periphyton growth followed by winter and monsoon. Myxophyceae was represented by *Phormidium* sp. *Aphanocapsa* sp. *Anabaena* sp. *Oscillatoria* sp. and *Merismopedia* sp. Chlorophyceae comprised a few species *viz., Microspora* sp. *Oedogonium* sp. and *Cladophora* sp., while *Pinnularia* sp. *Gyrosigma* sp., *Cymbella* sp. *Synedra* spp and *Surirella* sp. were the main constituents of Bacillariophyceae.

Zoomacrobenthos

Benthic macrofauna ranged from 365 units/m^2 in 1982 to 1994 units/m^2 in 1987 (Table 4) their population increased with the ageing of the reservoir as in the case of periphyton. Insect larvae represented by chironomids, phylopotamus, culicoides, *Chaoborus* and coleopterans formed the bulk (62.64%) of benthic fauna. Annelids were constituted by *Aulodrilus plurisita* and *Branchiura* sowerbyi. Molluscan fauna, though quantitatively poor (10.80%), was rich qualitatively. The main genera were: *Pisidium* sp. *Gyraulus* sp. *Limnaea* sp. and *Viviparus bengalensis.*

Fish and Fisheries

Fish fauna comprised 51 species, mainly belonging to families of carps and catfishes besides freshwater prawn, *Macrobrachium lamerrei.* The reservoir at initial filling (1980) was mainly dominated by rheophilic fishes though their population was very thin. Fishing rights of the reservoir was auctioned by the irrigation department in 1981 and the contractor fished out all the fishes by employing various fishing gear and by poisoning. Therefore, in later years, entire stock had to be rebuilt by stocking. The reservoir was auctioned again in 1986 for an amount of Rs. 63,000. The commercial fishing commenced immediately, resulting in a total catch of 48.5 q giving a yield of 67.40 kg/ha. The low yield was due to limitation of fishing only to a few months. The reservoir could not be auctioned due to low bid in 1987. However, it was again auctioned in 1988 for an amount of Rs. 32,300 and a high fish production of 100 q was obtained.

Estimation of potential fish yield and the stocking rate

The morpho-edaphic index or MEI (ratio of TDS or its correlate to mean depth) described by Ryder (1965) is a method for rapid assessment of fish yield potential from a water body. MEI value of 50 represents a standing crop of 200 kg/ha which, in turn, could yield 55 kg/ha when exposed to intensive fishing. The MEI computed for Bachhra reservoir ranged from 21.46 to 27.07 during the period of study. Thus, it gave an underestimation of potential yield for the Bachhra reservoir hence not found suitable. Same conclusion was drawn by Jhingran *et al.,* (1981) while studying fisheries of Gulariya reservoir.

The potential fish yield of the reservoir was estimated using trophodynamic model based on energy flow through different trophic levels (Hayes & Anthony 1964). The annual estimated carbon production for the reservoir fluctuated between 1,250 t and 1,402 t during 1982 to 1987. Based on the concept of Odum (1960) that 1.2% of primary production converted to fish flesh is desirable, the fish production potential of the reservoir was estimated at 212 to 240 kg/ha. Against this, actual fish yields of 67.40 and 140 kg/ha were achieved at a conversion efficiency of 0.314% and 0.58% during 1986 and 1988 respectively.

The main flow of energy was through detritus food chain. The detritophagus (mrigal and calbasu) fishes formed 29.54% to 31.85% of the catch, followed by predatory catfishes (29.66% to 17.82%) and omnivores represented by *Notopterus notopterus, P. sarana* and *Ompok* spp (22.36% to 25.40%) and the rest by miscellaneous fishes during 1986 and 1988 respectively.

Stocking rate for the reservoir was estimated on the basis of its potential fish yield of 212 to 240 kg/ha. Further assuming that about 80% of the potential yield (173 kg/ha) would be harvestable in view of drastic reduction in water level, the stocking rate was computed by using the following formula (Huet, 1960):

$$\text{Stocking rate} = \frac{\text{Expected fish yield (kg/ha)}}{\text{Individual growth of fish in kg}} + \text{loss}$$

Growth rate was estimated based on the recovery of tagged fishes. An average growth rate of 400 g per annum was computed for major carps. A loss allowance of 75% was given in view of small size of the fingerlings stocked, their escapement through irrigation canal, natural mortality and predation by carnivores. Thus, the stocking rate was estimated as:

$$\text{Stocking rate} = \frac{173}{0.4} + \text{Loss} = 432 + 324 = 756 \text{ fingerlings per ha.}$$

The total fingerlings required for an area of 72 ha (average) was estimated at 54,432, say 55,000. Thus, 55,000 fingerlings of major carps at average size of 55 mm (mrigal 45%, rohu, 40% and catla 15%) were stocked in 1985, 37,000 in 1986 and 63,000 in 1987. The stocking rate was reduced in 1986 in view of the profuse breeding of major carps in that year. The low percentage of catla in stocking material was due to non availability of its seed, otherwise even higher fish production could have been achieved.

Finally, it is suggested that a management calendar should be prepared for enhancing fish yield from small reservoirs. This should be based on ecological approach *viz.,* stocking rate based on potential fish yield and appropriate time of stocking. August-September is the best time for stocking so as to allow 10 to 11 months for fattening of stocked fishes, followed by complete harvesting of the stock. This package may give a fish yield of 100-200 kg/ha depending on biogenic capacity of the reservoir.

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Table 1. Range and average values of physico-chemical parameters and primary production in Bachhra Reservoir.

	1982 Range	1983 Range	1984 Range	1985 Range	1986 Range	1987 Range	Average (6 years)
Water Temp.(^{0}C)	20-32.5	17-32	20.50-32	18.30-31	18-31	17-31.5	26.66
Transparency (cm)	17-101.17	30-119	10-115	41.16-145	41.5-112	40.5-130	66.07
pH	7.4-6.50	7.60-8.30	7.6-8.4	6.96-8.20	7.2-8.2	7.2-8.2	7.89
Free CO_2 mg/l	Nil-4.60	Nil-3.5	Nil-3.80	Nil-6.73	Nil-6	Nil-7.2	1.32
Alkalinity mg/l	95-162	122 - 160	96-166	67.33-135	72-190	72-180	127.66
Hardness mg/l	30-78	35 - 45	28.5-40	21-39.33	22-42	29.5-80	37.6
Calcium mg/l	19.0-24.5	19 - 24	19.5-23.10	16-22.50	16-23	20-24.5	20.98
Nitrate mg/l	0.0850-0.180	0.11-0.16	0.10-0.13	0.10-0.150	0.12-0.15	0.11-0.15	0.127
Phosphate mg/l	0.06-0.25	0.09-0.150	0.80-0.12	0.08-0.14	0.10-0.14	0.09-0.12	0.144
Conductivity μ mhos/cm	242-369	250-375	182-300	149-213	150-205	149-334	236.52
Silicate mg/l	7.30 - 14	7.9-12	6.80-10	8.6-11.73	7.7-11.5	8.4-14	10.04
Dissolved Oxygen	6 - 8.6	5.80-8.2	5.40-7.90	2.25-8.0	5.0-8.3	5.8-8.2	6.82
Gross primary Prod-uctivity mgC/m^3/h	62.50 - 100	50-112.5	50-112.5	50-100	50-112.5	52-112.5	80.17
Net primary Product- ivity mgC/m^3/h	50 - 87.50	37.50-100	37.5-100	37.50-89.50	37.5-100	39.5-87	65.125
Respiration mgC/m/h.	12.5	12.5-25	12.5-25	10.5-25	25-12.5	11.5-33.5	22.99

Table 2. Plankton composition (%) in Bachhra reservoir during 1984-87

	1984 (Sep. - Dec.)	1985	1986	1987
Copepoda	22.04	13.50	10.70	19.28
Cladocera	3.31	2.90	0.60	4.91
Rotifera	14.49	11.30	14.65	19.97
Protozoa	0.50	-	-	6.87
Total zooplankton	35.99	27.70	25.95	51.03
Myxophyceae	29.29	41.20	35.93	9.99
Chlorophyceae	21.08	10.10	10.23	11.11
Bacillariophyceae	13.76	21.00	25.02	27.87
Misc.plankton	-	-	1.37	-
Phytoplankton	64.01	72.30	72.68	48.97
Range & average plankton units/l	135-8428 (4762)	804-2107 (438)	70-1986 (1135)	175-1653 (581)

Table 3. Percentage composition of periphyton in Bachhra reservoir

	1983 (Sep. - Dec.)	1984	1985	1986	1987	Avg. %
Myxophyceae	90	29	68.9	46.10	37.5	54.3
Chlorophyceae	5	23	7.6	11.65	26.10	14.67
Bacillariophyceae	5	48	23.5	42.25	36.40	31.03
Range & average (units/cm^2)	30-2,500 (275)	43-8,850 (2,376)	777-77,777 (20,857)	900-99,999 (20,148)	746-120,000 (22,105)	

Table 4. Composition of macrobenthos in Bachhra reservoir

Year	Percentage composition			Range and average units/m^2
	Insecta	Annelida	Mollusca	
1982	52.10	36.60	11:30	380 - 684 (490)
1983	59.90	33.10	7.00	342 - 950 (790)
1984	67.30	27.40	5.30	456 - 1716 (960)
1985	71.40	15.30	13.30	1320 - 3364 (1763)
1986	55.60	15.30	29.10	800 - 3254 (1679)
1987	67.80	23.50	8.70	1144 - 4620 (1894)
Average %	62.64	26.55	10.80	-

Design of cages and pens suitable for inland water bodies

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Introduction

Aquaculture in floating net cages and net pen enclosures in inland water bodies has a score of advantages over the conventional system of fish culture in ponds or impoundments. The little variation of water depth in the inland flowing system provides an ideal and undisturbed environment which in turn helps the aquatic biomass to avail wider opportunity of exploiting the aquatic niche to the maximum extent as possible for optimum growth with lesser chance of exposure to predation.

Design of cages

The cages for fish culture are basically of three types *viz., floating cages, submerged cages and fully submerged cages.*

Floating cages occupy the upper surface of the water column and have framework supported on floats with moving system and anchorage for keeping the cage system in position. Floating cages are generally flexible structures, suitable for fish culture in shallow water depths ranging from 3 to 5 meters. Submerged cages are anchored in mid-depth of the water column while the fully submerged cages rest at the bottom availing the entire column as culture medium. However, aquaculture in floating cages is widely practised in view of easiness of their construction and maneuverability.

The design of cage varies with the kind of fish to be reared, its feeding habit and living preference. For milkfish, trout and salmon, circular or octagonal cages are ideal as shapes of the cages extend favourable environment to the fish which swim fast at the water surface in an orbital motion. A circular cage provides room for free and fast movement of fish with less risk of collision and injury. However, square or rectangular cages are extensively used owing to easiness of their construction, operation and maintenance.

Depending on the physical properties of the materials used in constructing the cage, the size or area of a cage varies from 3 x 3 x 2.5 m to as high as 50 x 25 x 5 m especially for commercial operation. Depth of the cage is usually ascertained by the natural productivity of water and it is generally restricted to 5 m. Multiple units of cages are sometimes grouped together for easy operation and better management. But care should be taken to leave adequate space between the successive cages for satisfactory water circulation.

Selection of cage site

The site should invariably be well sheltered preferably on the leeward side of the direction of the wind, free from turbulance or wave onslaughts. Water should be clear, well oxygenated, free from algal bloom or vegetation and pollutional effects. Bed formation consisting of composite soil with moderate amount of clay content is suitable for holding the mooring system which in turn imparts stability to the floations of the cage. Current velocity and flow pattern at the location of the cage should necessarily be gentle and sufficient to carry away the waste matters. A flow velocity of 20-25 cm/sec ensures adequate water exchange within the cage. There should be easy acess to cage for operation, monitoring and maintenance.

Cage components

The major components of the cage are: a) a net enclosure or bag net which holds the cultured organisms and keeps away the predators, b) a floatation system which supports the cage framework and walkway, and keeps the entire cage unit afloat and c) a mooring system which maintains the cage unit in one position. The bag net made of synthetic or flexible meshes requires rigging. The net should be of adequate strength, and durability, and resistant to fouling. Synthetic meshes lose strength and undergo deterioration after several years of continuous immersion. Physical properties of a few mesh fabrics have been presented in Table 1. Rigid nets such as galvanised wire mesh or chain link mesh, although in less use, are stronger and serve most satisfactorily for deep cage in turbulent water. The mesh size should be small to prevent the escape of fish but it should allow adequate water circulation in culture medium. Flow rate through 5 mm mesh gets reduced by 40% while it is 25% less through 30 mm mesh.

Table 1. Strength of mesh fabrics 1" (25.4 mm)

Type of fabric	Dia (in)	Wet break (kg)	Strength retained (%)	
			After 1 year	*After 3 years*
Nylon	0.063	45.5	20	-
Terrylene	0.100	81.5	20	-
Polythene	0.06	45.5	80	50
Galvanised chain link	0.08	127	50	-
Galvanised weed mesh	0.104	205	90	70

(Milne, 1970)

Cage framework

Materials commonly used for cage framework are timber and bamboo. Galvanised iron pipes, fibre glass, steel and aluminium pipes are also used in constructing rigid framework for cage used in turbulent water bodies. To protect materials against corrosion and fouling, protective coating of coaltar or anti-fouling paint is applied to their surfaces. However, the framework should be adequately designed to withstand the overturning movement and deflection caused by the self weight and external thrusts. For protecting the cage structure against the wave damage, various types of breakwaters are utilised which damper the intensity of wave thrusts and in the process absorb the wave energy (Mukherjee, 1990).

Floatation materials

Floats should have considerable buoyancy to ensure safe and adequate floatation. They should be resistant to fouling and durable to hydraulic pressure and waves. Smaller cages in calm water can have asphalt painted bamboo poles tied with the cage as simple floatation. Styrofoam floats and painted metallic drums connected with the cage raft offer satisfactory floatation with reasonable flexibility. The floats are positioned in such a way that upright stability of the whole structure is maintained under all conditions. The expected life of various floats is presented in Table 2.

Table 2. Different types of floats and their expected life

Types of float	Expected life span
Bamboo	2-3 years
Unpainted oil barrel	3-4 years
Painted metallic barrel	7-8 years
Styrofoam	3-4 years
Aluminium container	16-18 years
Ferro cement	10 years

Mooring lines and anchorages

Mooring lines should be strong, pliable and resistant to impact, abrasion and twisting. The size of the line should be small for easy handling and for minimizing the drag on the line. Metallic wire ropes, synthetic fibre ropes and chains are some of the materials used as mooring line. Synthetic fibre ropes commonly used in aquaculture operation have excellent strength and durability. But they are less resistant to abrasion and cuts. Steel chains with coating of anti corrosive paint also serve the purpose well.

There are chiefly three kinds of anchors *viz., dead weight, embedment,* and *special anchors.* Holding power of dead weight anchor is derived from downward pull exerted by the self weight of the anchor. Embedment anchors, suitable for muddy and sloping terrain dig into the bed of the water course and is held firmly in the bottom material. Special anchors have the combination of both dead weight and embedment anchors. Sometimes wooden pegs driven into hand base act as anchors. Cage can also be anchored from the land if it is near the bank.

Design of net pen enclosure

A comprehensive design of net enclosure for inland water course includes the following considerations.

i) Site selection
ii) Characteristics of the catchment area
iii) River discharge, incidence of flash flood
iv) Water and soil properties
v) Computation of static and dynamic forces
vi) Planning and design of pen enclosure
vii) Selection of appropriate constructional materials

Site selection

Appropriate selection of site plays a key role in deciding economic viability and success of aquaculture in pen enclosures. The site should have a stable shoreline with gentle gradient towards the watershed. Closely spared undulations associated with steep gradients pose difficulties in the erection of pen and its operation.

The bed formation consisting of composite soil is ideal for supporting the weight of the pen structure because such soil offers fractional resistance and has moderate bearing capacity. Surface run-off from the adjoining catchment area flows to the watershed and influences directly the depth and river discharge. Details about the catchment should be collected beforehand to ascertain the flood flow.

Surface run-off from a catchment caused by rainfall may be calculated from the following rational formula:

Where $Q = R \times A \times P$ cusec
Q = Total run off or discharge (cusec)
R = Intensity of maximum rainfall (inches/hr)
A = Catchment or drainage area contributing to run-off (acres)
P = Impervious factor of surface

Absorbent soil and clayey soil have impervious factor of 0.25 and 0.60 respectively. The flow velocity of the water course must be non-scouring but quite considerable to carry away waste materials and keep the enclosure safe against contamination.

Design forces

The direct loadings and external forces which act on the pen structure are chiefly:

a) self weight of the pen structure nets and operational loadings
b) dynamic forces of the wind, turbulence, waves, etc.,

In addition to these, aquatic vegetation, drift wood, fouling organisms *etc.*, often add to the self weight often. Wind forces acting on the exposed solid parts of the structure create overturning movement and tend to lift the structure from its position.

Magnitude of wind force on a solid structure can be determined from the following equation (Van Boven, 1968):

$$F = 0.0965\ AV^2\ kg$$

where F = Wind force (kg)
A = Projected area (m^2)
V = Wind velocity (m/sec)

Planning and design

The planning of pen enclosure varies with the characteristics of the location of the installation. For shallow water of 3 to 5 m depth, a flexible type of enclosure closed on three sides leaving foreshore open, serves the purpose well. Pile supported enclosure with chain link mesh is suitable for water depth of 5 to 12 m. The pen should necessarily be well defined, either in square, rectangle or oval shape for constructional easiness and management. It should be preferably aligned to the prevailing wind direction for effective aeration.

The main components of pen are pen framework, enclosure net and lateral supports or stays.

Pen enclosure design

Bamboos, timber beams and battens or locally availble timber poles are the common materials used for building the pen structure. Bamboos being cheap, strong, durable and abundantly available are extensively used for enclosure work. Split bamboos at intimate spacing driven deep into the hard base form the main side of horizontal and diagonal bracings connected with it.

The fish retention net, mainly flexible type of synthetic fibres must be of appropriate mesh size for rearing fish and the mesh opening should permit adequate flow of water through the enclosure. Knotless net mesh is most suitable owing to its resistance to abrasion and clogging. The net fitted in a perfectly stretched condition cause no injury to the fish. Sometimes double nets are used in pens, the inner one serving as fish retention net and the outer net of larger mesh preventing the entry of predators and drifting objects striking the pen structure.

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Salient ecological features of *mans* and *chaurs* of north Bihar and their fisheries

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Introduction

The northern districts of Bihar (25°18' - 27°37' N and 83°48' - 88°17' E) are known for their fertile alluvial plains with a network of rivers and streams. The entire region is bestowed with a series of natural lakes formed either due to the meandering of rivers or accumulation of river water in tectonic depressions especially in the Gandak and Kosi basins locally known as *mans* and *chaurs*. These lakes are very rich in biodiversity. All the economic activities of the region, by and large, centre around these lakes. The plains of north Bihar have the distinction of receiving recurring floods from the rivers like Kosi, Gandak, Buri Gandak, Bagmati, Kamala, Balan, Mahananda and Kareh during the monsoon, inundating a large tract of land in the region. The impact of flood is generally very forceful as huge mass of water debouch suddenly into the plains from the highlands of Himalayan ranges of Nepal. A substantial volume of this water is being trapped in the oxbow lakes (*mans*) and tectonic lakes *(chaurs)*. The ingress of silt load brought in this process is also heavy, making the water bodies shallower every year. Till recently, the *mans* and *chaurs* of north Bihar had the distinction of supporting very high level of bio-production in general and fish yield in particular. But due to increased anthropogenic activities in the catchment areas and irrational modifications of river basins, the ecological balance of the lakes has been affected. Excessive proliferation of aquatic macrophytes is the hallmark of such changes, a factor which has assumed alarming proportions needing careful mitigating action in order to halt or at least to decelerate the process of their degeneration.

The natural lakes of the region are being used for dumping waste materials, both from the factories and urban settlements, thereby putting extra pressure on the already threatened ecosystems. The normal grazing chains of these ecosystems have been disturbed as a result of which the production functions have also gone array. The floodplain lakes have high production potentialities due to their shallow nature and extended euphotic zone, but the current level and nature of bio- production are not in the optimum level which is a matter of serious concern. Thousands of fishermen families have been dependent on these resources for their livelihood, since time immemorial and the lakes provided them lucrative fishery till 1970s. In recent years, however, the fishing activities have become a secondary occupation as the availabilty of fish per fisherman per day has been reduced to a paltry 300 g and that too of smaller size group, which is hardly sufficient to maintain a family of four or five. It is time that all people concerned should come forward to conserve these natural water bodies and their precious biodiversity while achieving the goal of sustainable development for human welfare. This communication deals with the salient features of ecology of these water bodies together with their fishery in brief.

Oxbow lake (*man*) resources of north Bihar

Estimated area under *mans* in north Bihar is about 4,735 ha. There are 63 perennial lakes of various shapes ranging in size from 8 - 405 ha (Sinha and Jha 1997a). Besides, there are 20,000 ha of incomplete lakes whose formations have been halted due to the raising of flood protecting embankments. These lakes get inundated during monsoon months but reappear after that. The lakes are 'U', 'L' or 'S' shaped. Broadly two distinct categories of *mans* could be seen *viz.*,

- The lakes which retain their connecting channel with rivers where the ingress of river water is a regular phenomenon (live lakes).

- The lakes without any connecting channels and therefore, no ingress of river water (closed lakes).

A third category of lakes also exists whose formation has been halted due to the raising of flood protecting embankments. They become part of the rivers during monsoon months but get separated as water recedes. These lakes act as a collection sink of riverine fauna and are known for their lucrative capture fishery.

Chaur resources of north Bihar

The geomorphological feature of north-eastern part of the area has a large tract of tectonic depressions where accumulation of flood waters is a common phenomenon. This is the area where maximum congregation of *chaurs* (tectonic lakes) is found. This part of the region falls under Kosi basin and comprises four distinct *chaur* areas *viz.*,i) Kabartal area ii) Kusheshwarsthan area iii) Simari-Baktiyarpur area and iv) Goga beel area. The shape and size of the *chaurs* are variable depending on the shape and size of the depression. In north Bihar, however, the size varies between 0.5 ha and 600 ha and they are generally saucer shaped. The water spread area of *chaurs* in the region has been estimated to be 45,978 ha (Sinha and Jha,1997b).

Ecologial status of *mans* and *chaurs* of north Bihar

The *mans* and *chaurs* of north Bihar are known for their high production potential and have remained the life-line of people of the region since time immemorial. However, these ecosystems have been subjected to environmental degradation resulting in eutrophication. The very existence of these ecosystems are under threat. Excessive growth of macrophytes has altered the normal grazing chain with the result the unwanted biota have occupied the niche to a large extent. The process of swampification has assumed an accelarated pace resulting in the shrinking of lake areas. Further, conflicts among various user groups also lead to the deterioration of the lake environment.

Abiotic Features

- The soil of these lakes is alkaline (pH 7.7- 8.5) with moderate nutritional status (PO_4, 0.4 - 1.2 mg/l; NO , 0.07 - 0.15 mg/l) and very high concentration of dissolved organic matter (0.32 - 2.8 %).

- Dissolved oxygen level has high fluctuations (0.05 - 14.00 mg/l) indicating stress condition specially in lakes receiving effluents. The concentration of DO in the lakes which do not receive effluents, however, fluctuates between 5.00 - 12.00 mg/l.

- The alkalinity level is on the increase and found in the range of 110.00 to 610.00 mg/l with relatively higher values in lakes receiving effluents.

- The nutrients PO_4 and NO_3, are generally low in ambient waters compared to the soil phase, a typical example of weed choked waters where locking of nutrients is a common phenomenon and thus very little is available in the water phase.

- The specific conductance values are also on the increase (300 - 950 μmhos/cm) with pattern of fluctuations similar to alkalinity. Relatively higher values of this parameter indicate increased nutrient loading in the system.

- Moderate values of primary production in the range of 0.00 - 125 mg C/hr has been recorded from the *mans* and *chaurs* of the area.

Biotic Features

- The *mans* and *chaurs* of the region, generally, harbour poor density of plankton assemblage (200 - 3,000 units/l) owing to poor availability of required nutrients, particularly, PO_4 and NO_3, a typical feature of weed choked aquatic systems. In stray cases, however, presence of algal blooms has also been reported (Jha, 1989; Sinha and Jha, 1997a), specially those receiving domestic sewage.

- The fluctutions of planktonic population normally follow the sequence of *Bacillariophyceae > Chlorophyceae > Cyanophyceae > Dinophyceae* (phytoplankton) and *copepods > cladocerans > rotifers > protozoans* (zooplankton). However, of late, the members of Cyanophyceae amongst phytoplankton and protozoans amongst zooplankton tend to increase due to enrichment of systems.

- The greater abundance of nannoplankton with high dominance of bacterioplankton (*Thallothrix* sp., *Thiopedia* sp., *Chlorobium* sp., *Sarcina* sp. , *etc.*) in these ecosystems is indicative of stressed ecological regime. It also reflects that these lakes are moving towards ultraoligotrophy owing to excessive utilization of ambient nutrients by thick stands of macrophytes and very little is available to support the growth of euplanktonic forms. The incidence is more pronounced in *mans* on account of the relatively higher macrophytic biomass.

- The growth of periphyton is generally high in these systems which are represented mainly by diatoms (>90%). Leaves and stems of submerged vegetation usually form excellent substrata for their proliferation.

- The *mans* and *chaurs* of north Bihar have excessive growth of macrophytes of various types *viz.*, submerged, floating, emergent and marginal covering 50 to 100 % of the area. The biomass has been reported in the range of 4.0 - 28.0 kg/m^2.

- The lakes which receive effluents have more luxuriant growth of weeds which lead to the shrinkage of *beel* area.

. The canopy of macrophytes at the water surface is affecting the benthic niche adversely and almost creating an ecological desert. The strata have largely been occupied by molluscan populations which are not contributing much to the grazing chain in the absence of efficient grazers.

Fish and fisheries

The floodplain lakes of north Bihar are known for their lucrative fishery, but in recent years, the production and productivity of these biolgically sensitive ecosystems have gone array in the face of increased human interference. Till the raising of flood protecting embankments along the river courses, the *mans* and *chaurs* of the region were considered as a renewable source of harvestable energy. These water bodies were the excellent nursery, grazing and shelter grounds for incoming juvenile as well as adult fish species from rivers and as such were the repository of rich biodiversity. However, utter neglect in the past and irrational exploitation in the present have done considerable damage to the systems and as a result the process of ecological imbalance has set in. Enrichment of nutrients both from internal and external sources together with continuous deposition of silt load has paved way for the colonization of various aquatic flora , which occupied a substantial part of the niche. Overgrowth of macrophytes, in these ecosystems, has done tremendous harm to fish and fisheries by promoting species of less economic values at the cost of prized ones. Shift in population structure is the resultant effects of broken grazing chain. Pattern of energy transfer from one trophic level to another has changed to longer chains from autotrophs to smaller forage fishes and to carnivores. Multiple breeding of forage fishes has thus helped to establish the carnivores at the cost of carp population. The present status of fishery of *mans* and *chaurs* could be summerised as under :

. The ingress of riverine fish seed has been affected adversely due to the construction of flood control embankments resulting in the dismemberment of lakes which had connection with the parent rivers. In case of closed lakes, no stocking schedule is followed.

- The share of major carps in the fish production has been estimated to a meagre 3-5 % or even less at times. The catch is dominated by catfishes (60 - 80%) in terms of biomass where forage fishes dominate. In those lakes where ingress of carp seed is taking place or some stocking is done, its percentage in the total catch has been found to be relatively better (26 - 28 %).

- The average catch per fisherman per day ranges between 300 and 500 g of mixed species which is not enough for subsistence and thus the fishery in these lakes has become a subsidiary occupation.

- The lake area of entire north Bihar is becoming a bone of contention among various users regarding the usefulness of these water bodies as they have conflicting interests. Reclamation of lake area either for agriculture or for urban development is on the increase. Evidently, this has done considerable damage to these ecosystems and in the bargain the biodiversity and fishery are the worst casualities

- The short term leasing policy of Fisheries Department of Bihar is another important factor affecting the fishery adversely. The lessees are not very keen to invest money for the development of fishery in these lakes. On the contrary, they try to catch the entire fish stock irrespective of size and quality, resulting in further depletion of fish population. At no point of time, the fishery of these lakes is allowed to build up.

- The gears used in the region are generally of primitive types and of smaller mesh bar which itself is an indicator that the lakes are dominated by smaller variety of fish species. The most disturbing trend is the use of *chatti jal*, a drag net made of mosquito net clothing. This amounts to converting these fragile ecosystems into fishery deserts by netting out all the fishes without any discrimination of sex, size or quality.

- The shell fishery is also common in this lake area and at times the output of smaller variety of prawn is quite substantial in the total catch (7.0 - 10.0 %). Hand picking of gastropods, during post monsoon months, is a common site in north Bihar specially in the *chaurs*.

Transfer of energy and productivity potential

The normal grazing chain , which starts with plankton and culminates at fish , has become irrelevant in the face of fast changing ecological scenario of these lakes . Conversely, continuous increase of detrital pool at the bottom is highly significant due to over growth of macrophytes in the system. The productivity of these lakes in terms of fish yield is due to the fact that the transfer of energy, from primary level to fish is only partial, as bulk of the energy remains unutilised in the form of detritus at the lake bottom . Moreover, poor or no management of these ecosystems coupled with excessive man-induced habitat changes has made the situation all the more difficult for smooth passage of energy from one trophic level to another. The photosynthetic efficiency of these ecosystems depends on two counts, first the level of their management and second the level of waste input in them. It has been observed that the photosynthetic efficiency ranges between 3.26 % (stressed lakes) to 4.86% (non stressed and partially managed lakes). Based on the level of primary production at various trophic strata, the *mans* and *chaurs* of north Bihar have the potential for producing 1,000 - 1,800 kg fish/ ha/year against the current yield of 30 to 300 kg fish/ ha/year. Evidently, there is enough scope for fish yield enhancement in the area, provided the lakes are managed on scientific lines and in tune with the norms of enviornmental and biodiversity conservation.

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Fisheries of Muktapur oxbow lake (*man*) - a case study

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Introduction

Muktapur is a typical 'U' shaped oxbow lake, located 5 km North of the district headquarters of Samastipur. This 100 years old perennial meander of river Burhi Gandak has an area of 40 ha . Its water is used for irrigation, drinking water, industrial use and fisheries. The fisheries right is vested with the State Department of Fisheries. Muktapur lake is an open type oxbow lake as it has retained its connecting channel with river. Colonization of aquatic macrophytes is of very high degree and these plants have assumed the status of weeds. Sluice gates have been provided at the mouth of the channel to regulate ingress and egress of water. However, in recent years, the sluice gate device has become almost defunct and the channel has been considerably silted up. Another reason for the poor ingress of riverine waters is the rising of the lake bed level. The fish and fishery, for the present, has been restricted to relatively less economic species in the face of excessive growth of macrophytes and poor recruitment of quality fish seed from the main river. Excessive withdrawal of lake water for irrigation and jute factory together with reclamation of marginal areas has accelerated the pace of eutrophication and further colonization of macrophytes.

An effort has been made here to highlight the status of fish and fishery of Muktapur lake, based on the studies made during 1988 to 1993.

Salient ecological features

The soil quality of Muktapur lake has been found to be productive as indicated by high values of pH and organic carbon together with fairly rich contents of plant nutrients (Table 1) while the water quality indicated a mixed trend of trophic status. The dissolved oxygen, total alkalinity and specific conductance were in the productive range. However, availability of nutrients reflected the characteristics of typical weed choked aquatic regime with poor values (Table 2).

Table 1. Soil quality of Muktapur lake

Parameters	Values (range)	Average
pH	7.6 - 8.5	8.05
Total nitrogen (%)	0.67 - 1.1	0.89
Total phosphate (%)	0.40 - 1.0	0.70
Organic carbon (%)	0.41 - 1.9	1.16

Table 2. Water quality of Muktapur lake

Factors	Values	Average
Transparancy (cm)	52.0-102.0	77.0
pH	7.1-8.2	7.65
DO (mg/l)	5.4-10.6	8.0
Total alkalinity (mg/l)	92.0-155.0	123.0
PO_4 (mg/l)	Tr.-0.009	0.004
NO_3 (mg/l)	0.12-0.45	0.285
Sp. Conductance (μmhos/cm)	392-498	445

Primary production

The rate of primary production in Muktapur lake was low to moderate range of 27 - 131 mgC/m^3 and a significant 71 % of this production was through nannoplnktonic chain. The macro- or net phytoplankton production was overshadowed by the macrophytic growth.

Biotic communities

In Muktapur lake macrophytes have been the most dominant biotic community, regulating the whole biotic regime of the lake. Availability of net plankton was poor (345-650 units/l) and the nannoplankton which dominated by bacterioplankton was relatively higher (5,010-1,800 units/l). Colonisation of periphyton was better (850-5,300 units/l) due to the presence of submerged leaves and stems of hydrophytes. The wet weight of macrophytic biomass was significantly high (7.0-13.8 kg m^2) and the production of benthic fauna of molluscan dominance was reasonably good . The composition of biotic communities was indicative of a stressed aquatic environment and an incoherent biotic association, with the result, the transfer of energy from one trophic level to another has been deviated from its normal path. The two dominant biotic groups, in terms of biomass, the macrophytes and the molluscs have failed to enter the grazing chain leading to fish production in the absense of efficient grazers.

Bottom energy

The average annual detrital load in Muktapur lake has been estimated at 14.3 x 10^5 K Cal /ha. But this large energy reserve at the bottom is not reflected in fish production. It has been estimated that 2,06,800 K Cal was the total energy that was harvested annually in the form of fish, out of which 53.25 % (1,10,112 K Cal) came through smaller fish, 24.84 % from carnivores and 13.12 % from plankton feeders. Only 8.79 % was contributed by the detritivores. Evidentlly, a large reserve of bottom energy remained unutilized or wasted (Sinha and Jha, 1997).

Fish and Fisheries

Fish fauna

Out of the 42 species of fishes recorded from Muktapur, only 15 were of economic value. Besides the Indian major carp, larger catfishes, featherbacks, air-breathing fishes and *Channa* spp. there were miscellaneous fishes which had good market acceptability such as *Setipinna phasa* , *Puntius sarana*, *Labeo bata, Mystus vittatus, Ailia coila, Nandus nandus, Mastacembelus armatus*, *M. puncalus etc.* (Jha, 1995).

Production

The rate of fish production increased from 60 kg/ha/yr in 1989 to 163 kg/ha/yr in 1992 to the natural and artificial recruitment of prized fishes. In 1988, though the connecting channels of River Burhi Gandak were silted up, the strong flood water could bring in fish seed to the lake leading to the natural recruitment of fish. Because of the partial management of the lake fishery encouraging results were discernible. Composition of major carps in the fishery increased from 9.03 % in 1989 to 21.00 % in 1992 together with a substantial decline in the abundance of catfish (from 24.67 to 14.99 %) and forage fish (60.08 to 53.77 %).

Production potential

The production potential of Muktapur lake has been estimated at 1,200 kg/ha/yr based on the energy reserve and therefore, ample scope exists to enhance its fish yield through effective management. The fish yield rate of the lake can be increased to 600 kg/ha/yr even if 50% of the actual potential is realised. However, to achieve this target scientific management of the lake is a prerequisite.

Feasibility of fish husbandry

Pen culture experiments conducted in Muktapur lake were very encouraging as yield of 3.5 to 4.0 t could be achieved in a rearing period of six to eight months. This mode of aquafarming comes handy for augmenting the yield from such of wetland ecosystems. It generates not only additional revenue and gainful employment but also helps in the effective utilization of marginal areas of the lakes without disturbing the main water body.

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Beels, the prime inland fishery resource of Assam

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Beels associated with the two major river systems, Brahmaputra and Barak, contribute to the bulk of inland fisheries resource of the State of Assam. These *beels* are in the transient phases of their evolution from the riverine ecosystem. They are ecosystems with unique, geo-hydrological processes followed by eco-biological successions. The geo-hydrological processes due to fluvial action of both the rivers cause the changing landscape of the State. Acting as natural filters and by way of regulating the hydrologic regime and nutrient exchanges, these *beels* preserve the fish germplasm of commercially important species, by providing excellent spawning and nursery grounds for all commercial species including the Indian major carps.

There are about 1,392 *beels* in Assam (Table 1) of which 423 (30.4%) are registered and 969 (69.6%) unregistered. Among the unregistered *beels*, 52.1% are under the control of the state government and 47.9% fall under the public sector. However, according to the present government records, there are 430 registered and 766 unregistered *beels* while the remote sensing data show more than 3,000 *beels* in Assam. These *beels* constitute about 72.45% of the total lentic water area (1,380,17 ha) of the State excluding two newly constructed reservoirs (10,730 ha). The rich riverine fisheries of Assam derive mainly from the potamonic stretches of 4,820 km (2,05,000 ha) of the Brahmaputra with 42 tributaries and the Barak with 13 tributaries, which mainly harbour rich fish fauna.

Table 1. Registered and unregistered beels of Assam at district level

District	Registered	Unregistered		Total
		GS	SGP	
Hailakandi	11	nil	18	29
Karimganj	26	21	12	59
Silchar	34	21	179	234
Darrang	17	13	1	31
Sonitpur	3	10	9	22
Dibrugarh & Tinsukia	19	nil	19	38
Dhubri	37	75	nil	112
Goalpara	13	32	nil	45
Kokrajhar	4	22	nil	26
Barpeta	48	25	2	75
Kamrup	23	9	14	46
Nalbari	26	8	14	48
Karbi Anglong	nil	nil	nil	-
Dhemaji	9	21	49	79
N. Lakhimpur	13	36	25	74
North Cachar	nil	nil	nil	-
Morigaon	44	62	11	117
Nowgaon	38	120	14	172
Golaghat	20	1	47	68
Jorhat	22	19	22	63
Sibsagar	16	10	28	54
Total	**423**	**505**	**464**	**1392**

Morphology

Assam *beel*s can be categorised into four morphologically distinguishable types, *viz.*, (i) Typical oxbow (horse-shoe shaped), (ii) Tube or canal type, (iii) Oval or saucer shaped and (iv) Dendritic tectonic type.

Habitat variables

There are two phases of productivity in the *beel*s, the flood phase (6-7 months) and transitional phase (2-3 months). The flood phase is important in the hydrologic cycle, exchange of nutrients, renewal of fish stock and production at various trophic levels. During the transitional phase, stability and growth of the *beel* ecosystem starts which culminate in the harvesting stage.

Physico-chemical features of water

Some of the physico-chemical features, *viz.,* water temperature, pH, dissolved oxygen, free carbondioxide, total alkalinity, total hardness, total phosphate, total nitrogen, calcium and magnesium are related to the fish productivity (Table 2).

Table 2. Ranges of water parameters showing productive and unproductive trend in the beels

Parameters	Present range	Productive/unproductive ranges	% of beels	Inference
Water temperature °C	19.0-34.0	-	100.0	Productive
pH	5.6-9.1	<6.0 6.0-9.0	28.6 71.4	Unproductive Productive
Dissolved oxygen (mg/l)	1.9-9.0	1.0-5.0 5.0-9.0	26.7 73.3	Unproductive Productive
CO_2	0.0-23.0	0.0-5.0 >5.0-20.0	35.7 64.3	Productive Unproductive
Total alkalinity (mg/l)	14.0-125.0	<25.0 25.0-125.0	68.4 31.6	Unproductive Productive
Total hardness (mg/l)	2.0-140.0	<15.0 25.0-100.0 >100.0	53.3 26.7 20.0	Unproductive Productive Less productive
Total PO_4 (mg/l)	1.4-3.9	<2.0 >2.0	12.5 87.5	Unproductive Productive
Total Kjl-N	0.7-7.3	<5.0 >5.0	57.1 42.9	Productive Unproductive
Ca^{++} (mg/l)	4.0-15.0	<25.0 >25.0	83.3 16.7	Unproductive Productive
Mg^{++} (mg/l)	2.0-60.0	<25.0 >25.0	81.8 18.2	Unproductive Productive

Plankton

Plankton diversity of *beels* is generally high suggesting a eutrophic condition but plankton volume is generally low (0.75 - 2.0 ml/100 l) except during bloom formation (6.0 - 7.0 ml/100 l). Chlorophyceae, Myxophyceae and Bacillariophyceae are the most dominant phytoplankton group and among the zooplankton, the most common groups are Protozoa, Rotifera and Crustacea (Cladocera > Copepoda).

Macrophytes

Most of the energy produced in the beels are wasted in the luxuriant growth of macrophytic biomass (3.0 - 7.0 kg/m^2) excluding the mat swamps. High macrophytic growth indicates a rapid eutrophication process.

Fisheries potential

Fish species

Altogether, 66 fish species of riverine origin are known to occur in the *beels* and their present status has been determined after random sampling in 50 *beels* (Table 3). Over the years, there has been a change in species composition; major group giving way to minor groups (Table 4).

Table 3. Fish resources of the *beels* of Assam

Major group	Intermediate group	Minor group
Catla catla	*Labeo bata*	*Puntius sophore*
Cirrhinus mrigala	*Cirrhinus reba*	*P.phutonio*
Labeo rohita	*Eutropiichthys vacha*	*P.conchonius*
Labeo calbasu	*Clupisoma garua*	*P.gelius*
Labeo gonius	*Ompok pabo*	*P.ticto*
Labeo nandina	*O. bimaculatus*	*Oreichthys casuatis*
Notopterus chitala	*Heteropneustes fossilis*	*Clupisoma atherionoides*
Aorichthys seenghala	*Clarias batrachus*	*Gadusia chapra*
A. aor	*Rita rita*	*Rasbora elanga*
R. corsula	*Channa punctatus*	*R.rasbora*
Wallago attu	*C. stewarti*	*R.daniconius*
Channa marulius	*Puntius sarana*	*Salmostoma bacaila*
C. striatus	*Mastacembelus armatus*	*Chela laubuca*
Bagarius bagarius	*M. puncalus*	*C. atpar*
Pangasius pangasius	*Macrognathus aculeatus*	*Amblypharyngodon mola*
	Nandus nandus	*Aspidoparia morar*
	Notopterus notopterus	*A.joya*
	Anabas testudineus	*Mystus tengra*
	Xenentodon cancila	*M.vittatus*
	Glossogobius giuris	*M.cavasius*
		M.bleekeri
		Batasio batasio
		Lepidocephalus guntea
		Chanda ranga
		C.nama
		Badis badis
		Tetradon cutcutea
		Brachidanio rerio
		Danio davario
		Chacca chacca

Table 4. Fish catch composition of *beel* fisheries-past and present

Group of fish	Past	Present
Major carps	58.0%	24.0%
Intermediate group	26.0%	19.0%
Minor groups	16.0%	57.0%

Autostocking

Beels are normally connected with the main river system. The river water circulation takes place during the monsoon or flood season when the rivers Brahmaputra and Barak swell. In Assam, depending upon annual rainfall and snow melting at the Himalayas, there may occur 2 - 3 spells of flood every year. The first two spurts of flood during June-August are very significant in the context of fish productivity in the *beels*. The pathways of water circulation in the *beels* are :

main river - river tributary - river meanders - rivulets - inlet canal - *beel* - outlet canal - river system.

During the river water incursion, the fishes migrate from the river to the *beel* for breeding and feeding. The autostocking system is mainly due to fish migration from deep water bed during breeding season. Migratory propensity of *beel* fishes particularly that of the commercial groups is of considerable significance from fishery point of view. There are three types of migrants which largely contribute to the autostocking system of the *beels*, *viz.*, breeding migrants, sporadic migrants and accidental migrants.

Occurrence of exotic carps

Three exotic carps, *C. carpio, H. molitrix* and *Ctenopharyngodon idella* enter the *beel* forming seasonal catch. Recently, catla - rohu hybrid has been found in two *beels*.

Hilsa fisheries

Hilsa (Tenualosa) ilisha occurs in Assam *beels* which may be pointed out with special reference to the report from Dhir, Dora and Sone *beels*. This constitutes a peculiar trend of migration from the mainstream of rivers Brahmaputra and Barak as presented in Table 5.

Table 5. Hilsa migration from rivers to *beels*

Beels	Year	Period of occurrence	Catch (kg)
Dhir	1982	May - November	715.0
	1982	May - September	10.0
	1983	May - October	40.0
Dora	1978	May	93.7
	1979	July	6.0
Sone	1979 & 1980	April - October	163.5
	1981	May - September	220.7

Fish yield

In spite of several constraints, *beel*s contribute *c* 12.5% to the total annual fish production of the State which has been estimated at *c* 1.51 lakh t, against the annual demand of 2.5 lakh t. Although the estimated total *beel* area is 1 lakh ha, no records are available on total fish yield from individual *beel*s. Data collected during 1994-95 from a number of randomly selected *bee*ls from five sectors of Assam clearly indicate an average fish production rate of 190.0 kg/ha (Table 6).

Table 6. Fish production from selected Assam beels

Zones	Production rate kg/ha
1. Upper Assam	120.0 - 207.0 (Av. 163.0)
2. Northern Assam	150.0 - 350.0 (Av. 243.0)
3. Southern Assam	102.0 - 419.0 (Av. 172.0)
4. Central Assam	150.0 - 300.0 (Av. 225.0)
5. Lower Assam	100.0 - 380.0 (Av. 173.0)

The catch per person per gear per hour (CPGH) in kg recorded with different nets is shown in Table 7.

Table 7. CPGH (in kg) with different gear

Gear	CPGH (kg)
Dolijal	0.135 - 0.631
Fashijal	0.110 - 0.172
Khewalijal	0.040 - 0.240
Paonajal	0.240 - 0.400
Musharijal	0.600 - 0.720
Berjal	0.215 - 0.355
Ghaijal	0.720 - 1.030

*Beel*s constitute the prime inland fishery resource of Assam. Conservation of these ecosystems is very essential to develop them on a sustainable basis, especially due to the fact that these water bodies depend on river systems for recruitment of fish and nutrients. *Beel*s are a continuum of riverine ecosystem and a holistic approach in the management of the two types of resources is very essential.

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Ecology of *beels* in West Bengal

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Floodplain wetlands of West Bengal, locally known as *beels* and *jheels,* play a major role in the lives of the rural people and economy of this densely populated State. More than 42,500 ha of water area is under *beels* spread throughout the State except few districts like Purulia and Midnapore. Though ranks second after the state of Assam in respect of surface area, the State gets much less fish from the *beels* than their potential. Indiscriminate exploitation is one of the reasons for the low yield rates. Many of the water bodies are in the state of unproductive, derelict or semiderelict condition. The fish production can be rejuvenated if appropriate measures for conservation and management of these resources are adopted on scientific lines. Knowledge of ecological processes and an integrated approach in biological productivity management are imperative for enhancing yield from the *beels*. Along with yield optimisation, measures for conserving the biodiversity richness of these natural water resources are also required.

Ecology of *beels*

Condition of majority of the *beels* have deteriorated considerably due to excessive siltation within the *beels* as well as in the channels connecting them with rivers or tributaries. Over-growth of macrophytes and siltation have further hastened the processes of swampification in the system. These processes have resulted in conversion of many *beels* into marshy lands.

Morphometry and hydrodynamics

Morphometrical heterogeneity is conspicuous in the *beels*. The morphometric features are dependent on resource contour and geomorphometry of the locations. In West Bengal, the *beels* are mostly cutoff meanders of the river Ganga and its tributaries. Some of them are oval, dumbell shaped or riverine in appearance.

The hydrodynamics of *beels* is determined by the effects of water inflow and outflow from the system. The open *beels*, linked permanently with rivers retain riverine level all along. When the riverine linkage is seasonal, only during monsoon flood, the *beel* level reaches river level, which later recedes due to water loss through evaporation.

The closed *beels* are significantly different from open ones as they are severed from river and exclusively dependent on catchment runoff for water recharging. Hydrodynamically the closed *beels* are not very stable due to the erratic water renewal through rainfall. Majority of the *beels* in West Bengal are vulnerable to high water level fluctuations. Low rainfall causes serious water balance problems for the closed *beels*. Unusual drought causes complete exposure and subsequent biodiversity losses in shallow and closed water bodies.

Nutrient dynamics

Water and soil form the principal media for all the biological activities in an aquatic system. Thus, the physico-chemical qualities of water and soil have direct bearing on productivity potentialities of the *beels*. Water is considered productive when rich in oxygen and nutrients and suitably warm for promoting physiological activities of organisms. The *beels* of West Bengal remain moderately warm under the geo-climatic situations of the region. However, the thermal amplitude varies with the water depth. The deep water *beels* are thermally stratified during summer months. Thermal gradient of 4-6 ^{0}C between surface and bottom is very often recorded in *beels* retaining more than 10 m of water column. *Beels* with less than 10 m of water depth are mostly homothermic. The clinothermic *beels* are also characterised by the chemical stratification in respect of oxygen, CO_2, alkalinity and pH. Bhandardaha and Gopalpur *beels* are the examples of thermally stratified water bodies. Occasionally, clinothermic conditions are also recorded in *beels* less than 10 m in depth and such conditions prevail temporarily during summer months only.

The *beels* are naturally rich in nutrients due to the allochthonous supply of organic matter through the catchment runoff and autochthonous sources of macrophytic decomposition besides the death and decay of other aquatic organisms. These two sources of nutrient supply are highly variable. The generation and supply of organic materials from the catchment depend on the characteristics and the extent of catchment area feeding the aquatic system. On the other hand, the macrophytic source of nutrients vary with the place and time. Shallow water areas are the most ideal habitats for the growth and proliferation of macrophytes. Seasonal fluctuation in vegetative growth is a natural phenomenon which is applicable for all the habitats.

Nutrient cycle in aquatic system is a complex process involving soil, water and their interphase. The process involves storing, releasing and utilisation of the nutrients either in organic or inorganic form. The undesirable piling of organic matter complicates the nutrient cycle further in *beel* ecosystem. The high nitrogen level interferes with the release and subsequent availability of phosphorus for the primary producers. Such interaction is pronounced in the shallow marshy water bodies where nitrogen gets gradually accumulated as undecomposed, semidecomposed and decomposed organic matters in the bottom sediments. Excessive organic deposition creates unconducive environment for many of the beneficial and mineralising microbes and produces eutrophic condition in the habitat. In deep water bodies which are less infested with macrophytes and with comparatively lesser accumulation of organic materials, an optimum balance in dissolved inorganic nitrogen and dissolved inorganic phosphorus is maintained which is ideal for optimum availability and utilisation of N and P for primary productivity.

Structure and functions of biotic communities

In an aquatic system the community structure is affected by the habitat alternation. The biotic communities consist of primary producers which synthesise food from the nutrients and the consumers of primary, secondary and tertiary trophic levels. Among primary producers, the role of macrophytes and phytoplanktonic organisms are well known, while the role of organisms < 10 µm in size are not well recognised, though they are extremely important in the production process and nutrient recycle in surface water. These organisms are identified as photosynthetic cyanobacteria.

Beels provide ideal habitats for plant organisms like macrophytes and phytoplankton. Macrophytes dominate marshy water bodies while the plankton prevails in deep water ecosystems. The cycle of planktonic biomass is well associated with fluctuation in solar radiation and the nutrient availability. The *beels* in West Bengal, by virtue of their high nutrient storage, exhibit two to three plankton pulses in a year. The planktonic peaks are mainly due to the blooms of filamentous algae like *Oscillatoria, Anabaena, Phormidium* or *Microcystis* and occasionally *Ceratium*. The zooplankton sometimes outnumbers the phytoplankton in some deep water bodies which harbour higher densities of planktonic population compared to the shallow ones. The weed infested *beels* are different in planktonic structure. Apart from having lower plankton densities compared to the deep water bodies, they are dominated by zooplankton (*Cyclops* sp., *Diaptomus* sp., *Daphnia* sp. *Bosmina* sp. *etc.)*.

Besides the macrophytes and planktonic organisms, a third group of community *viz.* the associated fauna is an important link in the food chain of *beel* ecosystems. The macrophytes provide support for these organisms in the form of food, shelter and breeding space. Marshy and weed infested *beels* are rich in macrophyte associated fauna. Weed associated fauna tend to be host specific. Soft and leafy vegetables are always preferred by the dominating population of gastropods. The bottom soil is occupied by various groups of benthic organisms. These organisms form an important link in the food chain, utilising the energy at the sediment phase. Dominance of benthic fauna in organically rich bottoms is, thus very common. The shallow, weed infested *beels* are always rich in benthic fauna both qualitatively and quantitatively. Molluscs mainly represented by the gastropods (*Gabia* sp. *Gyraulus* sp. *Lymnaea* sp. *Bellamya* sp.*etc.)* dominate over the other benthic communities (annelids, insects, decapods *etc.*) in the *beel* systems of West Bengal. By and large, these organisms are in their peak abundance during winter season when the habitat is favourable for their propagation and growth.

Beels are well known for their fish faunistic diversity. Besides harbouring a wide variety of endemic fish fauna, these water bodies are providing food and shelter for a number of non-resident species. The fish fauna in *beel* system varies with ecological status mainly food spectrum. Low depth, dense weed infestation and low planktonic growth restrict inhabitation of major carp species in shallow *beels*. The fish fauna in shallow *beels* comprises minnows (*Amblypharyngodon mola, Puntius* spp., *Gadusia chapra, Chela* sp. *Ambasis nama, A. ranga, Colisa* sp.*)* and carnivorous species (*Glossogobius giuris, Heteropneustes fossilis, Anabas testudineus, Notopterus notopterus)*. Management of *beels* takes into account, the pathways of energy transformation in *beels i.e.*, plankton-based and detritus-based systems.

Anthropogenic pressure

Growing population in the rural areas where there is high level of dependence on the *beels* for various activities is the main reason of increasing anthropogenic pressure on the *beel* ecosystem. The pressure due to water abstraction for agricultural purposes is on the increase. Agricultural post-harvest activities such as retting of jute is very common in *beels* of West Bengal. The process of retting jute stems in water, besides generating huge amount of organic deposit, introduces different types of harmful chemicals to the systems. Cumulative effect of these human activities is deleterious to the ecosystem functions. Catchment alteration is another serious anthorpogenic interference. Change in land use pattern poses serious threats to the very existence of the *beel* as a resource.

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Present status of fish production in the beels of West Bengal with suggestion for fish yield optimisation

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Although West Bengal tops the list of inland fish producing states in India, on account of high percentage of fish eating population, there is a big gap between the requirement and availability of fish in the State. In order to increase fish production, all existing water resources, natural or man-made, are being utilized for fisheries development. *Beels*, being a major component of the freshwater resource of the state, receive special attention. However, increasing pressure on these water bodies causes ecological imbalances. There is an urgent need to develop fisheries development norms which are environmentally sound.

Resource characteristics

Beels have diverse morphometric and hydrographical characteristics. Based on the hydrographical features, these water bodies are distinguished as open and closed types. Open *beels* are linked with rivers and get water regularly while closed ones are completely severed from the river connection. These categorisation is important for assessment or differentiation of recruitment potentialities. However, for ecological distinction and also for formulation of effective fisheries management practices, the *beels* can also be classified on the basis of depth variations.

Deep water *beels*

Water bodies more than 10 m in depth are chemically stratified with a euphotic zone limited to 2-3 m. Low dissolved oxygen and temperature, coupled with unfavourable chemical conditions create anaerobic conditions at the bottom layer. Energy flows mainly through the planktonic food chain and partially through the food chain of macrovegetation. Mono- or bimodal seasonal peaks of plankton are often recorded in these *beels*.

Medium deep *beels*

The medium deep *beels* are either silted up deep water *beels* or they are originally so due to geomorphometric features of their locations. These systems are ecologically balanced, highly productive and maintain equilibrium in macrophytic and planktonic food chains.

Shallow *beels*

These *beels* are less than 3 m in depth with highly fluctuating water balance. Extreme drawdown in summer causes drying up of many of the *beels* which are very shallow in nature. Problems of dehydration and subsequent biodiversity loss are severe in case of unusual drought and high rate of water abstraction for agricultural purposes. Adverse effects of stresses in environment on the life processes are more pronounced in shallow *beels* during summer season. Thick growth of hydrophytes is common in shallow *beels* often spreading up to 90 to 95% of the water area in winter months. Dominance of macrophytes hinders microphytic growth. Besides, decomposition of macrophytes contributes continuously to the organic storage and hastens the process of eutrophication.

Fish spectrum

A total of 94 fish species have so far been reported from West Bengal *beels*. In addition, some riverine species migrate to *beel* habitats for breeding and nourishing the young ones. Fish fauna varies with food spectrum of the aquatic system. The deep water *beels* by virtue of dominant planktonic food chain harbour combination of plankton feeding fishes like *Amblypharyngodon mola, Gadusia chapra, Puntius* spp., *Gambusia affinis, Colisa fasciatus, Chela bacaila, Osteobrama cotio, Esomus danrica, Ambasis nama* and *A. ranga*. Big sized carnivorous fishes *viz., Wallago attu, Mystus* sp. *Channa marulius* and the major carps like *Labeo rohita, Catla catla, Cirrhinus mrigala* and *Labeo calbasu* are also found . Fish spectrum is conspicuously different in shallow water ecosystems. Despite the high organic deposition, the fish fauna includes very few of the detritivores due to the unfavourable habitat. Fishes in these system mainly belong to small planktivores and carnivorous species such as *Channa punctatus, C. marulius, C. gachua, C. striatus, Nandus nandus, Glossogobius giuris, Xenentodon cancila, Notopterus notopterus* and air-breathing fishes like *Anabas testudineus, Heteropneustes fossilis* and *Clarias batrachus*. Medium deep *beels* have rich species diversity.

Fish yield pattern

Fish yield in *beels* fluctuates widely depending on the fish fauna and food spectrum, recruitment potentialities and overall habitat. These factors vary from one system to the other resulting in variation of the yield pattern.The average annual yield from shallow *beels* ranges between 150 and 350 kg/ha. This low fish production is attributable to the fish spectrum dominated by the small sized planktivores and carnivores. In deep water *beels*, the annual fish yield fluctuates between 250 and 475 kg/ha. The species contributing to the fish production are planktivores, detritivores and omnivores. Medium deep *beels* yield fish at high rates of 500 to 1,000 kg/ha/yr.

Stocking of fast growing major carps influences the production depending on the species selection, productivity and stock manipulation. In general, carps perform better in medium deep *beels*. The growth rate of *Labeo rohita, Catla catla* and *Cirrhinus mrigala* in Bansdaha *beel* in Burdwan and Haripur *beel* in Malda ranged between 0.85 kg and 1.00 kg, 1.25 kg and 2.5 kg, and 0.45 kg and 0.60 kg respectively during 1993-94. Annual production from these medium deep *beels* were 1,000 kg/ha (Bansdaha) and 850 kg/ha (Haripur) during the year.

Fishing methods

The fishing methods practised in *beels* are traditional. Gill nets, scoop nets, seine nets, encircling nets and lifting nets are deployed depending on the requirements and suitability of their operation. Hooks and lines are also used for catching large sized carnivores. Besides, various types of traps are also used. Gill and lift nets are intensely operated in deep and medium deep *beels* while traps and scoop nets are the principal gear in shallow, weed choked *beels*.

Management practices

The *beel* resources of the State are under the control of Revenue Department and are leased out to the fisheries cooperative societies on tenurial basis. Lack of funds and technical knowledge are the major constraints in management of *beel* fisheries of the State. However, efforts made by some cooperative societies for weed control and stock improvement by introduction of major carp fingerlings, though inadequate and unscientific, are helping in increasing production from these systems.

Development strategies

The *beel* resource of the State is enormous and diverse in ecological characteristics. For proper management, they need to be classified on the basis of ecological and production characteristics. Some efforts in this direction have been made by the scientists of CIFRI which resulted in development of classification criteria and also development of management technologies for fish yield optimisation from the *beels*. However, there is an urgent need to conserve these water bodies and protect them from environmental degradation due to anthropogenic activities. Reopening or excavation of the river linkages wherever possible is one of the prime needs. Embankment and sluice construction in the peripheries, besides preventing encroachment for agriculture and urbanisation, would restrain unwanted introduction of silt and organics from the catchment areas.

Water management

Water is amongst the essential prerequisites for agriculture, power generation, urbanisation, industrialisation and many other human activities. Since *beel* water is used for multiple purposes, a holistic management strategy needs to be developed to take care of various water needs.

Resource reclamation

The derelict *beels* need to be reclaimed gradually although the task is expensive and time consuming. This effort, besides rejuvenating the ecosystems, will enhance the surface storing capacity and subsequent recharging of the ground water. Further, the humus-rich top soil of marshy areas, if spread on agricultural fields, would enhance soil fertility.

Weed management

When in excess, the macrophtytes are a menace in *beel* ecosystems. Besides contributing to eutrophication, overgrowth of macrophytes competes with planktonic organisms for nutrition and fishes for space and shelters. Methods of weed control are of different types like manual, mechanical, chemical and biological. However, chemical methods of weed control is unsafe for large water bodies. The non-biodegradable elements of weedicides get accumulated in biotic components of the system. Biological methods like stocking herbivorous species, *Ctenopharyngodon idella,* are most effective in controlling submerged (*Hydrilla, Najas, Vallisneria, Ceratophyllum, Myriophyllum)* and floating *(Lemna, Wolfia, Azol, Pistia)* weeds.

Bio-conservation

Fish fauna contributing to the production needs be conserved and reintroduced from external sources for rehabilitation of the lost or endangered species. Research on reproductive biology of the endangered species needs to be emphasized. The species like *Gadusia chapra, Amblypharyngodon mola* are threatened with extinction and need special care for conservation.

Stock management

The nutrient storage and recycling through grazing chain of macrophytes, plankton chain, and the detritus chain need to be effectly used for yield optimisation. Moreover, optimum utilisation of food chains would help maintaining an ecological balance in the system. By and large, the detritus food chain remains under-utilised. This potential source of energy can be best utilised through stocking of detritivores like *C. mrigala, L. calbasu, L. rohita, etc.*

In medium deep *beel* systems, the technique of culture-cum-capture fisheries would be advisable. Deep *beel*s can be managed for conservation of the fish germplasm by adopting measures like declaration of closed fishing season, selective fishing and environmental protection.

Shallow, weed-choked *beel*s are not suitable habitats for multispecies capture and culture practices. Taking advantage of their shallow and evenly sloped contour, these water resources can be utilised for culture-based fisheries of prawn and fishes. This practice, besides utilising the natural nutrients and food resources, would help in generating fund for reclamation of the dwindling *beel* resources of the State.

Summer School on ***Fisheries Enhancement in small Reservoirs and Floodplain Lakes,***
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Role of fish stock assessment techniques in the management of small water bodies

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Primary objective of fish stock assessment

The basic purpose of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources such as fish and shrimp. Living resources are limited but renewable, and fish stock assessment may be described as the search for the exploitation level which in the long run gives the maximum yield in weight from the fishery.

Fig 1 illustrates this basic objective of fish stock assessment . On the horizontal axis is the fishing effort measured, for example, in number of boat days fished. On the other axis is the yield, *i.e.*the landing in weight. (If the landings consist of different groups of animals, for example shrimp and finfish, it may be more appropriate to express the yield in terms of value). It shows that up to a certain level we gain by increasing the fishing effort, but after that level the renewal of the resource (the reproduction and the body growth) cannot keep pace with removal caused by fishery, and a further increase in exploitation level leads to a reduction in yield. The fishing effort level which in the long term gives the highest yield is indicated by F(msy) and the corresponding yield is indicated by MSY, which stands for *Maximum Sustainable Yield*. The phrase *in the long term* is used because one may achieve a high yield in one year by suddenly increasing the effort, but then meagre years will follow, because the resource has been fished down. Normally, we are not aiming at such single years with maximum yield, but a fishing strategy which gives the highest steady yield year after year.

In reservoir fishery, multispecies are exploited by multigears and its assessment becomes difficult. Generally, the fish stock assessment is done for each species separately. The results are subsequently pooled into an assessment of a multispecies fishery. The fish stock assessment includes estimation of population parameters namely growth parameters and mortality parameters. The former gives the body size of a fish when it reaches certain age and the latter reflects the death created by fishing, called fishing mortality, and other causes, called natural mortality.

Models

A description of a fishery consists of three basic elements:

(1) the input (the fishing effort, *e.g.* the number of fishing days)
(2) the output (the fish landed)
(3) the processes which link input and output (the biological processes and the fishing operations)

Fish stock assessment aims at these processes, the link between input and output and the tools used for that are called *models*. A model is a simplified description of the links between input data and output data. It consists of a series of instructions on how to perform calculations and it is constructed on the basis of what we can observe or measure, such as for example fishing effort and landing.

The actual processes which lead from a certain number of days fishing with a certain number of boats to a certain number of fish being landed are extremely complicated. However, the basic principles are usually well understood, so that by processing the input data by aid of models we can predict the output.

INPUT --------------> PROCESSES -------------->OUTPUT
observation model observation

A model is a good one if it can predict the output with a reasonable precision. However, since it is a simplification of reality it will rarely be exact.

General procedure of fish stock assessment

INPUT :	FISHERIES DATA (+ ASSUMPTIONS)
PROCESS:	Analysis of historical data
OUTPUT :	ESTIMATED POPULATION PARAMETERS
INPUT :	ESTIMATION OF POPULATION PARAMETERS
PROCESS:	Prediction of yield for a range of alternative exploitation levels
OUTPUT :	OPTIMUM FISHING LEVEL MAXIMUM SUSTAINABLE YIELD

There are two groups of fish stock models : *holistic models and analytical models*. The simple holistic models use fewer population parameters than the analytical models. They consider a fish stock as a homogeneous biomass and do not take into account, for example , the length or age structure of the stock. The analytical models are based on a more detailed description of the stock and they are more demanding in terms of quality and quantity of the input data. On the other hand, as a compensation, they are also believed to give more reliable predictions.

The type of model to be used depends on the quality and quantity of input data. If data are available for an advanced analytical model, then such model should be used, while the simple models should be reserved for situation when data are limited.

Analytical models

The basic idea behind the analytical models may be expressed as follows:

(1) If there are "too few old fish" the stock is **overfished** and the fishing pressure on the stock should be reduced.

(2) If there are "very many old fish" the stock is **underfished** and more fish should be caught in order to maximise the yield.

The analytical models are **age structured models** working with concepts such as mortality rates and individual body growth rates.

The basic concept in age structured models is that of a *cohort*. To put it simply, a *cohort* of fish is a group of fish all of the same age belonging to the same stock. For example, a cohort of *Catla catla* could be all the fish of that species that hatched from July to August in 1996 in Rihand reservoir in U.P. Suppose there were one million specimens in that cohort. After August 1996 the original one million fish would gradually decrease in number because of deaths to either natural causes or fishing. However, while the number of survivors of the cohort decreases with time, the average individual body length and body weight increase.

Fig 2 shows an (hypothetical) example of the dynamics of a cohort, in the form of plots against age of the number of survivors (A), body length (B), body weight (C) and total biomass. Curve A shows the decay in the number of survivors as a function of the age of cohort. Curve B shows how the average body length increases as the cohort grows older. Curve C shows the corresponding body weight, while curve D is a plot of the total biomass of the cohort, *i.e.* the number of survivors times the average body weight against the age of the cohort.

It may be noted that the curve D has a maximum at age A1. Thus, to get the (hypothetical) maximum yield in weight from that cohort, all fish should be caught exactly when the cohort has reached age A1. This , of course, is not possible in practice. However, we may say that the goal of fish stock assessment is to manage fisheries in such a way that the catches come as close as possible to this theoretical maximum.

The implication is that the fish should neither be caught too young nor too old. If the fish are caught too young there is growth overfishing of the stock.

There are two major elements in describing the dynamics of a cohort;

(1) The average body growth in length and weight
(2) The death process

Holistic models

In situations where data are limited, simple holistic models are used. One such model is surplus production model. The model use catch per unit effort as input. The data usually represent a time series of years and usually stem from sampling the commercial fishery. The models are based on the assumption that the biomass of fish in a water body is proportional to the catch per unit effort as shown in Fig 3. An estimate is derived from the biomass.

Role of stock assessment in management of small reservoirs

The problems faced by the management in small water bodies are:

(1) What should be the fishing pressure for reaping maximum harvest, if it is autostocked.

(2) What should be the stocking number, if the water body is not autostocked or requires stocking.

The above problems may by solved with the help of the models described above. In stock manipulation, the number to be stocked is a function of growth of fish and mortality.

The number of fish at a point of time is dependent on age and mortality. If N_t is the number of fish at time t and N_o is the number at time t=0 *i.e.*, at birth

$N_t = N_o e^{-Zt}$, where Z is the total annual mortality rate.

From the equation it can be derived

$N_2 = N_1 e^{-Z(t_2-t_1)}$, where N_2 is the number at age t_2 (at the time of harvest) and N_1 is the number at age t_1 (at the time of stocking).

The total production may be calculated as $P = N_2 x W_2$, W_2 being the average weight at age t_2.

The total number N_1 at age t_1 which is to be stocked to harvest N_2 number at age t_2 may be put as: $N_1 = (P/W_2) \times e^{Z(t_2-t_1)}$

The primary criteria in stocking management in reservoir is to work out the maximum potentiality of the water body, average weight of the fish to be harvested, the age of fish and total annual mortality rate.

Suggested Readings

Gulland, J.A. 1983. Fish Stock Assessment:A Manual of Basic Methods, Vol - 1 - FAO/WILEY Series on Food and Agriculture - John Wiley & Sons.

Sparre, P., E. Ursin and S. C. Venema, 1989. Introduction to tropical fish stock assessment, Part-1 - Manual -FAO Fisheries Technical Paper 306/1

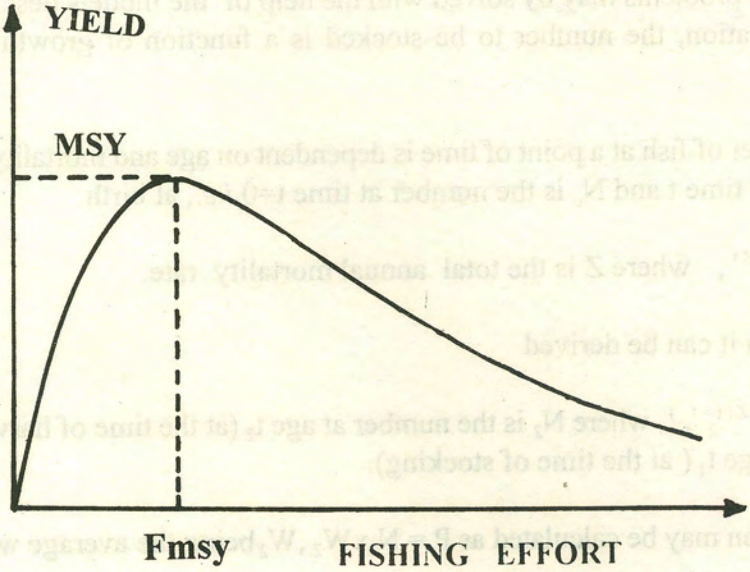

Fig. 1. The basic objective of fish stock assessment.

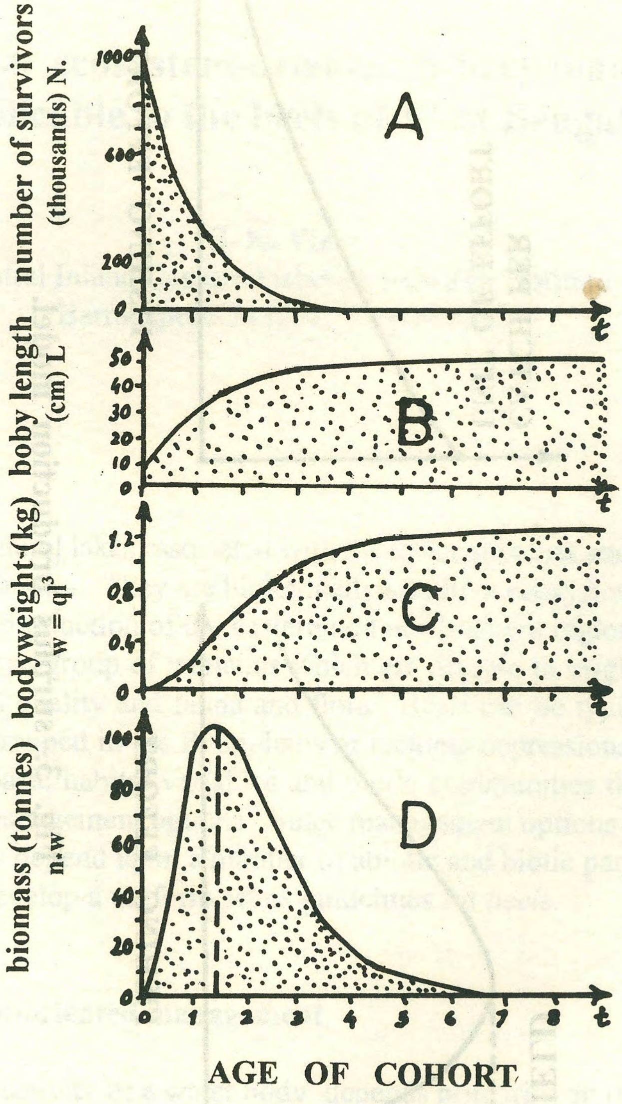

Fig. 2. The dynamics of a cohort

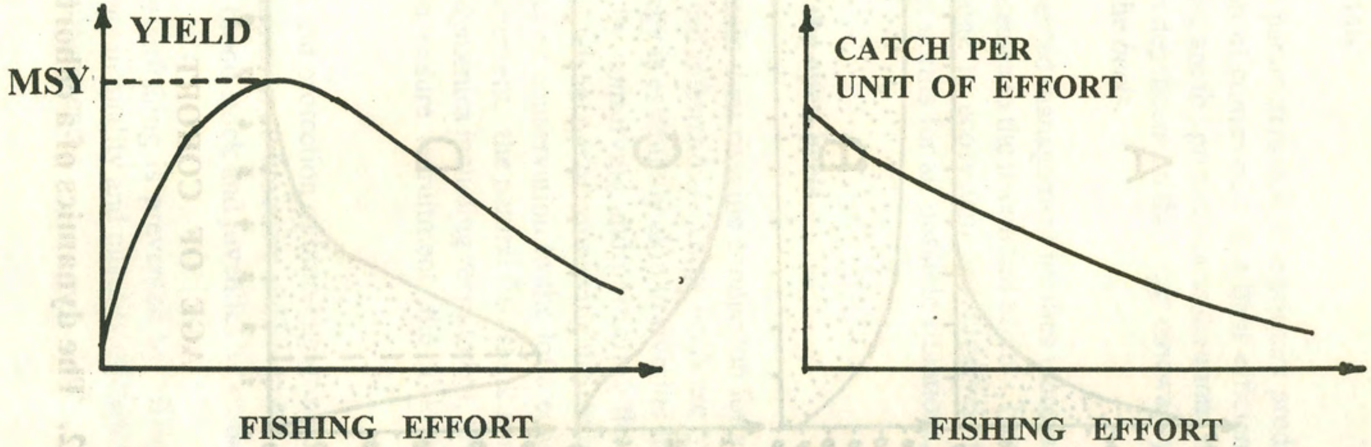

Fig. 3. surplus production model.

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Guidelines for ecosystem-oriented fishery management applicable to the beels of West Bengal

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Introduction

*Beel*s are the natural lakes associated with the lower stretches and coastal plains of the Ganga and Brahmaputra. They are biologically sensitive ecosystems playing a vital role in the inland fish production of the eastern and northeastern regions of the country. *Beel*s are a heterogenous group of wetlands which are diverse in origin, water renewal pattern, water and soil quality and fauna and flora. Beels can be typical oxbow lakes, residual flood waters trapped in the floodplains or tectonic depressions. Irrespective of their origin, it is the basic habitat variables and biotic communities that determine the suitability of various management options. Since management options to be adopted for obtaining higher yields depend upon a number of abiotic and biotic parameters it is well neigh impossible to develop a uniform set of guidelines for *beel*s.

Criteria for ecosystem-oriented management

Biological productivity of a water body depends primarily on the capacity of the system to trap solar energy and store them in the form of chemical energy. The energy conversion efficiency at trophic levels of consumers differs considerably from one water body to another, depending on the qualitative and quantitative variations in the biotic communities. Any conversion rate above 1% can be considered as good. In an ideal situation, the commercial species share the ecological niches in such a way that trophic resources are utilized to the optimum. At the same time, the fishes should belong to short food chain in order to allow maximum efficiency in converting the primary food resources into harvestable materials.

Thus, the basic parameters that abet primary productivity (soil and water quality) and affect composition of community and their efficiency to transfer energy from one trophic level to the other are the primary considerations in selecting management option. These factors are again dependent on the water renewal cycle and the species spectrum of the parent rivers and the *beel*s.

Ecosystem-oriented management implies increasing productivity by utilizing the natural ecosystem processes to the maximum extent. This will be more cost effective and to do minimum damage to ecosystem and biodiversity. Since it is very difficult to prescribe management norms for all possible situations, a few management options are described below:

Capture fisheries of the open beels

Some *beel*s retain their riverine connection for a reasonably long time which are relatively free from weed infestations. These *beel*s are typical continuum of rivers where the management strategy is essentially akin to riverine fisheries. Thus, basic approach is to allow recruitment by conserving and protecting the brooders and juveniles. These measures have the dual advantage of conserving the natural habitat of the *beel*s along with extending the benefits of conservation to the lotic ecosystem of the parent stream. In capture fishery management, the natural fish stock is managed. Therefore, a thorough insight of population dynamics including recruitment, growth and mortality is very much essential. In order to ensure recruitment, the following parameters are taken into consideration.

i) Identification and protection of breeding grounds
ii) Allow free migration of brooders and juveniles from *beel* to river and *vice versa.*
iii) Protection of brood stock and juveniles by conservation measures.

The growth overfishing is prevented by taking appropriate measures for gear selection. Adjustments in quality and quantity of fishing gear is an essential component of capture fishery management.

Common strategies followed are summarised as are :

i) Increase the minimum mesh size.
ii) Increase or decrease the fishing effort.
iii) Observe closed season to protect the brooders.
iv) Strict adherence of the restrictions on the minimum size at capture.
v) Diversity of the gear if required.
vi) Selective augmentation of stock, only if unavoidable.

Culture-based fisheries of the closed *beels*

Management of completely closed *beels* or those with a very brief period of connection with the river is more like small reservoirs. The basic strategy here will be stocking and recapture. *Beels* are the ideal water bodies for practising culture-based fisheries for many reasons. Firstly, they are very rich in nutrients and fish food organisms which enable the stocked fishes to grow faster to support a fishery. Thus, the growth is achieved at a faster rate compared to reservoirs. Secondly, the beels allow higher stocking density by virtue of their better growth performance and the per hectare yield is quite high. Thirdly, there are no irrigation canals and spillways as in the case of small reservoirs which cause the stock loss and the lack of effective river connection prevents entry of unwanted stock. The *beels* also allow stocking of detritivores as the energy transfer takes place through the detritus chain.

In a culture-based fishery, the growth is dependent on stocking density and survival is dependent on size of the stocked fish. The growth varies from one water body to another depending on the water quality and food availability. The right species stocked in right number, in right size and their recapture at right size are the determining factors. These have to be decided as a part of ecosystem-oriented management. The basic management strategies can be summarised as :

i) Size at stocking
ii) Stocking density
iii) Fishing effort
iv) Size at capture
v) Species management
vi) Selection of species
vii) Selection of fishing gear

Culture and capture systems

There are systems which combine the norms of capture and culture fisheries. The marginal areas of beels are cordoned off for culture systems either as ponds or as pens and the central portion is left for capture fisheries (Fig. 1). This has been tried in some *beels* of Manipur with certain degree of success.

Community metabolism

Community metabolism or the transfer of energy from one trophic level to the other can be the major criterion for selecting management options especially the species selection in culture-based fisheries.

In an ecosystem, the biological output or the production of harvestable organisms can be at various trophic levels. Under a grazing chain, a *phytoplankton > zooplankton > minnows > catfishes* system or a *phytoplankton > zooplankton > fish* system prevails. Since no grazing chain of *macrophytes* > fish exists in *beels*, macrophytes are invariably channelled through detritus chain. There are different detritus chains such as *macrophytes > detritus > detritivore* system, *phytoplankton > detritus > benthos > bottom feeders* system and *macrophytes > associated fauna > air breathing* fish system.

Two typical systems generally found in the closed and open *beels* of West Bengal are depicted in Fig 2 and 3. In both the cases, the birds are at the apex of the food chain. In Bandardaha, most of the energy are transferred through *phytoplankton > zooplankton > planktophagous >predatory fish* chain. This is more or less the case with most of the open beels. In sharp contrast, Beloon *beel* has a macrophyte based food chain with dominance of fish feeding on weed associated fauna or detritus. The management norms in both cases should aim at correcting the fish species spectrum with the above food chain in view.

Fishery options

i) Fishery based on Indian major carps

The *beels*, especially the closed ones can be developed as big ponds as their fishery solely depends on stocking with IMC. Although not done in a scientific way the *beels* are being stocked regularly. In the absence of natural recruitment, stocking with economically important species form the best management option.

ii) Fishery based on indigenous fishes

In many of the *beel*s the indigenous fish form a substantial share of the catch which fetch good price also in the local market. It is not necessary to develop all *beel*s as carp-based fisheries. *Amblypharyngodon mola, Puntius sophore, Gadusia chapra,* and a number of air breathing fishes etc. can also sustain economic fishery. Low yield rates can be compensated with the high price those fishes fetch. This practice will prevent the compartmentalization of *beel*s and their conversion into ponds.

iii) Fishery based on pen and cage culture

Many of the *beel*s are not productive and it is not practical to fertilize the whole open water area. Therefore a manageable part of the water body can be cordoned off to stock choice species. Pen and cage culture practices are the perfect management options for the weed-choked and the unproductive *beel*s. This solves the problems created by gear restrictions and catchability.

Conclusion

*Beel*s also can be part of an integrated system including navigation, bird sanctuary, post harvest, aquaculture and open water fisheries. A proposed scheme for Beloon *beel* in Murshidabad district, West Bengal has been shown as an example (Fig .4). This plan is a part of holistic development of the wetland which can benefit the local people and help retaining the biodiversity of the *beel* and its environment. It is proposed that the deep northern part of the lake can be retained in its natural state to conserve aquatic communities and fish populations. This will act as a reservoir for irrigation, and capture fisheries. The periphery of the swampy southern sector of the *beel* could be converted into aquaculture ponds/pens leaving the middle portion of this sector as bird sanctuary.

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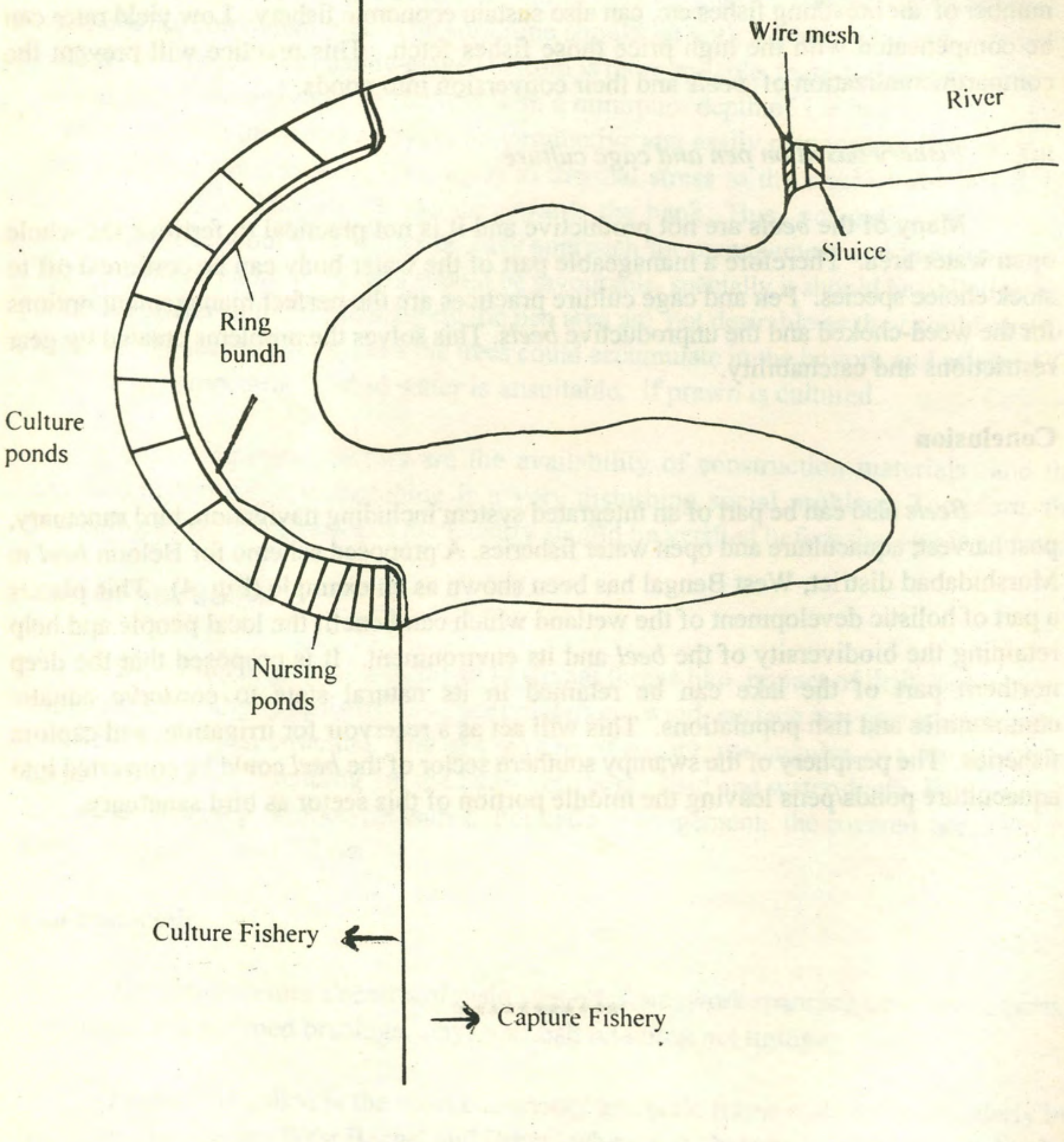


Fig. 1. Diagrammatic representation of culture-cum-capture fisheries

Fig. 2

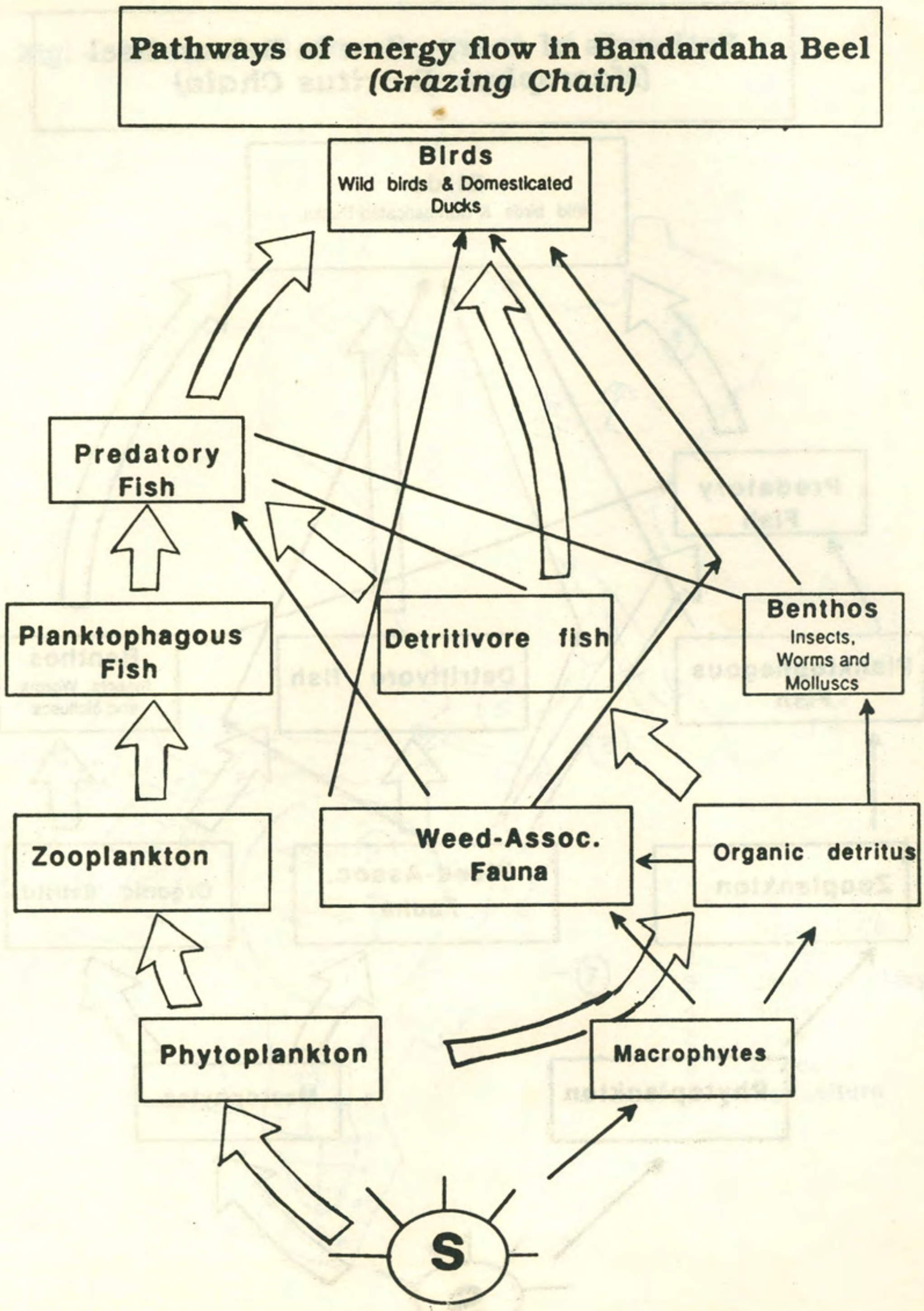

Pathways of energy flow in Bandardaha Beel
(Grazing Chain)
Birds
Wild birds & Domesticated Ducks
Predatory Fish
Planktophagous Fish
Detritivore fish
Benthos
Insects, Worms and Molluscs
Zooplankton
Weed-Assoc. Fauna
Organic detritus
Phytoplankton
Macrophytes
S

Fig. 3

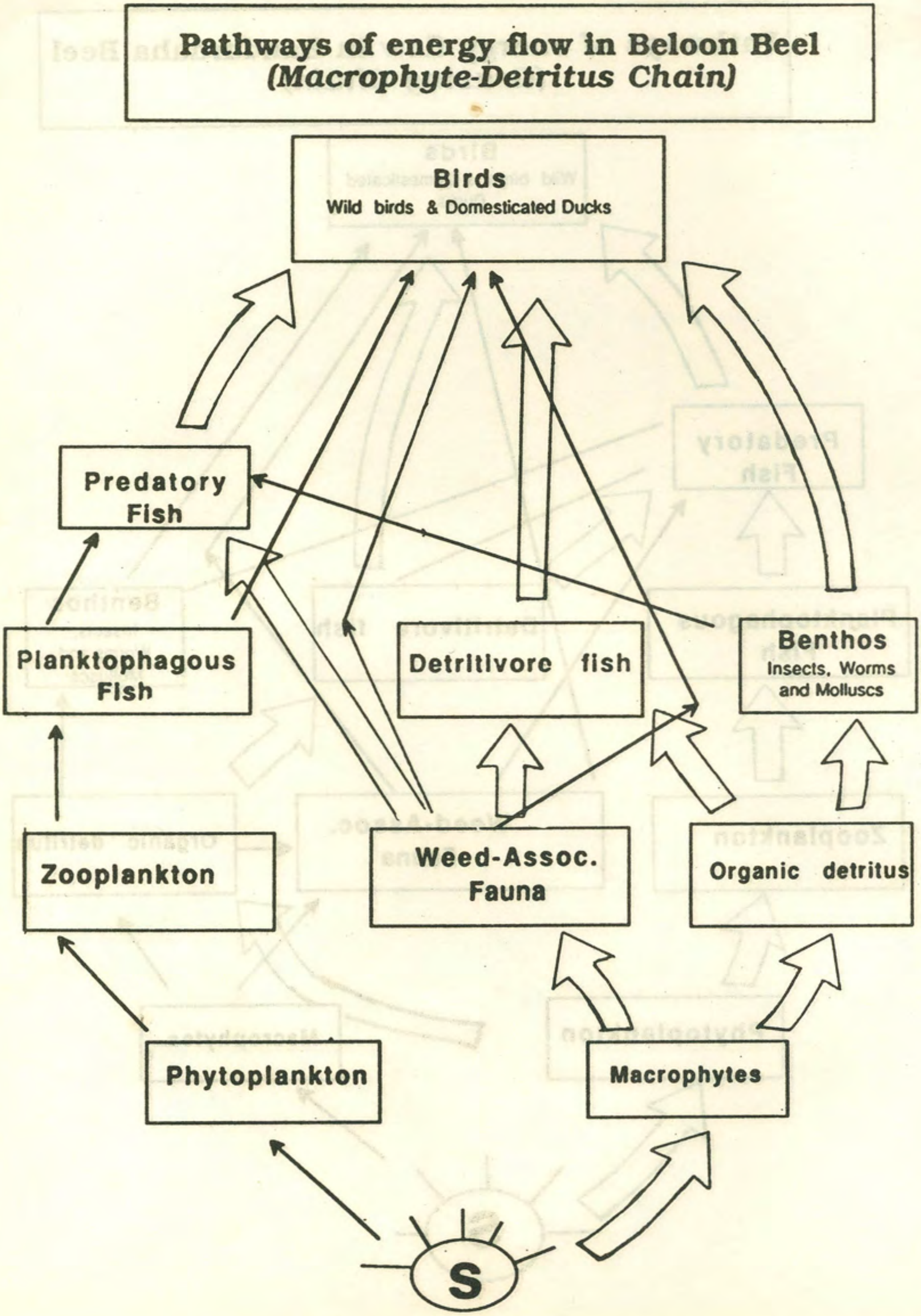
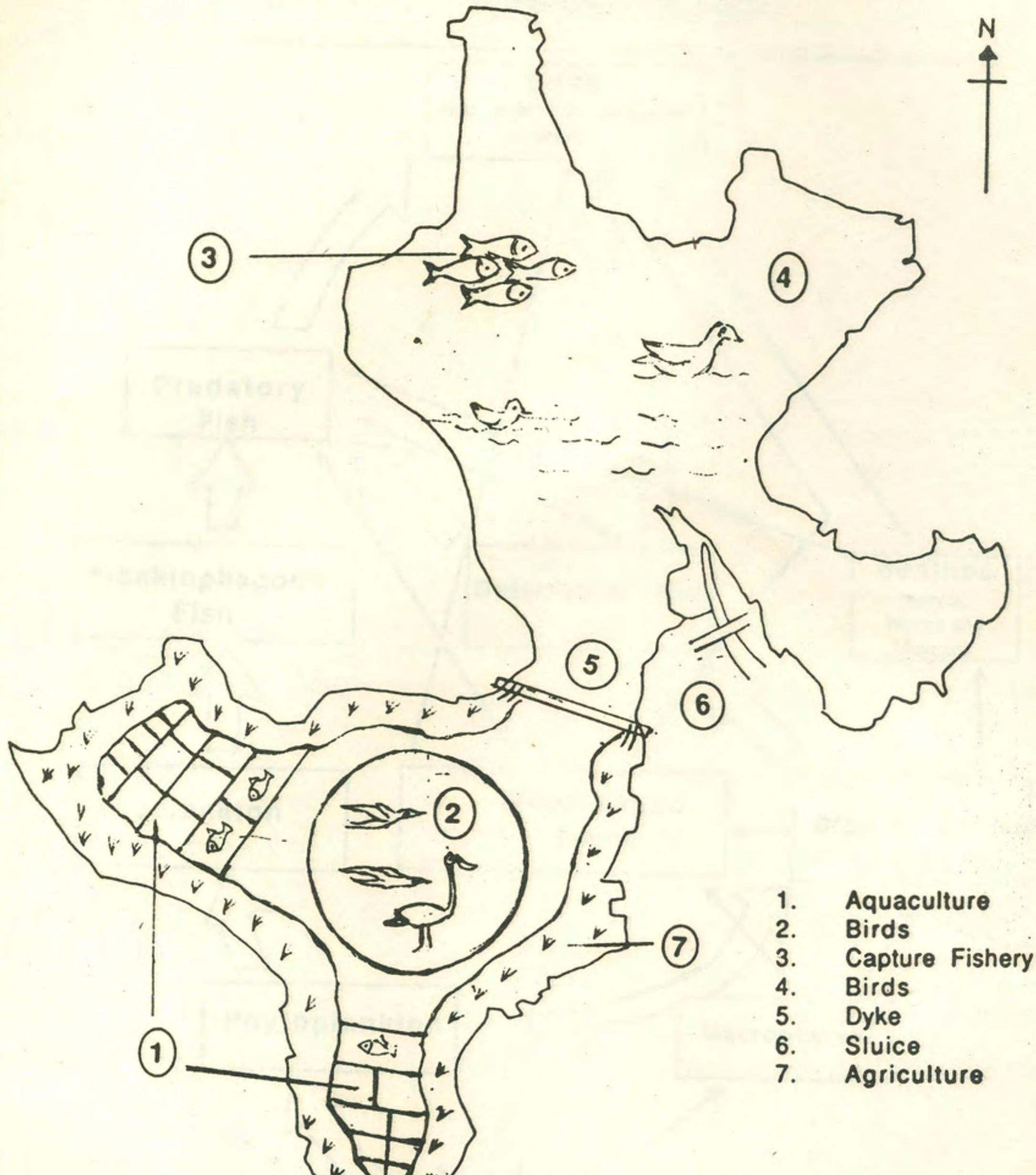

Pathways of energy flow in Beloon Beel
(Macrophyte-Detritus Chain)
Birds
Wild birds & Domesticated Ducks
Predatory Fish
Planktophagous Fish
Detritivore fish
Benthos
Insects, Worms and Molluscs
Zooplankton
Weed-Assoc. Fauna
Organic detritus
Phytoplankton
Macrophytes
S

Fig. 4 Integrated development of Beloon *beel*



*Summer School on **Fisheries Enhancement in small Reservoirs and Floodplain Lakes,***
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Pen culture, an effective tool for yield optimisation in the floodplain lakes of West Bengal and Assam

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Introduction

Throughout the world, floodplains and the wetlands associated with them are a source of living for humans. India has more than 200,000 ha of riverine wetlands locally known as *mauns, chaurs, beels, jheels* and *pats* along the Ganga and Brahmaputra river basins. Extensive flood control measures and irrigation works have reduced the fish production levels of many of these wetlands through siltation, habitat destruction and heavy weed infestation. The present level of yield from floodplain wetlands is very low (100-200 kg/ha/yr) but studies on these ecosystems point to a production potential ranging from 1,000 to 2,000 kg/ha/yr. They also provide ideal habitat for pen and cage culture operations.

As a management measure, especially in the weed choked *beels*, culture of fishes and prawns in pen enclosures has drawn much attention in the recent past. Pen culture offers scope for utilizing all available water resources, optimal utilization of fish food organisms for growth and complete harvest of the stock. Pen structures may be of varying shapes and sizes. Since these artificial enclosures are to be kept undisturbed during the culture period, their protection against external forces must be taken care at the time of installation. The following aspects are to be taken into consideration before pen construction:

Site selection

In any culture experiment, site selection is an important aspect. Ideal environment is an essential prerequisite for pen culture which decide the economic viability and success of the venture to a large extent. Before constructing a pen, a detailed engineering survey should be undertaken with special emphasis on the kind of terrain and the nature of surrounding catchment area. The shoreline should be with a gentle gradient. For prawn culture, sandy-loamy or sandy-clayey bottom is more suitable than clayey soils. The site for pen installation should be shallow with a minimum depth of 1.0 to 2.0 m. Low depth helps in keeping the pen area hygienic, productive and easily manageable. However, too low a depth, say less than 1 m, leads to thermal stress to the stocked animals during summer months. The site should be towards the bank. This not only cuts down the construction cost but also allows an easy approach for management and harvesting. The water stead and shore characters should be favourable, specially it should be pollution free. A large number of trees overhanging the pen area are not desirable as they could obstruct light and the leaves falling from the trees could accumulate in the bottom and release CO_2 through decomposing. Turbid water is unsuitable, if prawn is cultured.

Other important factors are the availability of construction materials and the accessibility to the site. Poaching is a very disturbing social problem. Therefore, the prevailing social atmosphere of the locality should be verified before the site is selected.

Pen size and design

Direct loadings (self weight) and external forces like impact of drift logs, aquatic vegetation, fouling organisms, mud accumulation, wind, surface waves, turbulence *etc.* can destroy the pen structure. The pen may be of square, rectangular, oval or elongated horseshoe shaped depending on the nature of shore, land and water depth. Pen height > 2 m needs special protection measures. For better management, the covered area should vary between 0.1 and 0.2 ha.

Pen materials

The pen structure consists of main support, framework spanning over the supports, horizontal and inclined bracings, stays and fish retaining net linings.

Frame: Bamboo is the most commonly available frame material particularly in the states like Assam, West Bengal and Bihar, where it is cheaper. Bamboo is found to be most suitable for *beels, mauns* or shallow impoundments. The bamboo for making frame should be of 6" to 8" in diameter and 30' or more in length. Depending on availability, logs can be used as a replacement of bamboo poles. Galvanised iron pipe frame also can be used with iron net, for durability and rigidity of the structure. However, the cost effectiveness of these materials is to be worked out before selecting them for pen construction.

Screen: Pen screens may be of varying sizes according to the requirements. Split bamboo or canes with smooth surface with sufficient length are preferred as screen materials. Iron mesh also can be used, though very costly. Considering their durability, synthetic nets are the most suitable pen materials if the chances of damage by various biotic agents and logs could be controlled. They are very popular in countries like the Philippines, Thailand, Indonesia, *etc.* Coir ropes or synthetic threads are the best weaving materials. The mesh size of the screen is decided on the basis of initial size of the stocking materials.

Net lining: Provision of lining the frame with net is necessary to protect unwanted entry and exist of organisms. Nylon nets are used for this purpose. The nets should be cleaned periodically for facilitating water exchange and aeration inside the pen area.

Pen preparation

Most of the wetlands are thickly infested with macrovegetation and unwanted fauna. The pen area must be cleaned before stocking.

Deweeding: Besides consuming the nutrients from the water body, excessive growth of aquatic vegetation poses serious problems like upsetting the oxygen balance, creating obstruction for light penetration, movement of stocked animals and in netting operations. The aquatic weed control could be done in four different ways, *viz.* (a) manual, (b) mechanical, c) chemical and (d) biological. Among these, manual method is recommended in pens as it is cheap, easy and efficient.

Eradication of unwanted fauna: Complete eradication of unwanted organisms from the pen before stocking is very important. While weed fishes compete with the cultured species for food, space and oxygen, predators prey upon the stocked young ones. Repeated netting is the best method for eradication of fishes from the pens. This also helps in removing other unwanted biotic communities like molluscs, insects *etc.* which could interfere with the management processes affecting production. Poisoning the pen area to eradicate the unwanted biotic communities is not advisable in pen culture.

Liming: Liming the water hastens mineralisation of organic matter and helps in maintaining the environment hygienic. Use of quick lime @ 400-500 kg/ha pen area is recommended with initial dose @ 200-300 kg/ha followed by monthly instalments @ 50-75 kg/ha.

Pen management

Water: The success of pen culture is largely dependent on the productivity and ecological suitability of water. The average depth of water in the pen is to be maintained for better production. This depends generally on various factors like rainfall and water abstraction for irrigation. Generally, pen culture period excludes the monsoon season to avoid the problems of flood. Extreme summer is equally bad for pen culture as the water level recedes drastically because of high rate of evaporation and water lifting for irrigation purposes. During summer, the temperature inside the pen shoots up and the resultant thermal stress is detrimental to the stocked fish/prawn. A water temperature range of 30 to 36 °C is ideal for faster growth of the cultured animals. Other desirable parameters are dissolved oxygen (4-8 mg/l), CO_2 (1-2 mg/l), alkalinity (50-150 mg/l), pH (7.0-8.0) and moderate nutrient contents (N-2.0 mg/l and P - 1.5 mg/l).

Soil: The bed soil should be sandy-clayey. The detritus load between 50 and 70 g/m^2 and organic matter between 1-2% are ideal for better production. Very high organic content of bed soil results in anaerobic condition at the bottom which is detrimental to the bottom dwellers, especially prawns.

Species selection: Species belonging to the groups planktophagous, detritivores and bottom feeders are the most suitable for pen farming. However, phytophagous species can also be introduced to keep weeds under control. In pen culture, the combination of indigenous and exotic carps with giant freshwater prawn has proved to be successful. However, from economic point of view, monoculture of giant freshwater prawn is more profitable. The suitable species for mixed culture of carps are catla, silver carp, rohu and mrigal. Under mixed culture of carps and prawn, catla, silver carp, rohu and *M. rosenbergii* can be considered. In monoculture, the prawns grow faster with a higher survival rate, compared to their culture along with carps.

Species ratio: Species ratio is fixed on the basis of available food in the environment, depth of the water body, seed availability, *etc.* In exclusive carp culture, the suggested ratio of fish species is given below:

Surface feeder	-	*(Catla catla,* 20%)	-	35%
		(Silver carp, 15%)		
Column feeder	-	(*Labeo rohita*)	-	20%
Bottom feeder	-	(*Cirrhinus mrigala*)	-	45%

The bottom slot of *C. Mrigala* can be replaced with prawn in the mixed culture.

Stocking size and rate: It is generally advisable to stock larger fingerlings (100-150 mm) for better survival in carp culture. Stocking size of prawn juveniles is much smaller between 65-70 mm.

Rate of stocking is fixed on the basis of the carrying capacity of the pen. In monoculture of carps, the recommended density ranges from 4,000 to 5,000 /ha. While in mixed culture, the density of carp and prawn could be 3,000-4,000/ha and 1,000-2,000/ha respectively, in monoculture of prawn stocking density could go as high as 30,000-40,000/ha.

Culture frequency: Pen farming could be done round the year, but it is advisable to avoid monsoon months. The culture period for prawns is about 4-6 months. Thus, two crops could be raised per year per pen.

Supplementary feeding : Since the objective of pen farming is to utilize natural productivity of the water body, role of supplementary feeding is marginal except for the prawn which needs highly proteinous diet for their growth. The prawn is fed once @ 2-5% of their body weight during evening hours depending on the availability of natural food. The supplementary feeding may be done with commercially available pelletised feed or locally made mixture of animal protein with carbohydrate and fat. Cockle flesh and fish meal are well known sources of animal protein. Feeding in trays saves loss of feed and thereby reduces the cost of production.

Precautions

Although pen culture paves the way for augmenting production and provides economic benefits, many potential social and environmental problems can crop up. Rapid growth of pen culture, impervious to environmental concerns can lead to disastrous consequences as happened in the Laguna de Bay in the Philippines. Rapid and haphazard development of fish pens, converted the Laguna lake from a lucrative fishery into a battery of pens reducing the open water fishing area. This also caused unemployment for traditional fishers. Supplementary feeding of the stocked fish in the pen can lead to eutrophication of the lake very fast. Therefore, pen farming, though considered as very lucrative, should be practised in a balanced way as part of an overall management plan for small water bodies.

Planning criteria

Before lanching any large-scale pen culture drive, it is necessary to conduct a survey of the resources with a view to selecting suitable sites after taking all environmental, social and economic aspects into consideration. It is also necessary to estimate the carrying capacity of each water body selected, so that its maximum pen area can be determined. This is essential to avoid Laguna de Bay type debacles. Moreover, the socio-economic impact of such measures needs to be determined. Conversion of open water fisheries into pen enclosures can change the pattern of employment generation, distribution of income and an array of other socio-economic parameters which need a careful consideration. If the present crisis in coastal aquaculture is any guide, the environmental and socio-economic impact assessment is an essential pre-requisite for adopting pen culture in large scale.

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Fisheries of small reseroirs in India - General guidelines for management

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Introduction

The small irrigation rservoirs, constructed on small intermittent water courses, serve to capture the surface runoff for its abstraction during seasonal irrigation demands. Built for the primary purposes of irrigation and soil and water conservation, many of them have multiple uses. Experience has revealed that these water bodies offer immense scope for various kinds of enhancements leading to higher productivity and income generation for the local communities. They can undoubtedly contribute significantly to country's inland fish production, if managed scientifically. Small reservoirs of the country which spread over nearly 1.5 million ha form one of the most important inland fisheries resources of the country on account of the large resource size and the huge untapped production potential. They have the advantage of enabling quick hike in production due to their small size and easy maneuverabilitty of fish stocks. The available technologies offer possibilities for achieving production levels of 100 to 200 kg/ha although the national yield is about 50 kg/ha. By virtue of their unmistakable role in promoting fisheries development through mass participation of local communities, the small reservoirs, therefore, assume special significance. For definitions and classification, please refer to Sugunan (1997).

Ecology and production processes

Unlike the natural impoundments which are formed when water is retained in deperessions, reservoirs are built by constructing dams across streams of rivers. Embankments of most reservoirs are earthen. Water sources are surface runoff, diversions from streams of rivers, or wells. While natural impoundments typically have no means of controlling inflow or outflow, man-made impoundments generally have a spillway or drain and may have structures for regulating flow such as diversion ditches and standpipes.

Determinants of productivity

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

Abiotic habitat variables

Abiotic factors are independent variables over which the fishery manager has little control. They relate to the geographical location and micro-climate of the impoundment. Included are temperature as a function of elevation and latitude, precipitation and water and soil chemistry. Biological productivity of a biotope is influenced by climatic, edaphic and morphometric features. The geographic location affects the metabolism of a reservoir through temperature regime, nutrition supply, shape of basin and the efficiency with which the climatic factors are able to act in the dynamic exchange. They all have varying effects on final productivity.

Area, mean depth and regularity of shoreline are the most significant morphometric measurements having a significant bearing on the productivity of a reservoir. The extent of drainage area, its rate of erosion and runoff are important in limiting the supply of nutrients to the lake.

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

The chemical properties of water in reservoirs are a reflection of the properties of bottom soil of the lake bottom or the catchment. When oxygen supply falls short in mud layers which are not well aerated, the decomposition of organic matter becomes slow. This low accumulation of products of decomposition and the presence of partially oxidized compounds and short chain fatty acids make the soil strongly acidic. The bacterial action is reduced and productivity lowered. pH also influences transformation of soluble phosphates and controls the absorption and release of essential nutrients at soil water interface. A slightly alkaline soil (pH 7.5) has been considered optimal for fish production. Productive soils range mostly between slightly alkaline to slightly acidic (7.5-6.5) in reaction. Range of physico-chemical parameters and their significance in productivity are shown in Table 1.

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

Biotic communities

Biotic factors are frequently dependent variables which can be manged for fishery improvement. To enhance fish yield, it is important to understand how these factors affect aquatic production. Basic productivity of the reservoir is dependent on the amount of solar energy available and the efficiency of the system to transform it into chemical energy. Besides, the energy conversion efficiency at trophic levels of consumers differs considerably from one reservoir to another, depending on the qualitative and quantitative variations in the biotic communities. Any conversion rate above 1% can be considered as good. In an ideal situation, the commercial species share the ecological niches in such a way that trophic resources are utilised to the optimum. At the same time, the fishes should belong to short food chain in order to allow maximum efficiency in converting the primary food resources into harvestable materials. But in reservoirs, such conditions seldom prevail. Biotic factors include fertility of the environment; diversity of fish populations in terms of structure and function; foraging efficiency of predators in predator/prey systems; modifications of aquatic habitat; and population manipulation through planned fishing mortality.

Table 1. Physico-chemical features of Indian reservoirs (range of values)

Parameters	Overall range	Productivity rating		
		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	upto O.2	0.2-0.5
Phosphates (mg/l)	Tr.-0.36	Negligible	Upto 0.1	0.1-0.2
Specific conductivity (µmhos/cm)	76-474		upto 200	>200
Temperature (°C)	12.0-31.0	up to 18	18-22	>22
		(with minimal/	stratifiction :	*i.e.*, >5°C)
B. SOIL				
pH	6.0-8.8	<6.5	6.5-7.5	>7.5
Availaple P (mg/100 g)	0.47-6.2	<3.0	3.0-6.0	>6.0
Availaple N (mg/100 g)	13.0-65.0	<25.0	25-60	>60.0
Organic carbon (%)	0.6-3.2	<0.5	0.5-1.5	1.5-2.5

(After Jhingran and Sugunan, 1990)

Aquatic weeds, found in shallow water bodies, also compete with beneficial plankton for nutrients, interfere with harvest and can contribute to oxygen depletions. To avoid excessive weed growth, banks of the water body should slope rapidly (2 : 1 or 3 : 1 ratio) to a depth of 75 cm or more.

Management systems

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

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

After a scrutiny of the various management practices followed in the country, it is difficult to miss a common underlying spirit of the common property norm. Majority of Indian reservoirs are public properties wherefrom a fixed number of licensed fishers make their living. The exceptions are the small reservoirs in some states like Karnataka and Uttar Pradesh, which are auctioned to private individuals on an annual basis. Technological support in the form of management practices either received low priority or it has been overlooked altogether as far as small reservoir fisheries in India are concerned. This resulted in arbitrary stocking and non-adherance to sound stock management norms leading to low productivity.

Assessment of yield potential

Several methods are in vogue to assess the fishery potential of small reservoirs by deriving equations based on area, depth, catchment area and the chemical parameters of soil and water. Later, morpho-edaphic index (MEI) has evolved in an attempt to combine the morphometric as well as chemical parameters. Relationships between MEI and catch are assumed characteristic for sets of lakes that possess a certain number of limnological conditions. A morpho-edaphic index as :

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

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

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

Asian reservoirs are known to have a lower yield potential. However, till an Indian formula is derived, this formula can be applied to obtain a rough indication of the productivity of any reservoir within the limits between one half and twice the estimate.

Enchancement

Majority of the small reservoirs and other community water bodies in India are essentially amenable to culture-based fisheries and there is a general consensus that any significant improvement in yield from them can be achieved only through some sort of enhancement activities. The common modes of enhancement which are relevant to inland water bodies in India are *management enhancement, stock enhancement, species enhancement* and *environmental enhancement* (more details in Sugunan, 1997).

Stock enhancement

Stocking of reservoirs with fingerlings of economically important fast-growing species to colonize all the diverse niches of the biotope is one of the necessary pre-requisites in reservoir fishery management. Ever since the reservoirs were considered as a fishery resource, it had become apparent that the original fish stock of the parent river was insufficient to support a fishery. Augmentation of the stock was also necessary to prevent the unwanted fish to utilize the available food niches and flourish at the cost of economically important species. The policies and guidelines on the subject are often erratic and even arbitrary. A proper stocking strategy needs evaluation of an array of factors viz., the biogenic capacity of the environment, the growth rate of the desired species and the population density as regulated by predatory and competitive pressures.

Despite a remarkable increase in carp seed production in India, the open water bodies of the country remain understocked, as all the seed produced in the private sector goes to the privately managed aquaculture industry. The Government hatcheries that have the responsibility to stock the public reservoirs could never produce fingerlings in the required number.

Selection of species for stocking

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

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

2. It should be quick growing and efficient in food conversion.

3. Herbivorous fishes with shorter food chain are more productive and hence energy-effective.

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

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

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

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

Stocking rate

A large country like India with too many water bodies to be stocked, has inadequate state machineries to meet all the stocking requirements. This has resulted in the understocking of reservoirs. Since the seed of some species, which are difficult to breed, are always in short supply, there is a common tendency to stock the ones that are readily available. It is a common practice to stock common carp in large numbers just to meet the stocking target.

The number of fish to be stocked per unit area has to be based on the natural productivity of the system, growth rate of fishes, natural mortality rate, size at stocking, growing time and escapement through the irrigation canal and spillway. The size of the reservoir, presence of natural fish populations, predation pressure, fishing effort, minimum marketable size, amenability to manuring and multiplicity of water use are the other factors to be considered. A formula to calculate the stocking rate (Welcolmme, 1976) is given below :

$$S = [\frac{q \cdot P}{W}] e^{-z(tc-t0)}$$

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

P can be estimated through MEI method and the range of mortality rates can be found out from the estimated survival rate. Table 2 illustrates the examples of calculating stocking rates based on the formula given above.

Table 2. Calculated stocking density at different level of mortality

Annual percent survival	-z	Estimated number of fish to be stocked (no./ha)
50	0.7	405
37	1.0	739
22	1.5	2,000
13	2.0	5,500

(After Welcomme, 1976)

The model assumes insignificant breeding by stocked population and therefore applies mainly to total cropping situations i.e., those in which fish are caught below their minimum size for maturity, those whose natural reproduction does not take place and those where water body is not permanent. It shows that numbers needed for stocking which depend on the natural conditions of productivity, growth and mortality are very sensitive to Z. Due to the very large numbers of fry needed, this practice may be of questionable value in large reservoirs.

Impact of stocking in small reservoirs

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

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

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

3. Proper stocking and harvesting schedule including staggerred stocking and harvesting, allowing maximum growout period, taking into account the critical water levels.

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

Aliyar reservoir in Tamil Nadu is a standing testimony to the efficacy of the management based on stocking larger fingerlings, staggered stocking and harvesting, and a higher size at harvesting. The result of the above management practice was an increase in fish production from 1.67 kg/ha in 1964-65 to 194 kg/ha in 1990. Success stories of stocking have also been reported from a number of small reservoirs in India, like Markonahalli in Karnataka, Meenkara and Chulliar in Kerala, Bachhra, Baghla, and Gulariya in Uttar Pradesh, and Bundh Beratha in Rajasthan.

Species enhancement

Decline of indigenous fish stocks due to habitat loss, especially that cuased by dam construction is a universal phenomenon. Planting of economically important, fast-growing fish from outside with a view to colonizing all the diverse niches of the biotope for harvesting maximum sustainable crop from them is *species enhancement*. It can be just stocking of a new species or *introductions*. Introduction means one time or repeated stocking of a species with the objective of establishing its naturalised populations. Introduction has more relevance to larger water bodies where stocking and recapture on a sustainable basis is not feasible.

Environmental enhancement

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

Fertilization of reservoirs as a means to increase water productivity through abetting plankton growth has not received much attention in India. Multiple use of the water body and the resultant conflict of interests among the various water users are the main factors that prevent the use of this management option. Surprisingly, fertilization has not been resorted to even in reservoirs which are not used for drinking water and other purposes.

Documentation on fertilization of reservoirs in India is scarce. Sreenivasan and Pillai (1979) attempted to improve the plankton productivity of Vidur reservoir by the application of super phosphate with highly encouraging results. As soon as the canal sluice was closed, 500 kg super phosphate with P_2O_5 content of 16 to 20% was applied in the reservoir when the waterspread was 50 ha with a mean depth of 1.67 m. As an immediate result of fertilization, phosphate content of water increased from nil to 1.8 mg/l and that of soil from 0.242 to 0.328%. Similar improvements in organic carbon and Kjeldahl nitrogen have been reported from soil and water phases on account of fertilization. Experiments were also conducted with urea in the same reservoir.

Fertilization can play a key role in many small reservoirs of India, which require correction of oligotrophic tendencies. A number of reservoirs in Madhya Pradesh, the Northeast and the Western Ghats, receiving drainage from poor catchments show low productivity, necessitating artificial fertilization. Chinese experience in fertilizing the small reservoirs for increasing productivity has been reassuring (Yang *et al.*, 1990).

Fertilizers are less effective in soft water with total alkalinity less than 20 mg/l. Soft waters have inadequate carbon (usually in the form of carbon dioxide and bicarbonate) for good phytoplankton production. Fertilizer response, hence productivity, can often be enhanced by applying lime to low alkalinity impounded waters. The application of lime equivalent to 2,000 to 6,000 kg/ha calcium carbonate is generally sufficient to maintain total alkalinity above 20 mg/l. Application of lime was tried in some upland natural lakes for amelioration of excessive CO_2 and acidity at the bottom (Sreenivasan, 1971).

Modelling approach in culture-based fisheries

In the culture-based fisheries of small reservoirs, fish yield is dependent on a number of parameters, such as stocking rate, growth rate, natural mortality and fishing mortality. Recent studies based on modelling approach have opened up new avenues for the culture-based fisheries of small reservoirs. Notwithstanding the fact that studies on the population dynamics based on modelling approach demand higher levels of inputs in the form of money and trained manpower, an insight into the modelling approach will help the manager in understanding the ecosystem approach.

Many of the small water bodies seem to be overstocked. In a culture-based fishery, an undue increase in stocking density can lead to severe loss of production. It is well known that at higher stocking densities, the fish grow at a slower rate with attendant higher rate of natural mortality. A moderate overstocking results in suboptimal production due to this slow growth and high mortality, but fishery can still operate. On further increase in stocking density, the asymptotic length of the population falls below the gear selection length (if the mesh is selective) and the fishery fails to remove biomass from the population. If stocking continues, the water body is literally choked with stunted populations without any production.

Available models have clearly confirmed thhat the production is a function of fishing mortality and stocking density. If some standard variables on population parameters, such as the density-dependent growth, size dependent mortality and weight-length relationship are known, the optimum stocking density and the fishing mortality can be arrived at. The optimum stocking density in a hypothetical situation with a gear selection length of 30 cm and mean seed size of 5 cm is given in Fig. 1. In the current example, reflecting the density-dependent reduction in indivudual growth and the consequent increase in natural mortality, the maximum biomass harvested is estimated at 67.6 kg/ha at a stocking density of 560/ha/yr. Since the maximum yield is attained at a stocking rate of 560 ha, any increase in this parameter will amount to overstocking and loss of production. Similarly, any increase in fishing effort above certain limits will be counter productive.

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

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

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

General considerations

Reservoirs constitute the prime inland fishery resource of India which has a pivotal role to play in the coming years in increasing the inland fish production of the country. A substantial part of the estimated requirement of 6 million tonnes of inland fish during the year 2000 should come from the culture-based fisheries and enhancement. This assessment is based on the environmental and socio-economic constraints associated with the aquaculture sub-sector. There is no room for unlimited growth of intensive aquaculture, which in any case is a capital-intensive activity, where the profit is conduited to a few investors. On the contrary, reservoir fisheries development is a labour-intensive and labour-productive activity, where the benefit of improved productivity is shared by more people, particularly the local communities, thus ensuring a better distribution of income. Moreover, since the local communities are involved in development and directly benefitted, there is lesser scope for social disruptions. At a modest rate of 100 kg/ha, small reservoirs in India can produce 75,000 t of fish per year which is 37,500 t more than the present production. Raising this much of fish through intensive aquaculture would entail enormous investment in terms of capital and infrastructure, apart from arousing many environmental and socio-economic problems. Conversely, increasing fish production through culture-based fisheries and enhancement in small reservoirs is economically viable, ecologically sensible, socially justifiable.

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DOs	DON'Ts
Estimate the yield potential for determining the stocking density and fishing effort	Do not stock without a plan.
In the absence of other criteria, use the recommended formula for determining stocking density, system of staggerred stocking and harvesting will lead to better yield	Do not overstock the reservoir. It will lead to stunted population and drastic fall in yield.
Carefully study the possible stock loss through inlet and outlet channels and account while estimating thhe stocking density. Explore possibilities for providing wire mesh guards to inlet and outlet channels in order to prevent escape of fish.	Do not try to provide the wire mesh structures without consulting the dam authorities. It may cause undue. increase in water pressure leading to collapse of hydraulic structures.
Fix the minimum size at capture and restrict the use of mesh size accordingly. Remember that theoretically, stocking at the smaller size fish in large numbers and catching them at the smallest marketable (acceptable) size will give more yield, compared to larger size. However, survival is size dependendent and growth is density dependent.	Do not catch the fish at too small or too large size. Do not grow the fish to higher size than marketable/acceptable size.
Fix a higher size of stocking at high where the predaor population is very high. Work out an optimum fishing effort and limit the number of fish units.	Do not stock higher sized fingerlings if there is no predator pressure.
Explore possibilities of stocking locally available indigenous species.	Do not stock exotic fish species without clearance from authorities.
Select fish species for stocking carefully taking into consideration the available fish food resources and the catchability.	Do not stock/overstock fish species only because they are available.
Explore the possibilities of integrating fisheries with animal husbandry practices to make the fisheries more profitable.	Do not practice animal husbandry in reservoirs used for drinking water purposes.
Participatory management often works better than punitive and deterrant measures to motivate the community to follow mesh size and fishing effort regulations. Therefore, involve the community in management.	Do not fertilise the reservoirs with organic and inorganic fertilizers, unless it is very essential and does not conflict with other water uses.

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Fish diseases and their control in inland open water

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Introduction

Floodplain lakes and small reservoirs in the country are increasingly used for enhancing fish production during the last few years. New methods of fish culture *viz.*, cage culture or pen culture are also being widely used to increase fish yield with the use of fertilizers, both inorganic and organic, on a limited scale. All these practices influence the environmental and parasitological factors in these culture areas and consequently various fish disease epizootics are encountered.

Fish diseases encountered in lakes

The common fish diseases recorded in the lakes where enhancement practices like stocking and fertilization are undertaken are discussed below:

1. Ulcerative dropsy

Fish species affected: *Catla catla, Labeo rohita* and *Cirrhina mrigala*

Symptoms: There is accumulation of water in the body cavity and scale pockets along with subcutaneous haemorrhages.

Causative agents: Pathogenic bacteria *viz. Aeromonas hydrophila* and *Pseudomonas* sp. A myxozoan parasite, *Neothelohanellus catlae* is also found infecting the kidney of affected *C. catla.* Affected fishes are normally found stressed due to certain environmental factors associated with the disease such as, low dissolved oxygen and large number of aquatic vegetation.

Treatment:

a) Lime (CaO) application @ 50-100 kg/ha
b) Bleaching powder application @ 1 mg/l after one weeek.

2. Columnaris disease

Fish species affected: *C. catla, L. rohita* and *C. mrigala*

Symptoms: Initial stages exhibit greyish patches over the head and dorsal sides of the body.

Causative agent: Pathogenic bacteria, *Flexibacter columnaris.* The disease is often associated with high organic load and increased temperature.

Treatment: Same as for ulcerative dropsy disease

3. Trichodiniasis

Fish species affected: *C. catla, L. rohita* and *C. mrigala*

Symptoms: Fishes with heavy infestations have pale coloured gills with creamish coating. Surfacing of fish occurs.

Causative agent:- Urceolariid ciliates *viz., Trichodina nigra, T. reticulata, Tripartiella bulbosa, T. copiosa* and *T. obtusa.*

Treatment:- No viable treatment methods for open waters.

4. White gill spot

Fish species affected: *C. catla* and *C. mrigala*

Symptoms: The gills of affected fishes are covered with whitish spots of different size. Excessive mucus secretion occurs and fishes surface for gulping air.

Causative agent: Myxozoan *viz. Thelohanellus catlae* and *Myxobolus bengalensis.*

Treatment: No feasible method of treatment for open water bodies.

5. Dactylogyrosis

Fish species affected: *C. catla, L. rohita* and *C. mrigala*

Symptoms: Excessive secretion of mucus occurs in the infected gills which are affected, often with localized haemorrhage.

Causative agent : Monogenetic trematodes of the genus *Dactylogyrus* sp.

Treatment: Application of lime @ 100 kg/ha

6. Argulosis

Fish species affected: *L. rohita, C. mrigala* and *C.catla*

Symptoms: Infestation is accompanied by excessive mucus secretion, irritability, erratic swimming behaviour and retarded growth. Heavy infestation often leads to circular depression with haemorrhage and ulceration.

Causative agent: Branchiuran species of the genus, *Argulus*

Treatment:

i) Gammaxene treatment @ 1 ppm

ii) The eggs of *Argulus* can be mechanically removed after collecting them on the hanging bamboo mats in water.

7. Epizootic ulcerative syndrome

Fish species affected: *Channa sp., Mastacembelus sp., Puntius sp., Nandus sp., C. catla, L. rohita C. mrigala, C. carpio* and *G. chapra.*

Symptoms: The fishes become lethargic and float on the surface of the water, sometimes with the head projected out of water. Initially, the disease appears as red coloured lesions, haemorrhagic in nature. These red lesions spread and enlarge gradually becoming deeper and assuming the form of ulcers. With further advancement, scales fall off, ulcers become deep necrotizing ulcerative lesions. Histopathologically, it is characterized in having mycotic granuloma in epidermis.

Causative agents: Role of suspected causative agents namely, virus, bacteria and fungus could not be established conclusively. In India, so far 20 species of pathogenic bacteria have been isolated from affected fishes of which *A. hydrophila* has been consistently found along with fungus *Saprolegnia.* The latest investigations point out the prime causative agent to be a fungus called *Aphanomyces sp.*

Treatments: can be tried only in lakes below 40 ha.

Prophylactic: During post-monsoon period, the desease prone water areas can be treated with lime, CaO @ 50 kg/ha followed by application of bleaching powder @ 0.5 ppm after one week.

Therapeutic: At the initial stage of lesion formation, lime (CaO) is applied @ 100 kg/ha followed by application of bleaching powder @ 1 ppm after one week.

Fish diseases encountered in reservoirs

The parasite fauna of a reservoir is derived mainly from its parent stream, but some may be added along with the stocked fishes. Later, rheophilous parasites tend to disappear and the typical lake, pond and sluggish river species tend to become more numerous. The potentially dangerous parasites and diseases existing in the Indian reserovirs are:

1. Ligulosis

Fish species affected: *C. catla*

Symptoms: Abnormal swelling of the abdomen, dark colouration, erratic swimming behaviour and emaciation.

Causative agent: Plerocercoid larval stage of the cestode *Ligula intestinalis*

Treatment: Since *L. intestinalis* is an endoparasite and the infections are more common in large water areas, chemical control is not feasible. The permanent hosts of the parasite are the fish eating birds which can be removed by scaring away or destroyed by shooting. The method has been successful in Tilaiya reservoir.

2. Black spot disease

Fish species affected: *C. catla* and *Oxygaster bacaila*

Symptoms: Affected fishes have black ovoid patches overlying cysts of metacercaria larvae. Growth retardation occur.

Causative agent: Metacercarial larval forms of the digenetic trematode *Diplostomum* sp.

Treatment: Removal of the resident molluscan population is one method of control.

3. Isoparorchiosis

Fish species affected: Murrels, catfishes and carps

Symptoms: Affected fishes are weak, emaceated with soft and flabby muscles. Infection is characterised by presence of black nodules in body cavity of fish.

Causative agent: Metacercarial larval stage of the digenetic trematode *Isoparorchis hypselobagri.*

Treatment: Remedial measures are limited to reducing the population of affected fishes.

4. Ergasilosis

Fish species affected: Mostly carps

Symptoms: Infestation occur in the gills, buccal cavity, operculum and fins. Heavy infestation leads to anaemia, respiratory distress and frequent surfacing.

Treatment: Gammaxene treatment @ 1 ppm

Quarantine and fish health certification

Stressing the importance of preventing fish diseases, it must be emphasized that the introduction and movement of fishes should be subjected to strict quarantine procedures. In recents years, stocking of phytophagous carps *viz. C. idella, H. molitrix* and *T. mossambica* has become common in India, either intentionally or accidentally in lakes and reservoirs. There is every possibility of dangerous parasites getting established on fish species. There are reports that some parasites from exotic fishes *viz. Trichodina reticulata, Tripartiella bulbosa, T. copiosa, T. obtusa* and *Neoergasilus japonicus* got established in the cultured native fishes. To prevent such diseases in future the following steps should be taken.

i) Transfer of eggs rather than fish for stocking
ii) Chemotherapy of fish if transferred
iii) Careful supervision of any introduced fish
iv) Enactment of fish control legislation

Suggested reading

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*Summer School on **Fisheries Enhancement***
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Infrastructural base and policy support measures for inland fisheries

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Under-employment or disguised or concealed unemployment is a notable feature of the majority of underdeveloped countries. Such unemployment is not voluntary but involuntary. People are prepared to work but they are unable to find work throughout the year due to lack of complementary factors. This is to be found in agriculture comprising crop husbandry, animal husbandry and fisheries where manpower engaged is not fully occupied due to low productivity and çapital deficiency. Though quantitative measurement of disguised unemployment is difficult, most economists agree that in densely populated countries disguised unemployment represents 25-30% of the agricultural labour force which could be withdrawn without affecting farm output

Underdeveloped countries are in the backward state of technology. Their technological backwardness is reflected firstly in high cost of production despite low wages; secondly in high labour-output and capital-output ratios. The technological developments aim at disturbing decisively the relationship between input and output. In other words, the production function is altered to the advantage of entrepreneur. Further, it leads to dependence on monetised inputs that, in turn, leads to higher capital requirements. The emergence of hypophysation techniques coupled with feed-fertilizer technology, is a watershed in the history of aquaculture. The production of fish and shellfish by adoption of scientific techniques did result in higher yield, but average cost of production also increased. The relationship between input and output prices determines levels of profitability in any site-based production system but fish production in natural waters such as rivers, streams, large lakes, reservoirs and *beels* is subject to various uncertainties and risks. The production function relationship is less precise as compared to site-based aquaculture.

One of the reasons for sluggish growth rates of production in open water fisheries has been lack of pre-harvest and post-harvest infrastructural support in terms of efficient marketing mechanism, institutional funding arrangement and prevalence of revenue-biased exploitation policies. Though government and inter-governmental bodies and financial and research institutions have been contributing to the cause of fishery development, existing policies have been more in the nature of piecemeal responses to a particular situation. The focus has been mainly on aquaculture and sustenance of export boom in respect of overheated overseas market for shrimps. This lop-sided approach has resulted in utter neglect of open water systems which are characterised by prevalence of low productivity and consequent low income.

The following techno-economic adjustments are necessary for sustainable fisheries.

Conservation and Fishery Management

Research in capture fisheries generally ends up in the advocacy of stringent conservation measures. Fishery management comprises regulation of fishing mortality, enhancement of natural fish production, and accelerated development of knowledge and technology required to convert latent stocks into economically useful resources, each carrying an important research component with it. Probably not many would advocate that fishery regulation should aim primarily at enhancing the welfare of the fish or at safeguarding the bureaucratic interests of government officials. The ultimate aim of fishery regulations is to improve the lot of people and primarily of the people who endure hazards of fishing or of investment in fish catching.

Income Generation and Productivity

Income being major determinant of living standard a need is keenly felt for improving returns by raising fish productivity of reservoirs and floodplain lakes as they are more amenable to effective human intervention as compared to rivers. Studies conducted by IIM, Ahmedabad and CIFRI reveal that fish productivity being low, catching fish from these water bodies hardly affords gainful employment. The income ranging from Rs 2,000 to 4,000 per family keeps fishermen at starvation level. As against an average potential of 1,000 kg in *beels* and 100 - 200 kg/ha in reservoirs the current yield rates are stagnating round 15-20 kg/ha respectively. If by appropriate stock management and post-harvest technology yield is increased four fold, fishermen may cross poverty line, a limit, criterion for which is fast changing due to steep rise in general price level. Market interevention by Corporations and Cooperatives can certainly improve the price realisations of fishermen, particularly in the wake of stagnating productivity.

Input Supply Sub-System

Input supply sub-system has to be streamlined through Cooperatives for ensuing regular supply of fishery requisites to the fishermen. The inventory finance in industrial fisheries of marine origin has been quite adequate, but in the inland fishery sector, only site-based pond culture has occupied the attention of funding bodies. Since fishermen belong to the poorest of the poor class, they may not have the economic resource base to take up heavy investment. Therefore, it calls for policy of selective subsidisation for the purchase of boats, nets and marketing finance during peak harvest. While leasing reservoirs and *beels*, it should be ensured that individual fishermen or Cooperatives will no way impair the overall health of ecosystem to the detriment of other user classes. In fact, licensing should be resorted to with such stipulations like mesh size of nets and close seasons in autostocked floodplain waters and reservoirs along with ban on destructive methods of fishing.

Remunerative Prices to Fishermen

Besides input subsidy, fishermen may be assured of remunerative prices particularly in a situation of localised glut or distribution failure due to transport bottlenecks. Though fish markets have been overheated in recent years, high ruling prices have neither benefited producers of fish nor the consumers due to imperfections of marketing systems. The market intervention by reducing market margins is very essential so as to offer production incentive to fishermen as also protect the interests of consumers.

Legal Fremework

There is an urgent need to integrate fishery laws with environmental legislation. Although the common heritage of mankind has proven to be a useful concept for developing international regulatory regime, it does not harmonise with legal sovereignty over natural resoueces including wetlands. It, thus, provides a less compelling conceptual justification for regulating such internal issues as the conservation of biodiversity or emission of green house gases. National sovereignty over natural resource has been well recognised in international organizations. Access to genetic resources can be regulated through national legislation but Stockholm Declaration 1976 and Rio Declaration of 1992 stipulated that no harm will be caused to the interest of other nation states.

Will legislative support helps us in arresting deterioration in environment ? One of the duties of an Indian citizen as enshrined in Article 51(g) is to protect and improve the environment including forests, lakes, rivers *etc*. and to have compassion towards wildlife and other living creatures.

There is an imperative need to have coprehensive legislation that will provide regulatory mechanism for sustainable use of wetlands. The existing constitutional provisions, as enshrined in entry 56 of article 246, entry 17 of State List,17-A,17-B and entry 32 of the Concurrent List need to be ammended so as to take care of wetlands. It is also necessary to provide reconciliation machinery for settlement of inter-state disputes as also inter-sectoral disputes among multiple end users of wetlands. Though legislative support is not a complete answer towards achievement of the objective of conservation and sustainable use of wetlands, some modest beginning has to be made.

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Socio-economic constraints in open water fisheries with special reference to reservoirs and floodplain lakes

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Fish production in the country has increased from 7.52 lakh tonnes in 1950-51 to 47.88 lakh tonnes during 1994-95 with inland fisheries contribution going up from 2.18 lakh tonnes to 20.97 lakh tonnes. The annual average growth rate in production during the period 1984-1985 (base year of the VIIth Plan) to 1994-95 was 7%. The growth rates in the marine and inland sectors have been 5.8% and 8.8% per annum respectively during this period.

Taking stock of past trends and techno-economic adjustments coupled with appropriate research back up, the likely fish production by 2020 A. D in inland sector may register a two fold increase at a level of 42.30 lakh tonnes as against 20.97 lakh tonnes in base year *i.e.,* 1994-95. In order to reach this target socio-economic constrains need to be well identified. The conventional literature on open water fisheries is replete with studies on physico-chemical parameters of water quality, productivity potential estimated on the basis of ecological investigations and some isolated studies on M. S. Y with the help of infirm and inadequate data. Rarely fisheries have been subujected to rigorous economic evaluation as a business activity mainly due to absence of reliable data on resources as also on productivity.

The succeeding paras deal with some of the problem areas in respect of inland fisheries.

Riverine Fisheries

Major river systems, particularly the Ganga and Brahmaputra, have been well researched in respect of ecological parameters, but economic data with regard to productivity, production and arrivals have been conspicuous by their absence. In the absence of specific landing centres in riverine fisheries, fish arrivals are in few isolated pockets. Directorate of Economics & Statistics, Ministry of Agriculture, do not publish data on arrivals as is being done in case of other agricultural commodities. Further, in the absence of time-series data on production and productivity, it is difficult to assess fluctuations and their impact on employment and income. Research in riverine fisheries does not seem to have created the desired impact by way of higher fish productivity and consequent high income to fishermen as management of common property resource has its built-in limitations. Multiplicity of users of water like human population, agriculture and industry makes it almost impossible to evolve a national policy for even and rational utilization of resources.

Reservoir Fisheries

The research in reservoir fisheries has been mainly confined to morphometry, limnology, biology, production potential estimated on the basis of food resources, and stock manipulation. Except a few success stories, there has always been a persistent hiatus between projected potential and actual yield rates due to a number of imponderables. Till today, reservoirs are characterised by prevalence of low fish yield (20 kg/ha/year), revenue biased unimaginative exploitation policies, disregard for ecological considerations and low income of fishermen (ranging from Rs. 1,000 to 4,000/yr). The exploitation system comprises open auction, royalty, and preferential lease to fishery cooperatives. However, small reservoirs have shown greater promise mainly due to intense human intervention.

Flood plain Wetlands

Wetlands are transitional environments between terrestrial and fully aquatic ecosystems. The Ramsar Convention defines them as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six metres". The true value of wetlands needs to be recognised for supply of goods and services which are provided free of financial and environmental costs, if used wisely. Sectoral organization *e.g.*, agriculture, transport, industry, wildlife, forestry *etc.* is a feature of most societies and Governments. This has usually adverse implications for wetlands because they are potentially impacted by human activities. The existing exploitation of wetlands by multiple users needs to be planned on the basis of scientific data on various aspects.

Ownership

The public ownership of wetlands in many countries makes them the target for abuse by the local population eager to seize the opportunities for development. Virtually throughout Francoplone Africa, there is a concept of "domaine publique hydraulique" where permanent inundated land is state owned. This gives birth to conflicts in wetland where precise definition of the limits of permanent inundation is virtually impossible. For instance, in Assam and West Bengal, the land ownership of wetlands is of extremely cumbersome nature. Multiple ownership among various departments and private individuals makes it almost impossible for adoption of ecologically sound exploitation policy.

Fisheries of Floodplain lakes

Floodplain wetlands of Assam, Bihar and West Bengal, have been engaging the attention of fishery experts for some time past and there is a belated realization that low lying areas known locally as *beels* and *mans* serve as habitat for variety of fish. The accelerating pace of industrialisation has been contributing to destruction and degradation of wetlands and this is reflected in ever increasing scarcity of wildlife and consequent high prices for wetland products such as fish. Of late, there has been a true recognition of the value of wetland goods and services which are made available at less financial and environmental costs. Classification of wetlands is fraught with controversies and problems partly because of varietal enormity of their highly dynamic character and partly because of the lack of any precise definition.

Floodplains are a halfway house between flowing river and pond. The sheer vastness of area of floodplains makes it akin to *common property resource* like rivers and streams and they are vulnerable to irrational modes of exploitation. Sluggish growth rates of fish production due to low yield call for planning at pre-harvest stage, lest the hiatus between potential and actual fish productivity may widen.

In order to sustain commercially profitable fishery of floodplain lakes, there should be enough fish for harvesting, otherwise low production may depress the income of fishermen. Therefore, floodplains need to be harnessed so as to augment domestic availability of fish. As against an average potential of 1,000 kg/ha in floodplain water bodies the existing yield rates range between 160 kg/ha to 200 kg/ha in the states of Assam, Bihar and West Bengal. Appropriate stock management and post-harvest technology may help in improving the fish yield to a remunerative level so as to make an effective dent on poverty of fishermen. No country can succeed in improving socio-economic status of fishermen unless frontal attack is made on illiteracy. Glorification of poverty has been rooted in the traditional beliefs of many Asian countries.

Outlook

Evaluation of socio-economic milieu under which fishermen operate is a condition precedent to any worthwhile development strategy is contemplated for rivers, lakes, estuaries and reservoirs. The environmental degradation and low fish productivity due to natural and man-made interferences have been resulting in the fall in income levels of fishermen. Moreover, hardly any capital formation in terms of inventory building takes place in the inland sector at pre-harvest level due to high propensity to consume. Therefore, some measure of stability in yield rates needs to be imparted inorder to obviate the possibility of violent fluctuations in income of fishermen.

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Role of participatory management approach in reservoir and beel fisheries

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India is bestowed with vast expanse of reservoirs and *beels*. As a result of many breakthroughs in research, several programmes in the development of fisheries for such water bodies have been initiated. The demands made upon transfer of technologies, for accelarating fish production from reservoirs and *beels*, are enormous. Therefore, integrated functioning of research, education and extension has become the most desirable component for development of fisheries from such waterbodies. It is important to involve all groups of people including administrators, scientists, extension functionaries and fish farmers/fishermen in the process of formulating and implementing management measures for the development process. Fish farmers/fishermen, individually or in group, are required to participate in management system for larger benefit.

Management *vis-a- vis* appropriate technology

According to Encyclopaedia of Social Sciences (1933) management is defined as *the process by which execution of a given purpose is put into operation and supervised.* To our purpose, the word management is used in the specific context of *scientific management*. Dasgupta (1969) states that Management is the creation and control of technological and human environment of an organisation in which skill and capabilities of individuals and groups find full scope of their effective use in order to accomplish the objectives for which an enterprise has been set up. It is involved in the relationships of the individual, the group, the organisation and the environment.

The processes of technological innovation, technical and scientific communication, and technology transfer have been the subject of considerable research in recent years. From a behavioural point of view, technological change and innovation occur as a result of complex sets of human interactions, information flows and transfers and risk taking and decision making capabilities. These factors involve human beings with right kind of motivation, perception, attitude, belief, ability, ambition, personality, knowledge and experience.

The innovated technologies are sophisticated in nature and high input intensive. It is interdependent on so many inter-related practices each one of which has to be applied rationally in time and in the manner recommended by the scientists. A communicator concerned with the fisheries of reservoirs or *beels*, therefore, has to understand the characteristics of the resources in order to select appropriate methods and techniques for effective and rapid communication of appropriate technology to the clientele for their easy adoption.

Appropriate technology may be designated as an approach in which technical innovation and adoption go hand in hand with social and cultural integration. It implies that the technology to be developed should pay attention to adopting the technology with the framework of local environment. Development from within a population, requires working with people in their existing situation, by utilizing their existing resources and skills.

Extension system and holistic participatory approach

At every step of the management of fisheries in reservoirs or *beels*, people's participation in all the four extension systems *viz.,* Research System, Extension System, Client System and Support System is more important than the product or process put to use.

Local participation is not the only new criterion by which the management of reservoir or *beel* fisheries needs to be judged. It is equally important that the problems be approached holistically taking into account the full range of human and community potentials.

Fisheries management of open waters necessarily involves both individual and group action where the need for participatory approach is probably maximum. In fact, participatory approach is indespensable for successful management of such projects.

The very purpose of development activity as seen in its broadest socio-political sense is :

- to enable people to critically understand their situations and problems,
- to identify their needs and to prioritize them,
- to evolve methods of resolving these needs and problems,
- to mobilize local resources,
- to implement activity in an organised manner, and
- to monitor, evaluate and learn from the effort

Naturally, participation of the people is necessary for such an effort. Since development efforts can not stipulate people's participation as an initial condition, such participation should be actively promoted as an integral part of each practice of fisheries management and should work, within a time frame, towards an ideal (even if it may not be wholly achievable) condition.

People's participation - a desired phenomenon

Encouraging people's participation in the management of fishery projects is not a new concept. But, the concept of people's participation itself seems to mean many things to many people and there has been much confusion and misapplication in its implementation. Therefore, there is a need to clearly understand the level of people's participation, that is necessary to achieve the goals of a specific programme on fisheries. To arrive at such an understanding, people's participation should be looked at in terms of:

i) quality of participation,
ii) types of participation possible,
iii) phases of participation,
iv) proportion of those potentiallly affected who really participate in such schemes,
v) representativeness and accountability of the leader and the local organisations of the potentially affected community, and
vi) degree of people's participation in terms of labour and money inputs

Participation, with its peculiar dual nature of being a tool and an end to be achieved by the tool, suggests that, no matter how little the participation is to begin with, it is a positive step towards not merely efficient and socially feasible action but towards development itself. Development, welfare and problem - solving were, in the past, activities that families, kinfolk and communities talked. But with development and welfare increasingly and unfortunately, often exclusively becoming government responsibilities, or at best, agency functions, the question of who participate in whose activity becomes very relevant.

Generally speaking, it is the Government / Development agencies who, nowadays, do something for the beneficiaries, whether this involves transferring technology or building infrastructure, or whatever other task.

Organizations in participatory management

Participatory management activity by its very nature means working in management process with groups and communities. The research agency and agents of change will have to make the management of the fisheries in reservoir /*beel* possible by the people themselves rather than doing it for them. This shift in thinking will have far reaching implications not only to the management process but also to the agency's culture. A shift is required from the developer-developee hierarchy to a situation of partnership where both the research / extension agency and the people see themselves as partners in the management process. This shift in attitude might be required in the research/extension agency to hold back on what it believes to be true, scientific and modern, and begin a dialogue that, in time, will enable the beneficiary to, on his or her own, come to the same learning - perhaps to a learning which blends the research/extension agencies learning with indigenous learnings and realities.

There are two essential aspects to the organizational approach - one facilitates day-to-day activity with the community choosing representatives to speak on its behalf or undertake specific talks, and the other involves empowering the community to make sure that it gets its rights and to hold external agencies responsible.

Research/extension agencies by their very nature, work with communities only for a short period of time. If the development activity has to be self-sustaining and self-perpetuating, then the participating people's organisation has to have permanence and the ability to sustain the involvement of the community.

An important fact worth considering is that the existence of an organization in a community does not ensure people's participation. Frequently, only the wealthy and influential members of the community are benefitted by the organizations. It is also ground reality that several socio-cultural traditions tend to be authoritarian. In such communities, the leadership would oppose any form of organization that promotes democratic and egalitarian norms. The research/extension agency would then have to consider whether it should use an existing traditional form of organization in the community or to help it to form a new one. Governments and research/extension agencies relevent to the development of the fisheries in reservoirs/*beels* are particularly attracted to the cooperative form of organization. If it functions properly, it can be an ideal organization, ensuring democratic management and egalitarian distribution of benefits. However, barring a few isolated successes, the experience in general with fishermen cooperative societies has not been always encouraging.

In India, government considers the cooperatives as a channel for passing on development benefits to the community. It views underdevelopment in fisheries as a result of primitive nature of the traditional technology leading to low productivity. So, its solution has been to enable fish farmers/fishermen to acquire assets that would help them to obtain better yield.

The role of the organizations involved in participatory management is understandably very important and almost a necessity. However, it places a heavy burden on the Government agencies involved in research and extension which often has to strengthen themselves and are accountable to the Government for their activities. Thus, they can not be depended upon to display such benevolence for all times. Therefore, participation through organization, in this sense, is much more unpredictable and difficult to plan. It suggests that there is need for the research/extension agency to commit itself first to participatory development and to the associated ideologies and attitudes, before it seeks strategies to foster organization among fish farmer/fishermen.

Meaningful participatory approach

Participation grows out of meaningful relationships that enable people to share and work together. Th ere are several reasons why participation approaches succeed or fail. The reasons mentioned below could be considered as *dos* and *don'ts* for the developental agencies. But it might be wiser to consider the suggestions more as guidance for giving direction to the activity rather than deterrents to action.

Have a legitimate role : The management of reservoir/*beel* fisheries is a participatory project where a sort of negotiated activity in which people and the research/extension /developmental agencies work together for commonly shared objectives. To be able to negotiate successfully, fish farmers/fishermen, scientists, extension functionaries and developmental officials have not only to respect each group but also appreciate that there is a legitimate role for each group to play. The agencies and their members must really see a role in the organisational process.

Enable 'equalness' to facilitate negotiation : For negotiations to be conducted meaningfully, all involved such as the fish farmers, fishermen, scientists, extension functionaries and developmental officials must be reasonably equal. Unfortunately, agencies and the people they negotiate with, are often at different levels not only in terms of power but also of knowledge and ability. This could lead to the activity to be implemented being more agency oriented. So, the agencies have the key role and the responsibility of first creating 'equalness'. This can be achieved through educational programmes that develop communication and negotiation skills as well as power of analysis.

Begin with the needs of the people : For participatory management to be successful, it is necessary for all the groups involved (mentioned earlier) to know what they want. The agencies and the people have their own separate mandates. Not only the content, but the priorities may also vary. But, if successful participation is the aim, a begining has to be made with *what, the people consider, are their needs* and *which, the agency agrees, are areas of concern*.

Learn from and with people : Participation suggests that the people and the agency agree to do something about the way things are to be moulded. But the agencies might not fully appreciate the circumstances and predicament of the people unless it is willing to learn from them. Only by learning from, and with the people - their social dynamics and their needs and priorities, can the right agenda be mutually agreed upon and implemented with whole-hearted participation of all in the community.

Build confidence as a prelude : People may be dissatisfied, but they must do something about that dissatisfaction. More important, they must have the confidence that they have the ability to do something about themselves. A whole range of cultural, social and historical factors, including past failures, can weaken this confidence. Thus, confidence-building is a task. The agencies may have to set itself before participation can be assured.

Help organisation to emerge : Some form of organization like Fishermen Cooperative Society, Fish Club, *etc.*, is necessary if participatory management is to succeed because there is a need to take decision, take responsibility for particular tasks, allocate tasks, all of which can be done better when a community or group is organised.

No autocratic behaviour : Scientists/extension functionaries/developmental officials often feel that they alone know what needs to be done. Since they are not democratic in their own functioning and not participative in their decision making, it will be extremely difficult for them to convince communities they work with. In most cases, the characteristics and behaviour of the communities can be the most important factors determining the success of participatory management.

Flexible approach : The agencies usually tend to specialise in order to be more efficient. Their managerial cultures also tend to make them more rigid and time-conscious. In participatory management, where others are involved, these characteristics may work against the activity. The people's needs may not coincide with the agency's capabilities, the time taken to achieve something real in the field may not fit well with reporting and budgeting schedules, and mid-course corrections may not be easy to bring in. Agencies need to have a far more flexible approach to their work if they wish to promote participation.

No place for unilateral decisions : The participatory approach grows out of the exchange of the agency's knowledge with that of people and the process blends *the modern and the scientific* with *the traditional and the indigenous.* If the agencies really intend to become participative, the directions, objectives and priorities must evolve out of negotiation and not out of unilateral decisions.

Need to realise limitations : If the agencies wish to work with and help to develop a community, it really has only two choices *viz.,*

- it can diversify its capabilities or bring in other agencies to be able to address the special needs of the people ; or
- it can accept its limitations and negotiate for the use of its particular ability, of course, keeping in mind that management in these circumstances would only be partial

The agencies must be more realistic about the objectives that can be achieved, given their limited capabilities.

Getting the people do more : Agencies must do less and help people to do more. Since the goal is to get the people to do it at their own, the agencies should design tools with which they can get others to do what agencies have the expertise to do. If the communities are to participate actively in the management process, the technology and techniques will have to be demystified, made simpler and more accessible. The agencies will have to release information freely to the people.

Coping with change : Working with communities, empowering them, and enabling them to work with justice and democracy, the agencies will find the community going through basic structural changes. The agencies have to face, accept and cope with those changes and their implications.

Conclusion

The experience with people's participation in fisheries-related activities was initially limited. Significantly, it was the last sector to change from *top-down* approach to a *bottom-up* one. However, at present, concerted efforts must be made to prioritise participatory management approach for not only getting better fish production from the reservoirs and *beels* of the country but also for eradicating poverty from the rural areas.

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